

Industrial Pollution and Its Impact on Freshwater Sources

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Abstract—The Euphrates River which is a major water source in Iraq is subjected to a lot of pressure by industrial effluents. This paper is a detailed seasonal report (Winter 2024 - Summer 2025) of the pollution load of the Al-Musayyib Thermal power plant (TPP) and Gas power plant (GPP). With the help of a paired sampling design (influent vs. effluent), we quantified such key physicochemical parameters as EC, TDS, Cl⁻, SO₄²⁻, NO₃⁻, PO₄³⁻, and COD using standard procedures. Findings have revealed that the TPP is a hard and consistent contaminant of ionic pollution, and that there is great degradation between influent and effluent, especially in winter and fall when effluent TDS was greater than 1700 mg/L. GPP showed extremely fluctuating performance, with effective treatment in Winter 2024 (effluent TDS: 8.5 mg/L) and extreme failure in Spring 2025 (effluent TDS: 2343 mg/L, SO₄²⁻: 1491 mg/L). The effluent of both plants particularly the TPP often contained chloride and sulfate levels that were above the ecotoxicological thresholds. The study validates these plants to be significant, changeable point sources of contamination, leading to the ecological degradation of the Euphrates River, and suggests that immediate measures of developing advanced wastewater treatment and Zero Liquid Discharge (ZLD) methods should be taken.

Keywords— Euphrates River, Thermal Power Plant, Ionic Pollution, Wastewater, Zero Liquid Discharge (ZLD), Iraq.

I. INTRODUCTION

The pollution of freshwater ecosystems with industrial and municipal effluents is one of the most significant issues on the planet, which has direct consequences on the biodiversity, human health and water security [1]. The Tigris and Euphrates rivers are the main sources of water in Iraq, and they are the acute embodiment of this crisis in the country. The extreme pollution load of such rivers has been reported in the heavy metals in Baghdad, Tigris River [2, 3], and the massive water quality deterioration in the Euphrates River moving through urban centers such as Al-Najaf, Fallujah and Nasiriyah, among others [4-6]. The ubiquitous aspect of this pollution is even further witnessed by the large-scale research done on the heavy metals contamination of water and sediments across the river bed, Al-Qaim to Thi Qar [7-14].

Euphrates River (supplying more than 60 percent of the total water in Iraq) is specifically stressed due to a set of sources, such as agricultural return flow, untreated municipal wastewater, and industrial effluent [15, 16]. Although past studies have successfully described overall water quality impairment and hard metal pollution in long stretches of the river [7, 8, 17-19], recent evaluation has also reported alarming pollution rates in the Babylon and Karbala governorates, both of which are located directly upstream of the study region [20]. Research on the direct and measurable contribution of the larger point sources, e.g., big thermal power complexes, is less widespread.

This paper explores how the Al-Musayyib power complex, which is one of the important industrial centers, affects the river Euphrates. It is based on the main conceptual approaches: the dynamics of thermal and ionic pollution [21, 22], the ion imbalance theory of osmoregulatory stress in aquatic organisms [23], and the nutrient threshold hypothesis

predicting the threat of eutrophication [24]. To directly measure the efficacy of treatment and measure the pollution load that the power plants can contribute, a paired sampling design (influent vs. effluent) was used in both of the plants, and it bridged an important gap in the literature on industrial point-source pollution in the Iraqi river system.

II. METHODOLOGY

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Study Area and Sampling Protocol

The strict seasonal tracking campaign was carried out during Winter 2024 2025 Spring. Each season had 4 sampling points, which were influent and effluent of the Al-Musayyib Thermal Power Plant (Thermal Power Plant), Al-Musayyib Gas Power Plant (Gas Power Plant). This design in a pair results in an accurate calculation of the net pollution contribution of each facility. Collected samples were stored and transported to the laboratory on ice and with the standard procedures [25].

In-Situ Physicochemical Analysis

On-site measurements were done on critical parameters by a multi-parameter meter (HQ40d, Hach, USA/Germany) and a portable meter (Multi 3630 IDS, WTW, Germany). The standard solutions were used to calibrate these instruments before using them.

- pH, EC, TDS, Temperature: Directly measured with the use of the corresponding probes.
- Dissolved Oxygen (DO): The constant agitation was utilized by measuring the DO probe of the Hach HQ40d, and the readings were taken [25,26].

Laboratory Analysis

All the analyses were done using Standard Methods of the Examination of Water and Wastewater [25].

- Chloride (Cl⁻): Argentometric Titration (Method 4500-Cl- B) with standardized AgNO₃ was the method of analysis.
- Sulfate (SO₄²⁻): Obtained by Turbidimetric Method (Method 4500-SO₄²⁻ E) with the Hach turbidity meter.
- Nitrate (NO₃⁻): Determined by means of the Ultraviolet Spectrophotometric Screening Method (Method 4500-NO₃⁻ B). The correction of the two wavelengths (220 - 2.5 x 275) was used to eliminate organic interference.
- Phosphate (PO₄³⁻): Phosphate analyzed using Ascorbic Acid Method (Method 4500-P E) at 700 nm.
- Chemical Oxygen Demand (COD): The value was determined with a Hach COD meter and the reactor digestion procedure (Method 5220 D).
- Alkalinity: Titrimetric Method (Method 2320 B) using methyl orange as indicator.

III. RESULTS AND DISCUSSION

Seasonal Variation and Plant Performance

The seasonal statistics make the two plants sharply different in terms of performance profiles. The TPP effluent was continuously displaying a grave malfunction of its treatment procedure in all the measured seasons. EC, TDS, Cl⁻, and SO₄²⁻ parameters were always 1.5-3 times more in the effluent than in the influent (e.g., Effluent TDS = 1811mg/L vs. Influent TDS = 721mg/L), which indicates a process that concentrates pollutants as opposed to eliminating them. Conversely, the GPP had very shaky and untrustworthy performance. It depicted a phase of moderate treatment (e.g., Spring 2024) which could be observed by the coincident nature of influent and effluent, a phase of apparent bypass or system malfunction where effluent and influent were almost the same (e.g., Autumn 2024), and a phase of extreme failure where the quality of the effluent was dramatically poorer than that of the influent (e.g., Spring 2025: Effluent TDS = 2343 mg/L vs. Influent TDS = 1405 mg/L). This variation indicates that there are crucial operational and maintenance problems at the GPP.

TABLE 1: Seasonal Water Quality Analysis of Influent and Effluent for TPP and GPP (Winter 2024 - Spring 2025)

			PH	E.C µS/cm	TDS mg/L	COD mg/L	SO ₄ mg/L	NO ₃ mg/L	Cl mg/L	PO ₄ mg/L	DO mg/L	Temp	Ca mg/L	Mg mg/L	T.H mg/L	
Winter-2024	TPP	Inf	7.8	1290	799	4	342	4.24	165	0.26	-	-	-	-	-	
		eff	6.5	2720	1705	9	391.5	5.39	256	0.28	-	-	-	-	-	
	GPP	Inf	7.7	1276	791	3	374.3	4.08	171	0.27	-	-	-	-	-	
		eff	7.6	17.02	8.5	0	2.9	2.15	3	0.15	-	-	-	-	-	
Spring-2024	TPP	Inf	7.6	1163	721	0	285	5.9	183.5	0.49	5.2	24	-	-	-	
		eff	7.7	2830	1811	12	524	9.5	239.1	1.015	5.3	24	-	-	-	
	GPP	Inf	7.5	1162	720	0	331	4.6	180.3	0.36	4.5	24	-	-	-	
		eff	7.5	1000	620	0	276	4.8	171.1	0.4	4.8	24	-	-	-	
Summer-2024	TPP	Inf	6.7	952	590	-	261	12.2	179.4	0.46	-	-	-	-	-	
		eff	6.7	2007	1284	-	523	10	368.7	0.53	-	-	-	-	-	
	GPP	Inf	6.9	886	549	-	260	6.4	254	0.39	-	-	-	-	-	
		eff	7.6	1504	947	-	463	12.1	278.3	0.7	-	-	-	-	-	
Autumn-2024	TPP	Inf	7.8	1435	875	-	245	8.38	179.4	0.34	-	24	-	-	-	
		eff	8.4	2910	1804	-	517	14.2	414.1	0.6	-	24	-	-	-	
	GPP	Inf	8.1	1400	854	-	443	7.49	197.2	0.34	-	24	-	-	-	
		eff	8.1	1390	848	-	310	9.75	185.3	0.47	-	24.3	-	-	-	
Winter-2025	TPP	Inf	7.7	988	602	-	505	-	153.7	-	-	-	121.1	30.1	450	
		eff	7.8	7	2700	-	1701	-	1560	-	-	-	-	471.3	351	126.8
	GPP	Inf	7.7	988	602	-	505	-	153.7	-	-	-	-	121.1	30.1	450
		eff	7	880	536	-	450.6	-	143.1	-	-	-	-	110.3	28.8	410.3
Spring-2025	TPP	Inf	7.3	1420	866	-	579	-	183.3	-	-	28	-	-	-	
		eff	7.4	1446	882	-	557	-	165.6	-	-	28	-	-	-	
	GPP	Inf	7.2	1405	857	-	574	-	167.6	-	-	27.9	-	-	-	
		eff	7.4	3720	2343	-	1491	-	457.2	-	-	28.6	-	-	-	

Violation of Environmental Thresholds

The assessment shows serious and systemic non-observing of the environmental norms. The effluent produced by TPP was regularly exceeding significant limits of all seasons indicating a total failure in its treatment. Salinity parameters were the worst: Total Dissolved Solids (TDS) levels (e.g., 1804 mg/L in Autumn 2024) exceeded the USEPA secondary standard (500 mg/L) and irrigation hazard limits exponentially, and parallel Electrical Conductivity (EC) parameters had consistently exceeded 2000 uS/cm, surpassing the 1500 uS/cm warm-water aquatic life standard [22]. This was added by the levels of Chloride (reaching 414.1 mg/L)

which are significantly higher than the EU regulatory levels of 250mg/L of irrigation [28], and the The historical Euphrates baseline levels (less than 100mg/L) [4, 6, 20]. Although the performance of the GPP was fluctuating, its failure to perform resulted in equally severe violations that will culminate in a disastrous effluent quality in Spring 2025 (TDS: 2343 mg/L, Cl⁻: 457.2 mg/L). Moreover, high Nutrient (NO₃⁻, PO₄³⁻), having deviations to the Redfield ratio, means that eutrophication is highly possible [24]. These pollutants occur together, posing a complex ecological hazard, with a prominent deterioration of the quality of the receiving water and in line with the reported indicators of high-levels of

industrial and municipal waste disposal into the Euphrates River [28-30].

Discussion

Theoretical Implications, Ecological Risk, and Regional Context

The records of Al-Musayyib are solid to support the theoretical frameworks of ionic and thermal pollution in the reported context of the severe water crisis in Iraq. One of the major observations is that there is a continuous imbalance in ion in the effluent of TPP where the EC values are always greater than 2000 uS/cm. This causes acute osmotic stress to aquatic animals, an effect known to affect physiological processes, which is consistent with the known models of ionic stress [31]. The maximum chloride concentration of 414.1

mg/L has an immediate ecological and farming hazard because it contravened the EU irrigation limits [27]. These results are not new ones, but they coincide with certain investigations of the Diyala-Sirwan River, where the release of municipal wastewater has been shown to provoke drastic ionic degradation rates, resulting in the substantial increase of chloride and salinity rates [29,32]. This trend of pollution is congruent with the larger scale evaluations that have documented extensive ionic pollution in most parts of the river systems of Tigris and Euphrates by way of industrial and urban waste water sources [28, 33] and is supported by the recent water quality measurements in the Euphrates in the Babylon and Karbala governorates [20].

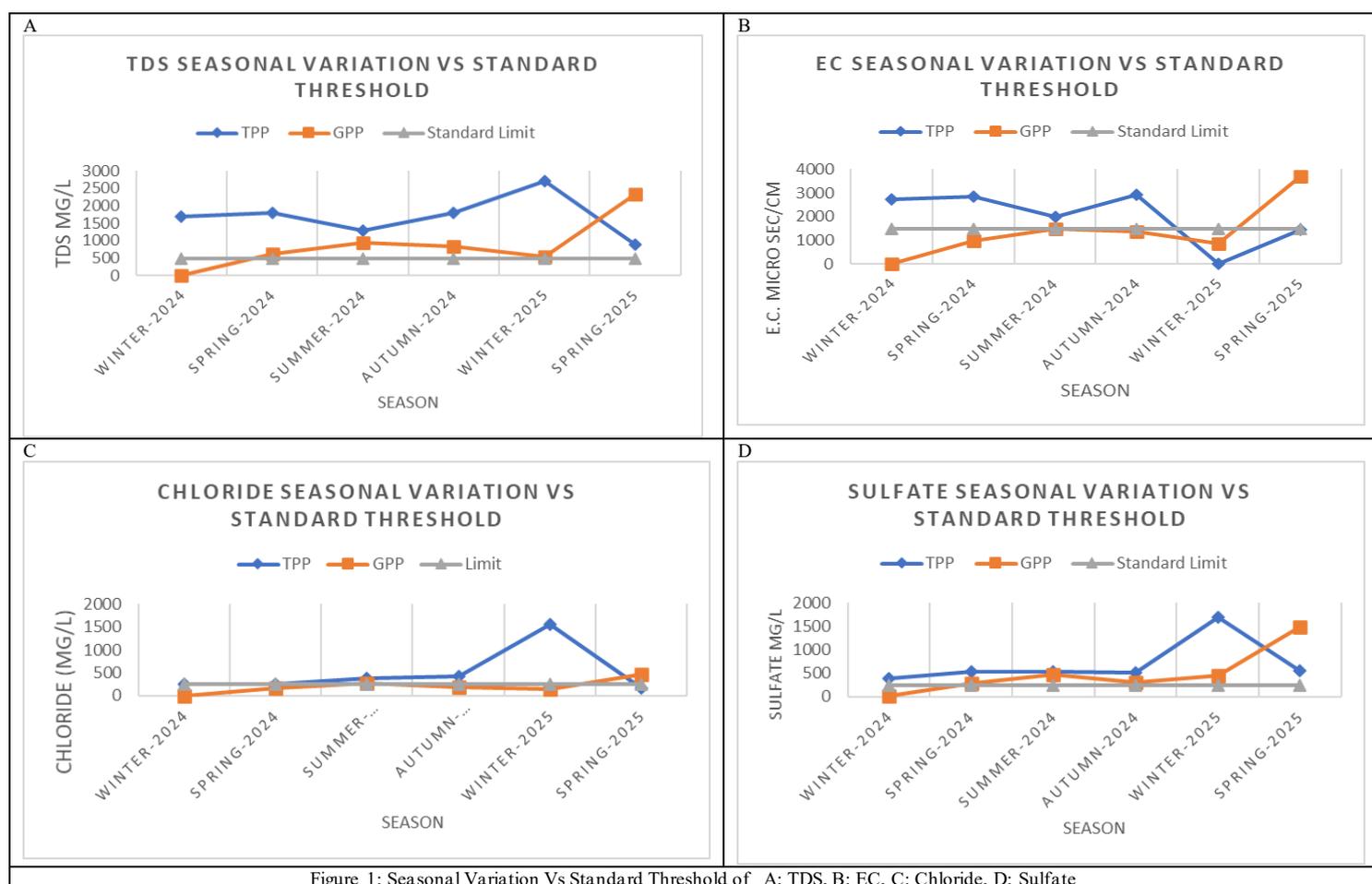


Figure 1: Seasonal Variation Vs Standard Threshold of A: TDS, B: EC, C: Chloride, D: Sulfate

The steady multi-stressor system observed in our study; which was caused by thermal discharge, nutrient loading, and high TDS, exceeds numerous ecotoxicological limits. Such circumstances contribute to the explanation of the trend of ecological degradation recorded in the larger Euphrates researches which show the worsening of the health of the river in the lower cities [5,6,8]. The accumulation of heavy metals in the river biota as recorded, is yet another demonstration of the ecological intensity of the perpetuated pollution [10]. Our research will offer mechanistic information on the ecological

risks involved by identifying the specific effluent parameters and the magnitude of each from a large point source.

Sociohydrological and Health Effects

The high levels of pollution recorded here translate into physical health hazards of the population, which is becoming an issue of concern in Iraq. An increase in renal cases of 32% in Al-Musayyib is not isolated. It is consistent with the tendencies in other industrial regions, as well as with the research that displays the direct influence of water pollution on the population of Iraq [34]. This confirms the "industrial

nephropathy" model associated with years of high-TDS water and heavy metals [36], which is also applicable to the analysis of groundwater pollution in Duhok and surface water in Diyala [29, 37]. The pollution of the power plants, therefore, itself, is a part of a vicious sociohydrological cycle, with industrial action being polluting the same source of water that the downstream population relies on in the form of water, and, hence, resulting in extra health costs [34,36].

Recommendations for Mitigation

According to the results, there are two main mitigation measures that are highly recommended:

1. Deployment of Zero Liquid Discharge (ZLD) Systems: ZLD is a vital approach that thermal power plants should adopt to reduce the amount of liquid discharged into the environment to promote sustainable water management. As shown in international case studies, ZLD approaches are technically feasible. As an example, the Muara Karang Power Plant in Indonesia has introduced water recycling initiative, which lessened the amount of wastewater and enhanced efficiency in operations [38]. Likewise, the Navajo Generating Station in the USA has utilised elaborate water management solutions that are in line with ZLD to maximise on water utilisation in the plant [39]. These instances show that ZLD technologies can help the power sector to manage water sustainably.

Engineered Wetland Buffer Zones Construction: Phytoremediation through the use of native wetland plants like *Phragmites australis* and *Typha domingensis* is an inexpensive, natural polishing process to the final effluents. The species have shown high levels of pollutant uptake capacity including *P. australis* with a high capacity in organic and nutrient removal and *T. domingensis* which is a hyperaccumulator of heavy metals like Pb, Zn and Cd with bioaccumulation factors of more than 9000 to some metals [40, 41]. The combination of these plants into engineered wetlands can be used to improve wastewater treatment, contribute to the recovery of degraded riverbank ecosystems, and reduce the accumulation of pollutants in the bed sediments over the long term through phytostabilization and phytoextraction processes [40, 41].

IV. CONCLUSION

This overall seasonal evaluation shows conclusively that the Al-Musayyib power complex is a significant and continued source of threat to the water quality of the Euphrates River. The analysis shows that there are two marked but critical pollution profiles namely; Thermal Power Plant (TPP) is a severe and chronic point source of ionic pollution and its effluent is always in breach of the environmental standards because it contains excessive levels of TDS, chloride, and sulfate. By comparison, the Gas Power Plant (GPP) has much more erratic and unpredictable performance with treatment varying, at best, to disastrous breakdown and thus becoming an unpredictable and meaningful point of intermittent pollution. The effluent of both plants often surpasses the ecotoxicological limits to protect aquatic organisms and irrigation standards, which lead to ionic disequilibrics, osmotic stress in the biota, and is

highly likely to cause eutrophication. The reported health concerns in the region are consistent with these findings, which offer a clear argument against the plants contributing to the river's deterioration. In order to prevent the continuation of the harm, immediate introduction of enhanced wastewater treatment, especially Zero Liquid Discharge (ZLD) systems, and building of engineered wetland buffer zoning to conduct phytoremediation is urgent to conserve the precious waters of Euphrates River.

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