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Original Article

Spatiotemporal Variations in Water Quality under Land Use/Land Cover in the Khabur River

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ABSTRACT

One of the most pressing water quality issues in semi-arid regions, where seasonal pressures and anthropogenic impacts reduce river flows, affects ecosystem health and human well-being, as well as sustainable water management. Thus, the research investigated spatiotemporal changes in Khabur River water, including physicochemical parameters and heavy metals, with correlations drawn from probable land use/land cover in that geographic area**.** Ten sites spaced ~13 km apart over a 130 Km stretch were sampled once a month for a year. In situ measurements were made for water temperature, pH, electrical conductivity, and total dissolved solids, while laboratory parameters included dissolved oxygen, turbidity, major ions, nutrients, and the heavy metals Ag, Al, As, B, Ba, Li, Sr, and Cd. Land-use/land-cover changes percentages were calculated for each site within a 500-meter buffer using ArcGIS Pro. The results showed that temperature, pH, and EC varied between (7.1-31.1°C), (7.4–8.9), and (344.62 µS/cm), respectively, while the mean value of TDS was (172.59 mg/L), showing a clear seasonal variation. Heavy metal Boron ranged from (1-3.01), exceeding the WHO guideline limits. Concentration of some heavy metals was decreased by the presence of forests and shrublands, whereas cropland, bare land, and sediments enhanced levels of heavy metals such as Cd, B, Sr, and Ag. Most variables exhibit a marked seasonality factor, though their spatial gradients are seemingly quite specialized as the spatial scale increases. The physicochemical qualities that determine water quality are mainly governed by the interaction of hydrological regimes and the impact of land-use/land-cover changes (LULC) on metals and nutrients. Therefore, sustainable land management coupled with constant monitoring should be instituted immediately.

Keywords: Heavy Metals, LULC, Seasonal Variation, and Physicochemical.

1 Introduction

Rivers are fresh, dynamic systems that transport water, nutrients, and sediments, sustain biodiversity, and serve human societies, particularly in the semi-arid watersheds where they deliver most of the fresh water [1]. The quality of drinking water is one of the fundamental environmental issues worldwide, directly affecting human beings, aquatic species, and sustainable development. Major parameters include physical indicators such as temperature, turbidity, and conductivity; chemical indicators such as pH, dissolved oxygen, and nutrients; and concentrations of heavy metals (lead, cadmium, chromium, and mercury) potentially stemming from industrial, agricultural, or urban sources [2,3].

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It is through LULC changes arising from urbanization, agricultural expansion, and deforestation that the most detrimental effects on freshwater are associated with changes in hydrology, alteration in sediment transportation, and non-point source pollution, leading to enrichment with nutrients, salinization, and build-up of heavy metals [4-6]. Impervious surfaces in urban areas accelerate water runoff; denudation and farmland increase the land surface erosion and nutrient leaching; climate change further worsens water stress, pointing out how LULC and sustainable water management are related [7-1].

Climate changes more increase the stress on water [8-9] because land-use changes, agriculture, deforestation, and urbanization over-enrich nutrients, salinize rivers, and load them with heavy metals. Hence, a Mediterranean environment is characterized by very little rainfall and high evaporation rates, which also includes human interferences, rendering the environment very vulnerable regarding its water resources.

In Iraq, the rivers Tigris and Euphrates sustain water supply, agriculture, and energy, but ever since water quality deteriorated due to decades of ill agricultural practices, wastewater discharge, and urbanization, it has caused salinization, nutrient, and heavy metal pollution [10]. However, very few studies directly establish a link between LULC changes and spatiotemporal variations in water quality.

In the Kurdistan region of Iraq, the water resources, especially the water resources of the Khabur River, were under increasing pressure due to a rapidly growing population, intensified agriculture, and fast urban expansion [11,12]. Although some studies have dealt with the water quality parameters for northern Iraq, most have concentrated on general pollution status rather than the quantitative analysis of the impact of LULC dynamics on physical, chemical, and heavy metal concentrations [5]. This represents a significant research gap, as localized studies are crucial for effective water management, the rehabilitation of polluted environments, and sustainable land-use planning.

The present study aims to address the gap by examining the impact of LULC on water quality in the Khabur River. This study, therefore, renders new scientific evidence of such interactions between anthropogenic activity and riverine ecosystems by combining spatial analysis of land cover changes with data related to water quality monitoring [13].

2 Materials and Methods

2.1 Study Area and Sampling Design

A survey was completed along a 130 Km stretch of the Khabur River in 2024-2025, which the Khabur River is one tributary of the Tigers River, a typical semi-arid river system with mixed land use that included land-use systems ranging from forests to shrublands, grasslands, and croplands, settlement areas, bare lands, etc.

Ten sampling sites were established with a distance of about 13 km so that the sampling sites cover the upstream, midstream, and downstream areas of the river in ten sites: Begova, Pasi, Dokari, Barzir, Gond Kosa, Chamdalal, Tawki, Chamsermo, Zakho (Shabanik street), and Ibrahem Khalil (Figure 1). Water samples were collected monthly from July 2024 to June 2025 at each site over a complete hydrological year. Three replicate samples were collected at each site. A sampling of about 20 liters at a depth of 15-20 cm [14] was stored in pre-cleaned polyethylene bottles and preserved at 4 °C until analysis [7].

Due to its Mediterranean climate, it has hot and dry summers and very cold and wet winters. The cold season extends from October to April, and the hot months begin from May and end in September, with precipitation totals of 782.56 mm. Most commonly, the average summer monthly temperature ranges from 9.5 °C to 38.5 °C; all winter temperatures are from 0.8 °C to 23.5 °C. The average annual humidity was 44.28%. The monthly average wind speed is reported based on unpublished statistics from the Directorate of Meteorology in Duhok (2025).

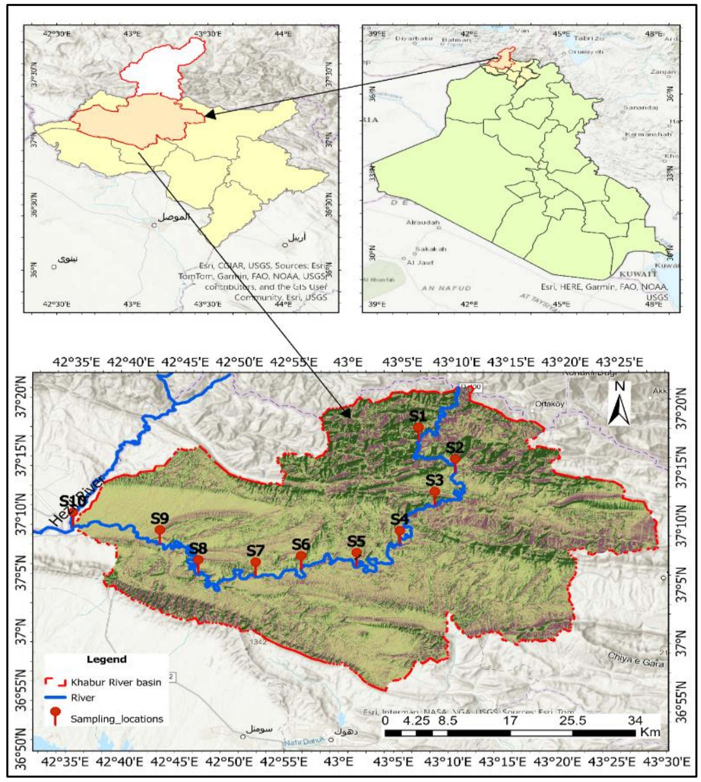

Figure 1: The location of sampling points in the Khabur River.

2.2 Physico-Chemical Analysis

Using the portable multiparameter probe (Hach HQ40d), in situ measurements of water temperature, pH, electrical conductivity (EC), and total dissolved solids (TDS) were obtained, and other physicochemical measurements such as dissolved oxygen (DO), turbidity, concentrations of major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), and anions (Cl^{-}, SO_4^{2-}, NO_3^{-}), total hardness (TH), and nutrients were analyzed in the laboratory according to standard methods [7].

2.3 Evaluation of Heavy Metals

For the analysis of heavy metals, water samples were filtered through a 0.45 µm filter paper and oxygenated with nitric acid (pH < 2). Concentrations of Ag, Al, As, B, Ba, Li, Sr, and Cd were analyzed via ICP-MS, and quality control measures were carried out using blanks, duplicates, and certified reference material. The seasonal trends and WHO guideline exceedances were then assessed [15].

2.4 Land Use/Land Cover (LULC) Analysis

The class percentages of LULC were calculated for the following classes: forest, shrubland, grassland, cropland, settlement/built-up areas, bare land, and waterbodies. In ArcGIS Pro 3.4.0, each sampling point was given a buffer of 500 meters (Figure 2), and the class percentages were calculated using high-resolution satellite imagery and existing land cover maps [16].

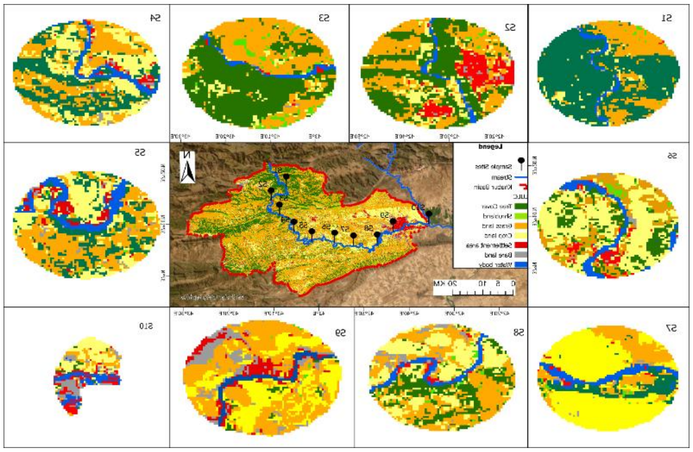

Figure 2: Buffering of LULC in the study area.

2.5 Statistical Analysis

Descriptive statistics (mean, standard deviation, minimum, and maximum values) for all physicochemical parameters and heavy metals were calculated. Pearson correlation analysis was performed to see any relations between LULC classes and water quality parameters. Two-way analysis of variance was applied to study the influence of seasons, sites, and their interactions on the physico-chemical and heavy metal concentrations. All analyses were carried out using Minitab 21, and statistical significance was established at $p < 0.05$. Graphs and charts were prepared from Minitab and exported into ArcGIS Pro 3.4.0 for visualization.

3 Results and Discussions

3.1 Physicochemical Parameters

3.1.1 Water Temperature

Water temperature fluctuated from 7.1 °C in winter and reached a maximum of 30.1°C in summer, with a mean of 18.14°C (SD = 6.68), Table 1, and Figure 3. The lower winter temperatures minimize microbial activity and slow down all biochemical reactions, while higher temperatures increase metabolic rates in the summer, which may reduce oxygen solubility in water [17].

3.1.2 pH

All year round, the river remained alkaline. Actually, the pH varied in winter from 7.4 to 8.9 in September 2024, with a mean of 8.2 (Table 1 and Figure 3) lying within or very slightly above the WHO guideline of 6.5-8.5 [18]. High pH levels could be explained by carbonate-rich geology and seasonal anthropogenic inflows such as agricultural runoff [19].

3.1.3 Turbidity

Turbidity levels showed a seasonal variation, with the least during dry months (mean value of 2.47 NTU) and peaks going up to 10.6 NTU in the last location in March (Table 1, Figure 3), during the rainy months, reflecting the runoff and sediment transport activities influenced by land use [20].

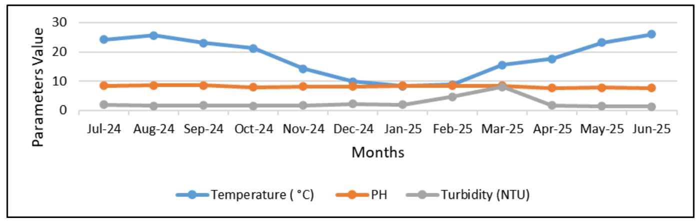

Figure 3: Monthly variation of water quality parameters: water temperature, pH, and turbidity.

3.1.4 Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

The mean of EC was 344.62 µS/cm, and TDS varied from 105 to 279 ppm according to the Analytical Result for TDS due to both monthly and seasonal variations, where an increase was observed in the dry months by dissolved minerals from the rains, and a decrease from natural dilution in the wet months [21] as shown in Table 1 and Figure 4**.**

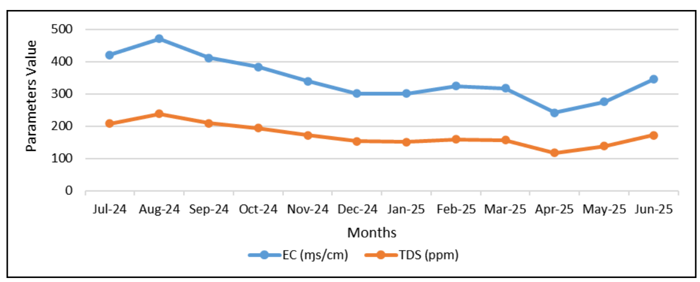

Figure 4: Monthly variation of water quality parameters: EC and TDS.

3.1.5 Dissolved Oxygen (DO)

DO reached a minimum during the summer months and a maximum in the winter months, according to the analytical result for TDS. The better minimum was 3.5 mg/L in summer, and a maximum in winter of 15.39 mg/L (Table 1 and Figure 7) [1] while lower levels were noted in warmer months due to increased biological oxygen demand.

3.1.6 Calcium, Magnesium, and Total Hardness

Calcium (Ca^{2+}) has an average concentration of 29.04 mg/L and ranges between 16.8 and 38.64 mg/L (Table 1). Higher concentrations of calcium would probably therefore represent the major cation and, likely, contribute towards water hardness due to dissolution of carbonate and gypsum. Magnesium (Mg^{2+}) has an average concentration of 11.10 mg/L (5.20-21.40 Mg/L) (Table 1 and Figure 5): mostly derived from dolomite weathering and clay mineral dissolution, with only a minor contribution from agricultural leaching. Together, these cations control total hardness, which averaged 118.36 mg/L (71.66-161.73 mg/L), as shown in Figure 5, and classify the water as moderately hard. This trend reflects the hydrogeology of a carbonate weathering-dominated basin typical of semi-arid settings [22]. Notably, they are all well below the [23] guideline of 500 mg/L, thereby indicating no health implications with respect to these parameters.

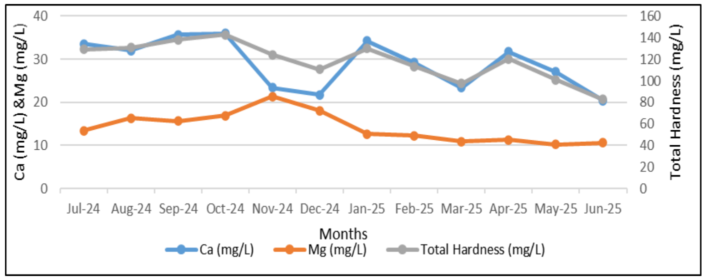

Figure 5: Monthly variation of Ca^{2+}, Mg^{2+}, and total hardness in water quality.

Table 1: Descriptive statistics of physicochemical water quality parameters measured in the Khabur River.

Variables	Mean	Minimum	Maximum	StDev	Standard WHO limited
Water Temp (°C)	18.14	7.1	30.1	6.68	< 25 °C
pH	8.2	7.4	8.9	0.38	6.5 – 8.5
EC (µS/cm)	344.62	226	558	67.24	< 1,500
TDS (ppm)	172.59	105	279	35.32	600 – 1,000
Do (mg/L)	9.059	3.56	15.39	1.89	> 5
Ca (mg/L)	29.04	16.8	38.64	6.097	≤ 75
Mg (mg/L)	11.10	5.2	21.4	3.05	≤ 50
Total hardness (mg/L)	118.36	71.66	161.73	20.59	80 – 100
Cl (mg/L)	12.79	5.1	22.84	4.45	≤ 250
No_3 (mg/L)	1.95	1	3.8	0.61	≤ 50
SO_4 (mg/L)	20.26	11.2	31.76	4.84	≤ 250
K (mg/L)	5.80	0.91	17	3.95	0.96
Na (mg/L)	12.48	6.0	24	3.56	200
Turbidity (NTU)	2.47	0.9	10.6	2.02	< 5

3.1.7 Chloride (Cl^-)

Hence, the average chloride concentration was noted at 12.79 mg/L (5.1 to 22.84 mg/L) (Table 1 and Figure 7), which is below the permissible limit of 250 mg/L laid down by the [23] for drinking water. The natural inputs are mainly due to salt dissolution and atmospheric deposition, and only a minor contribution comes from return agricultural drainage. Such low concentrations speak for little anthropogenic salinization synonymous with saline semi-arid [1].

3.1.8 Nutrients (Nitrate and Sulfate)

Average concentrations of nitrates were lower at 1.95 mg/L, as seen in Table 1, versus the [24] guidelines for 50 mg/L, while sulfate was measured at 20.26 mg/L (Figure 6), slightly increasing during runoff periods. These trends suggest low nutrient load pollution in the basin.

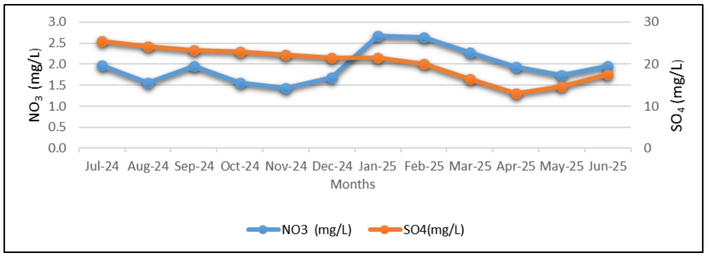

Figure 6: shows the trend of monthly concentrations of SO_4^{2-} with the water quality of NO_3^-.

3.1.9 Potassium (K^+)

Mean potassium concentration values remained very low at 5.80 mg/L (range of 0.91-17 mg/L) (Table 1 and Figure 7). However, unlike Na+, K+ ions are readily adsorbed by clays and soils and thus are less mobile. Small peaks may be linked with fertilizers, since K-based fertilizers are often used in irrigation agriculture [13-24].

3.1.10 Sodium (Na^+)

Sodium, on average, in the water was at 12.48 mg/L (6 - 24 mg/L), concentrations, not widely vary from season to season, which means that anthropogenic influence is limited (Table 1 and Figure 7). Mainly, natural feldspar weathering and ion exchange processes are responsible for these concentrations. With salinity hazard for irrigation, these concentrations are well below the threshold values defined by [16], showing low risk for soil degradation.

3.2 Heavy Metals

The data suggest that there is little seasonality in heavy metal concentrations. Values of Ag, As, Cd, and Li remain very low (near 0-0.02 mg/L) (Table 2 and Figure 8), whereas Al and B values show a greater concentration, with B reaching up to a maximum of around 3.01 mg/L. Some metals, namely Cd, As, Ag, Al, and B, exceeded WHO guidelines, and this provided an indication of potential risk to public health and aquatic ecosystems as well. The increased concentration of metals indicates combined sources of natural and anthropogenic origin, like mineral-rich soils and industrial effluents, as well as agricultural runoff. On the contrary, Ba, Sr, and Li showed moderate levels and thus could be considered somewhat "geogenic". Little increases in the metals concentration during peak runoff events indicated mobilization from soils and sediments, which coincides with the latest studies in Iraq, reflecting widespread cause for concern over heavy metal contamination in surface and spring waters [25]. Continual monitoring and effective water management strategies are necessary to mitigate ecological and human health risks.

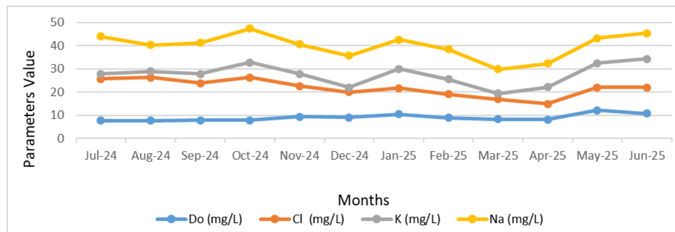

Figure 7: Monthly variation of DO, Cl^-, K^+, and Na^+ in water quality.

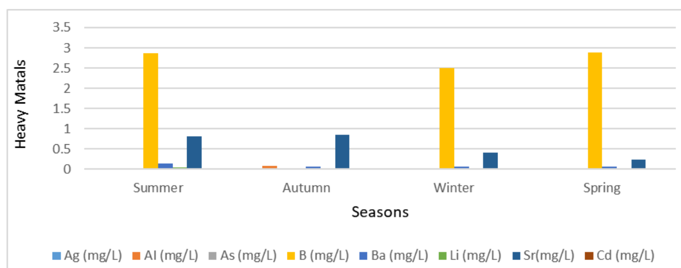

Figure 8: Seasonal variation of heavy metal concentration in water quality.

Table 2: Seasonal mean, minimum, maximum, and standard deviation of selected heavy metals (mg/L) in the study area.

Variable	Mean	Minimum	Maximum	St.Dev	WHO limited (mg/L)
Ag (mg/L)	0.01	0.01	0.01	0.001	0.5
AI (mg/L)	0.08	0	0.76	0.22	0.2
As (mg/L)	0	0	0.01	0.00	0.01
B (mg/L)	2.35	1.00	3.01	0.79	2.4
Ba (mg/L)	0.06	0.05	0.07	0.01	0.7
Li (mg/L)	0.02	0.01	0.02	0.00	2.0
Sr (mg/L)	0.34	0.22	0.43	0.07	7
Cd (mg/L)	0.03	0	0.09	0.003	0.003

3.3 Seasonal and Spatial Variations in Physicochemical Water Quality

Statistical analysis involving two-way ANOVA showed that temporal variation (seasonal effects) is the most dominant factor in influencing the fluctuations in water quality. Most of the physicochemical parameters: temperature, EC, TDS, Ca^{+2}, Mg^{+2}, TH, Cl^{-}, SO_4^{2-}, Na^{+}, $NO\text{-}_3$, and turbidity have been found to have significant seasonal variations of more than ($p > 0.001$), Table 3. Such seasonal changes were found to be closely related in such hydrological and climatic cycles, where wet seasons promote leaching, runoff, and sediment resuspension, while dry seasons enhance evaporation and concentration of dissolved salts. These types of seasonal control are similar to those described in semi-arid rivers [9,26] . In contrast to the above parameters, pH, DO, and K were rather constant during the different seasons of the year, indicating a stronger buffering capacity and minor seasonal influence [27].

In most cases, the other parameters did not differ spatially across locations ($p > 0.05$) and indicated a fairly homogeneous hadrochemical background. However, the spatial variation between nitrate (NO_3^-) and sodium (Na^+) is significantly higher ($p < 0.001$), Table 3. The observed patterns are most likely caused by anthropogenic input from fertilizer application, wastewater discharge, and agricultural runoff that enrich specific sites in these nutrients and ions. Similar patterns have previously been observed in rivers of Iraq and the Middle East, which have been impacted by agricultural usage and urban effluents [28].

Generally, location interaction with season (L × S) was non-significant, which showed that even when water quality parameters varied according to seasons (Table 3), such variations were observed consistently across all sites. This suggests that temporal drivers such as rainfall, runoff, and evaporation act uniformly at the basin scale, while spatial heterogeneity is restricted to nutrients and salts influenced by site-specific human activities. Similar observations with uniform seasonal controls and limited site-specific deviations were also reported in regional hydrological studies [29].

Table 3: Spatial and Seasonal variation of physicochemical water quality parameters.

Locations	Temp	PH	EC	TDS	Do	Ca	Mg	TH	Cl	NO_3	SO_4	K	Na	Tur
1	16.11	8.192	328.1	161.7	9.827	27.59	9.6	108.5	11.77	1.658	20.79	5.096	9.53	1.918
2	16.65	8.183	336.1	167	9.58	29.11	10.05	114.2	11.33	1.499	19.91	4.71	10.2	1.989
3	17.24	8.249	337.5	169.3	9.482	30.22	9.91	116.4	11.24	1.818	20.47	4.082	11.11	2.252
4	17.75	8.196	333	171.8	9.292	29.59	10.81	118.5	13.09	1.847	20.05	5.036	10.64	2.404
5	18.41	8.142	341.6	170.1	9.359	26.99	10.68	111.5	13.39	1.659	17.9	5.716	12.26	2.267
6	18.58	8.211	350.4	172.6	9.291	28.7	10.96	116.9	12.25	2.019	19.65	6.057	12.66	2.433
7	18.79	8.19	341.9	170.3	8.983	29.88	11.47	122	11.35	2.016	19.27	5.424	13.33	2.615
8	19.33	8.131	345	170.9	8.959	30.05	12.16	125.2	12.78	2.141	22.08	6.989	12.79	2.638
9	19.64	8.146	369.3	185.6	8.178	29.32	13.38	128.6	15.09	2.533	23.84	7.32	16.27	2.971
10	19.57	8.152	363.3	186.8	7.634	28.94	12.01	121.8	15.56	2.304	18.64	7.561	15.97	3.177
Seasons														
1	25.25	8.208	412.2a	206.4	8.748	28.65	10.32	114.2	15.98	1.826	22.4	5.629	12.92	1.573
2	19.51	8.224	378.7b	192	8.395	31.71	13.51	134.9	15.96	1.651	22.81	5.231	13.5	1.666
3	8.98	8.321	309.0c	154.4	9.528	28.39	11.41	118	10.79	2.335	21.09	5.6	13.03	2.937
4	19.09	7.964	278.5c	137.6	9.563	27.4	9.16	106.2	8.42	1.986	14.73	6.737	10.46	3.689
	Summary of ANOVA tables (P-values)													

Locations (L)	0.111	1.00	0.456	0.255	0.204	0.979	0.015	0.303	0.002	<0.001	0.001	0.546	<0.001	0.919
Seasons (S)	<0.001	0.012	<0.001	0.000	0.057	0.089	<0.001	<0.001	<0.001	<0.001	<0.001	0.564	<0.001	<0.001
L × S	0.98	1.00	1.00	1.00	0.999	1.00	0.871	1.00	0.995	0.961	0.167	0.997	0.565	1.00
Means in the last three rows sharing are significantly different at P-value < 0.05.														

3.4 Seasonal Variations in Heavy Metals: Water Quality

Boron and strontium revealed significant seasonal differences ($p < 0.001$). Moderate seasonal differences were exhibited by cadmium ($p = 0.027$) and lithium ($p = 0.007$), whereas silver, aluminum, arsenic, and barium remained stable during the various seasons ($p > 0.05$) and showed comparatively weak seasonal influence. Highest concentrations of boron were recorded in the fourth season (2.893 mg/L) and lowest in the second season (1.137 mg/L) (Table 4), possibly indicating seasonal runoff and hydrological influences. The maximum strontium value was registered in the third season (0.418 mg/L) due to inputs from groundwater and geochemical mobilization during the season. The stability of silver, aluminum, arsenic, and barium indicates limited input from seasonal processes [8]. Such patterns indicate the need for seasonal monitoring of elements that are sensitive to hydrological and anthropogenic changes.

Table 4: Seasonal Fluctuations of Heavy Metal Concentrations in Water and Their Statistical Significance (ANOVA)**.**

Seasons	Ag	AI	As	B	Ba	Li	Sr	Cd
Summer	0.0103	0.253	0.0018	2.893	0.056	0.0138	0.245	0.0007
Autumn	0.0106	0	0	2.86	0.059	0.0159	0.340	0.001
Winter	0.0123	0.076	0.0018	1.137	0.065	0.017	0.372	0.0017
Spring	0.0110	0	0	2.510	0.0607	0.017	0.418	0.006
P – values	0.317	0.520	0.421	<0.001	0.394	0.007	<0.001	0.027
Means in the last columns sharing are significantly different at P-value < 0.05.								

3.5 Correlation of Water Quality Parameters and Heavy Metals with Land Use/Land Cover

Using ArcGIS Pro 3.4.0, a 500-meter buffer has been created around each sampling point. The area of each Land Use/Land Cover class-Forest, Shrubland, Grassland, Cropland, Settlement, and Bare Land-was calculated in percentage, which was then correlated with water quality parameters to study possible land-use impacts on water chemistry [30].

The correlation analysis revealed quite distinctive patterns between water quality parameters and land use/land cover (LULC). Electrical conductivity (EC) had a high correlation with TDS ($r = 0.97$, $p < 0.01$) (Table 5), suggesting that it contains high ionic concentrations, either due to mineralization or pollution in waters. Dissolved oxygen (DO) was negatively correlated with EC, TDS, Ca, and Mg. This indicates lower oxygen levels in the presence of ions, which is caused by both seasonal variations and anthropogenic activities [30]. Of all the LULC classifications, forests reduced the turbidity ($r = -0.37$, $p < 0.01$) and improved Ca ($r = 0.27$, $p < 0.01$) (Table 5), thus helping in soil stabilization and minimizing sediment runoff. Shrublands and grasslands had low to moderate correlations with turbidity and nitrate, indicative of partial retention of nutrients. Strong association with Cl and K revealed that land has similar characteristics to croplands (Cr %), which was due to the application of agricultural fertilizers and irrigation. Settlements and bare lands were also recorded to correlate positively with EC, TDS, and different ions as their sources or sinks of pollutants [30]. Basically, natural vegetation filters contamination, while all the anthropogenic and disturbed lands supercharge ionic and nutrient enrichment, underscoring the need for holistic land management to conserve water quality.

Table 5: Correlation Matrix of Physiochemical Water Quality Variables with Land Use/Land Cover in the Khabur River.

P	Temp	pH	EC	TDS	Do	Ca	Mg	TH	Cl	No_3	SO_4	K	Na	Tur	Fo %	Shr %	Gr%	Cr %	Se%
pH	-0.14																		
EC	0.54**	0.49**																	
TDS	0.54*	0.48**	0.97**																

Do	-0.13	-0.25**	-0.40**	-0.40**															
Ca	0.15	0.23*	0.33**	0.32**	-0.24**														
Mg	-0.12	0.23*	0.26**	0.30**	-0.33**	0.09													
Th	0.04	0.31**	0.40**	0.42**	-0.38**	0.79**	0.68**												
Cl	0.47**	0.31**	0.82**	0.83**	-0.39**	0.39**	0.37**	0.52**											
No_3	-0.23*	0.18*	-0.09	-0.08	-0.08	0.11	-0.01	0.07	-0.11										
SO_4	0.01	0.40**	0.59**	0.58**	-0.35**	0.29**	0.41**	0.47**	0.59**	0.00									
K	0.14	-0.51**	-0.32**	-0.30**	0.41**	-0.14	-0.25**	-0.25**	-0.18*	0.22*	-0.32**								
Na	0.11	0.17	0.32**	0.34**	-0.40**	0.16	0.43**	0.38**	0.48**	0.29**	0.32**	0.05							
Tur	-0.32	0.30**	-0.09	-0.11	-0.17	-0.18*	-0.09	-0.19*	-0.26**	0.41**	-0.11	-0.22*	-0.04						
Fo %	-0.19	0.05	-0.15	-0.17	0.27**	-0.03	-0.32**	-0.22*	-0.22*	-0.37**	-0.01	-0.21*	-0.54**	-0.16					
Shr %	-0.03	0.06	-0.04	-0.07	0.13	0.06	-0.13	-0.04	-0.18	-0.08	0.02	-0.13	-0.16	-0.05	0.35**				
Gr %	0.00	0.00	0.00	-0.01	0.07	0.03	0.06	0.05	0.00	0.00	0.20*	-0.04	-0.06	-0.03	0.10	0.24**			
Cr %	0.14	-0.02	0.08	0.08	-0.15	0.04	0.21*	0.15	0.07	0.25**	-0.06	0.13	0.34*	0.11	-0.78**	-0.25**	-0.40**		
Se %	0.07	-0.04	0.11	0.14	-0.22	-0.02	0.13	0.06	0.21*	0.13	-0.06	0.14	0.32*	0.09	-0.49**	-0.47**	-0.24**	0.06	
Bar %	0.12	-0.05	0.15	0.19*	-0.32**	0.01	0.25**	0.16	0.30	0.36**	0.04	0.22*	0.50*	0.16	-0.62**	-0.45**	-0.21*	0.17	0.77**

*Correlation coefficient significant at P – value < 0.05.
**Correlation coefficient significant at P – value < 0.01.
Fo = Forest, Shr= Shrubland, Grassland= Grassland, Cr= Cropland, Se= Settlement area, Bar= Bare land

Correlation analysis of heavy metals (Ag, Al, As, B, Ba, Li, Sr, Cd) with LULC showed that B and Li were significant at the 0.05 level (Table 6). Tree cover negatively correlates with Ba and has a high correlation coefficient (r =-0.75), showing restricted mobility of toxic elements. Shrubland and grassland do not correlate, as both show lower metal bioavailability and limited plant uptake [31].

Ba has a very strong positive correlation with both cropped and settlement areas, as both these areas show anthropogenic contributions from fertilizers, pesticides, irrigation water, construction materials, traffic emissions, and urban dust. Runoff transports Ba into water bodies (Table 6), where it reaches sediments, making these environments similarly affected by anthropogenic sources across these land-use types [31].

Table 6: Correlation Matrix of Heavy Metals Water Quality Variables with Land Use/Land Cover in the Khabur River.

P	Ag	AI	AL	B	Ba	Li	Sr	Cd	Fo %	Shr %	Gr%	Cr%	Se%
AI	-0.15												

As	0.19	-0.20											
B	-0.38	0.09	-0.29										
Ba	0.88	-0.22	-0.02	-0.26									
Li	0.15	-0.21	-0.43	-0.60*	0.14								
Sr	0.39	-0.37	-0.34	-0.38	0.45	0.77**							
Cd	0.20	-0.19	-0.27	-0.09	0.10	0.41	0.67*						
Fo %	-0.47	0.02	0.20	-0.22	-0.75**	0.28	-0.07	0.02					
Shr %	-0.44	0.30	0.15	-0.08	-0.45	0.12	0.01	-0.17	0.62*				
Gr%	-0.32	0.36	0.09	0.00	-0.20	0.02	0.04	-0.22	0.28	0.93**			
Cr%	0.48	-0.02	-0.20	0.22	0.75**	-0.28	0.07	-0.02	-1.00**	-0.63*	-0.30		
Se%	0.51	-0.16	-0.20	0.17	0.68*	-0.23	0.04	0.07	-0.92**	-0.88**	-0.63*	0.93**	
Bar%	0.49	-0.25	-0.18	0.13	0.57	-0.18	0.01	0.13	-0.77**	-0.98**	-0.83**	0.78**	0.96**

*Correlation coefficient significant at P-value < 0.05.
**Correlation coefficient significant at P-value < 0.01.
Fo = Forest, Shr= Shrubland, Grassland= Grassland, Cr= Cropland, Se= Settlement area, Bar= Bare land

Conclusion

In this study, we evaluate the spatiotemporal variability of physicochemical parameters, heavy metals, and land-use influences on the Khabur River, demonstrating that seasonal dynamics are the main driving factors of water quality. Most parameters—temperature, electrical conductivity, total dissolved solids, dissolved oxygen, turbidity, and major ions—showed strong seasonal variation, while pH and potassium had stable values. Nitrates and sodium exhibited localized variations correlated with agricultural and urban input sources. Heavy metals such as B, Sr, and Cd have changed with hydrological actions, while Ag, Al, As, Ba, and Li are mostly geogenic, several of which have exceeded the WHO limits.

Additionally, land-use and land-cover types have further contributed to the changing water quality patterns. Forests and shrublands help to reduce turbidity and metal mobility, while croplands, grasslands, barren land, and settlements have increased EC, TDS, nutrients, and metals through fertilization, soil disturbance, and runoff characteristics. Water bodies acted as sinks for metals such as cadmium (Cd) and boron (B).

The river continues to show moderate water quality but is very sensitive to both seasonal variations and anthropogenic pressures. Hence, maintaining vegetated strips and improving land and agricultural management are key to the sustainability of water quality within the basin.

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Conflict of Interests

None.

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