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Index Based Spatial Assessment of Heavy Metals in Damsa Dam Lake, Cappadocia/Türkiye

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Abstract

Damsa Dam Lake is significant value to the Cappadocia/Nevşehir region in terms of recreation, fishing and agricultural irrigation. The study was conducted to assess potential harmful elements (PHEs) in the dam and to examine the distribution eco-toxicological effects by Geographical Information System (GIS). Samples were collected for one year at 12 stations on the dam lake according to standard methods. The results of analysis obtained field studies along the spring mix period in the dam showed that high harmful metal(loid)s content (especially, average of 7.38 µg / L As and 4.94 µg/L Cu). According to the average concentration level in surface water, the order of PHEs was determined as follows: Fe > Zn > As > Mn > Al> Cu > Se > Pb >Cr > Hg > Ni > Cd. The findings obtained from the sampling were evaluated according to the relevant water quality regulations. Index-based spatial distribution maps created with ArcGIS showed that heavy metal-polluted lake water layer may have a significant effect on the ecological balance at some stations in the lake. This situation reveals the necessity of ongoing rehabilitation measures in the lake and the importance of sustainable conservation priority management practices.

Keywords
Heavy Metals, Surface Water Quality, Spatial Analysis, Damsa Dam, Ürgüp

Damsa Baraj Gölü'nde (Kapadokya/Türkiye) Ağır Metallerin İndeks Tabanlı Mekânsal Değerlendirmesi

Özet

Damsa Baraj Gölü, Kapadokya/Nevşehir bölgesi için rekreasyon, balıkçılık ve tarımsal sulama açısından önemli bir değere sahiptir. Çalışma, barajdaki potansiyel zararlı elementleri (PZE) değerlendirmek ve ekotoksikolojik etkilerinin dağılımını Coğrafi Bilgi Sistemi (CBS) ile incelemek amacıyla yürütülmüştür. Baraj gölü üzerinde bulunan 12 istasyondan bir yıl boyunca standart yöntemlere göre örnekler toplanmıştır. Barajda ilkbahar karışım döneminde yapılan arazi çalışmalarında elde edilen analiz sonuçlarına göre yüksek zararlı metal(loid) içeriği (özellikle ortalama 7,38 µg/L As ve 4,94 µg/L Cu) olduğu belirlenmiştir. Yüzey sularındaki ortalama konsantrasyon seviyelerine göre PZE'lerin sıralaması şu şekilde belirlenmiştir: Fe > Zn > As > Mn > Al> Cu > Se > Pb > Cr > Hg > Ni > Cd. Örneklemeden elde edilen bulgular ilgili su kalite yönetmeliklerine göre değerlendirilmiştir. ArcGIS ile oluşturulan indeks tabanlı mekansal dağılım haritaları, göldeki bazı istasyonlarda ağır metal yönünden kirlenmiş göl suyu tabakasının ekolojik denge üzerinde önemli bir etkiye sahip olabileceğini göstermiştir. Bu durum, gölde devam eden rehabilitasyon önlemlerinin gerekliliğini ve sürdürülebilir koruma öncelikli yönetim uygulamalarının önemini ortaya koymaktadır.

Anahtar Sözcükler
Ağır Metaller, Yüzey Suyu Kalitesi, Mekansal Analiz, Damsa Barajı, Ürgüp

1. Introduction

Surface water is used for a variety of purposes, including agriculture, drinking water, and other services. Therefore, its quality is crucial for irrigation, human welfare, and health. The ecological integrity of surface waters is frequently threatened by human activities that can lead to toxic or organic pollution through changes that can reduce connectivity. Moreover, seasonal changes and non-point pollution sources attributable to surface runoffs and groundwaters in urban areas compromise water quality. The main pollutants in water include suspended particles, toxic metals, nutrients, parasites, microbial disease-causing organisms, volatile and biodegradable organic compounds, and parasites. Heavy metal(loid)s are the primary cause of inorganic water pollution. The chemical form of heavy metals is a primary factor contributing to their toxicity (Sophocleous, 2002; Paul, 2017; Tirink & Ozkoç, 2021; Azhari et al., 2022; Cüce et al., 2025). The discharge of untreated domestic and industrial wastewater constitutes a micro source of pollution, thereby effecting alterations to the hydrochemistry of water. Nevertheless, critical levels of potentially toxic elements (PTEs) entering surface waters have been shown to have adverse effects on the reproductive processes of aquatic organisms.

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Industrial discharges and agricultural runoff have often been found to contain toxic metals that have the capacity to threaten ecological life, especially the general dynamics of local fish populations (Kormoker et al., 2024; Din et al., 2023; Rakib et al., 2022). Because they can come from a variety of sources, withstand environmental changes, readily enter the food chain, and build up in large quantities within animals, these are the most common chemical contaminants. Potential harmful elements (PHEs) are naturally occurring elements that can be transported into surface waters as a result of various processes, including geological erosion, the separation of metals from sedimentary deposits, and the degradation of organic matter. Through rock pieces carried by erosion, the atmosphere, wind-borne dust, volcanic activity, forest fires, and plants, heavy metal(loid)s contaminate water and have an impact on the water system (Şeker et al., 1998; Bakan et al., 2010; Sancer & Tekin-Özan, 2016; Sibal & Espino, 2018; Findik & Aras, 2023). The establishment of a reliable monitoring programme is contingent upon an understanding of the spatial and temporal variations in water quality. In addition, many studies have reported that PHE accumulation rates together with environmental factors such as bedrock erosion and mineral oxidation at varying rates depending on climatic conditions can lead to significant deterioration in water quality under the cumulative effect (Bilgin & Konanç, 2016; Ustaoglu & Aydın, 2020; Cüce et al., 2022a; Muhammad et al., 2024; Cüce et al., 2022b; Yüksel et al., 2024).

Water pollution represents a significant challenge, particularly given its impact on both environmental and human health. The current context of uncontrolled industrialisation and urbanisation has led to a heightened risk to numerous water sources (Kucukosmanoglu & Filazi, 2020; Egbueri & Mgbenu, 2020; Taş & Şişman, 2020; Aras et al., 2024). Water resources and water quality are very important for urban development and ecological environment, especially in the serious water shortage area (Vörösmarty et al., 2010). Drought is causing Anatolia's water resources to dry up, making the effects of global warming more noticeable. Along with the effects of water pollution caused by humans, the lack of water for agriculture is also a major issue that is causing regional issues to arise. The quantification of pollutant loads from point sources is generally more controlled and manageable than non-point sources. In this respect, the fact that agricultural activities play a dominant role in the formation of diffuse pollution in surface waters makes it necessary to prevent pollution from these sources (Tepe et al., 2006; Mutlu et al., 2013; Kalipci et al., 2020; Tirink, 2021; Cüce et al., 2022c; Baki & Baki, 2023). Industrial effluents and sewage represent a significant source of environmental toxicity, posing a threat to aquatic life and degrading water quality. Because of their toxicological characteristics and ability to accumulate in aquatic biota, PHEs introduced into aquatic ecosystems from geogenic and anthropogenic sources have been shown to have negative effects on species diversity and ecosystem health (Türkmen et al., 2018; Türkmen & Aydin, 2021; Cüce et al., 2022d; Ustaoglu et al., 2022; Kalipci et al., 2023; Karadeniz et al., 2024). In addition to the detrimental impact on aquatic organisms, the continuous receiving environments of dam lakes are also adversely affected by environmental contamination to a significant extent. This contamination also has an impact on humans through the food chain. It is imperative that rivers, lakes, dams and wetlands are preserved and managed in a manner that maintains biological balance and ensures the effective utilisation of water resources. To this end, it is essential that water quality is monitored at designated intervals and that the key factors driving changes in pollution are identified, enabling the relevant authorities to take appropriate action. In particular, the sources of pollution in the vicinity of the dams, which are used as a source of drinking water, for irrigation and for utility purposes, should be subject to control measures (Yilmaz, 2004; Karadavut et al., 2012; Islam et al., 2015; Kalipci et al., 2017a; Kalipci et al., 2017b; Cüce et al., 2025). Çiçek et al. (2016) observed a considerable reduction in freshwater resources in Nevşehir as a result of field studies. Existing resources are generally dammed for purposes such as agricultural irrigation and are also threatened by pollution. The irregular and unconscious use of limited river resources in the Cappadocia region causes changes in the water regime, which results in habitat loss.

The objective of this study is to ascertain the heavy metal content and ecotoxicological effects of Damsa dam lake water through a comprehensive and multidimensional statistical analysis. Using various heavy metal parameters such as arsenic, cadmium, chromium, copper, iron, nickel, lead and zinc, the main objectives of this study are to conduct a multi-index assessment to examine the effects of anthropogenic activities on the water quality of Damsa dam lake in Cappadocia, which is the centre of tourism and recreational activities, and to contribute to local decision makers with recommendations for sustainable resource management. The main reasons for the surface water pollution in the dam are the domestic wastewater discharged into Damsa Stream without treatment, pesticide-derived agricultural drugs and their packaging used in agricultural activities, industrial wastes that are not disposed of properly and as a result are released into the environment in an inappropriate manner, and the flow of leachate resulting from improper storage of domestic solid wastes with chemical properties towards the lake basin. In this study, PHE levels were determined at a total of 12 points in the surface water of Damsa Dam Lake during the spring mixing period. Furthermore, the results will be compared with national and international criteria, the index status of the dam lake based on metallic pollution will be analysed using GIS, and the protection measures of this dam against climate change will be discussed, as these are important in terms of sustainable irrigation and recreational needs.

2. Material and Method

2.1. Study Area

The Damsa Dam was constructed on Damsa Stream in the Ürgüp District of Nevşehir Province between 1965 and 1971 for the purpose of agricultural irrigation. It is situated 30 km from the city centre and 9 km from the district centre. Damsa Dam Lake represents a significant inland water resource within Central Anatolia, particularly in the vicinity of Nevşehir. It plays a pivotal role in the region, serving as a vital source of irrigation and providing opportunities for recreational activities. The Damsa dam measures 862,000 m³ in volume and is an earth-fill structure. At normal water level, its lake volume is 7.12 hm³, and it is 31.50 m above the riverbed. At normal water levels, the lake's area is 0.82 km². 1,390 hectares are served by the dam's irrigation services (Findik et al., 2019; Kalipci et al., 2024). Although its quality has decreased in terms of fishing, Damsa Dam Lake is one of the highly recreational water resources of the Cappadocia region that plays an active role in agricultural irrigation. The most frequently caught fish species in the Dam Lake include *Cyprinus carpio*, *Leuciscus cephalus* etc. Furthermore, it has been claimed that *Atherine boyeri* was found in 2012, and *Oreochromis niloticus*, an invasive species of tropical climate fish, has been found in Damsa Dam (Treer et al., 2003; Mert & Çiçek, 2010). The map showing the study area and sampling stations is presented in Figure 1.

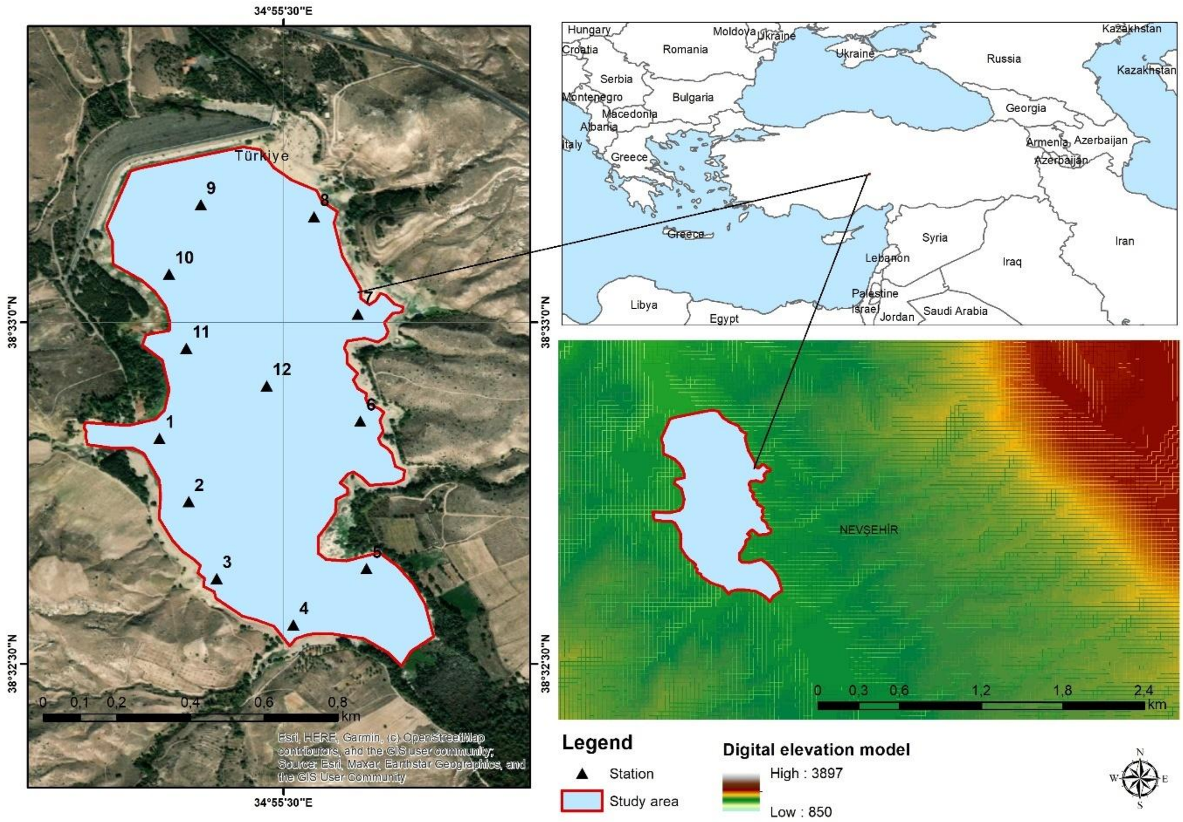

Figure 1: Map of Damsa Dam Lake and the sampling locations

2.2. Collection and Analysis of Surface Water Samples

Dam lake water samples were taken from 12 sampling stations (during spring mix period) in May 2020. The geographical coordinates of the sampling stations were taken by GPS (Magellan Exp710) and water samples were collected in 1.5 L plastic bottles as a composite sample from at least two points at each sampling station, with the objective of achieving optimal mixing. Potential toxic metal concentrations in the dam lake samples brought to the environmental chemistry laboratory and stored at +4 ˚C were determined in accordance with standard methods by American Public Health Association (American Public Health Association, 2007). Analytical purity chemicals were used in all analyses and the concentration of PHE in the dam water samples was determined by an ICP-MS (Agilent Corporation, 7700x-USA). Water samples were filtered into 10-mL Teflon tubes (0.45-µm Sartorius brand) and acidified with 65% nitric acid in order to determine the amounts of soluble metals. The autosampler pump was subjected to a three-step cleaning process between injections, comprising the following steps: The cleaning process was initiated with a 30-second wash with ultrapure water. This was followed by a 50-second rinse with 2% (v/v) nitric acid. The process was concluded with a further 50-second wash with ultrapure water. For calibration of the instrument, set of standards was created from analytically pure solutions (approximately 95 percent precision and accuracy) for each metal and all of the measurements were repeated 3 times.

2.3. Statistical and Thematic Spatial Analysis

The application of diverse statistical methodologies was employed to assess the quantification of elements in water samples. Potential toxic metal levels in water samples were tested for significant correlations using the Pearson rank correlation coefficient and analysis of two-way cluster were applied to reveal theater-element/sampling station relationship. Multifaceted statistical analyses of all results obtained in the study were performed using a statistical program of (SPSS 22 package). Thematic spatial analyses of the PHEs detected at each station were created using ArcGIS 10.8 software. This involved the creation of a continuous surface for the study area, which was achieved through the utilization of the IDW technique (inverse distance weighted approach), within the domain of interpolation. The methodology employed in this study is predicated upon the assumption that surface water bodies distributed across the research area are interconnected (Shukla et al., 2020; Tercan et al., 2022).

3. Results and Discussion

3.1. Levels PHEs Detected in Surface Water of the Dam Lake

The results of the analyses of the concentration of the following elements (Al, Cr, Mn, Fe, Ni, Cu, Zn, As, Se, Cd, Hg, Pb) in the surface water samples of Damsa Dam are presented in Table 1 while heat mapping of PHEs values is illustrated in Fig. 2. The majority of the toxic metals discussed in this study are found in the biosphere, such as water, soil and rock, and are also released into the environment from anthropogenic sources, mostly commercial and industrial. Toxic heavy metals such as lead, cadmium and arsenic are common in many industrial processes and are important pollutants of the environment. The average PHE concentrations were presented in this order: Fe > Zn > As > Mn > Al> Cu > Se > Pb >Cr > Hg > Ni > Cd, and their average levels are 15.69 > 14.88 > 7.38 > 6.35 > 6.09 > 4.94 > 1.49 > 0.82 > 0.44 > 0.27 > 0.13 > 0.07 μ/L, respectively. The mean PHE concentrations of the surface water samples collected during the designated sampling period are presented in Table 1 and Fig. 2 alongside the established limit values set forth by the World Health Organization (WHO), U.S. Environmental Protection Agency (USEPA), and Türkiye Standard Institute (TSE) (Table 2). The comparison of the average metal concentrations detected during the study period with the results of research in surface waters of similar nature in the international literature is given in Table 3.

Table 1: ICP results of potentially harmful elements (PHEs) for 12 stations (μ/L)

Sample Stations	Al	Cr	Mn	Fe	Ni	Cu	Zn	As	Se	Cd	Hg	Pb
P1	2.77	0.1	0.2	5.21	0.40	0.50	2.08	6.51	1.85	0.08	0.22	0.29
P2	3.55	0.1	0.04	5.52	0.40	0.45	2.20	6.25	1.60	0.08	0.21	0.34
P3	11.85	0.06	5.4	44.72	0.17	0.10	6.40	10.17	1.70	0.08	0.27	0.38
P4	12.53	1.06	0.4	13.92	0.09	0.54	32.44	12.21	1.34	0.05	0.20	1.63
P5	2.38	0.42	0.26	7.14	0.01	1.71	16.66	5.83	1.39	0.06	0.24	0.82
P6	4.53	0.20	0.71	12.40	0.06	2.4	18.44	2.96	1.19	0.08	0.43	0.91
P7	3.65	0.32	0.65	12.22	0.0	2.79	18.82	3.09	1.44	0.08	0.39	0.78
P8	9.60	1.07	0.48	13.2	0.05	0.48	31.27	12.81	1.52	0.05	0.18	1.57
P9	5.60	0.66	0.19	10.80	0.09	0.12	14.39	6.24	1.85	0.05	0.31	0.97
P10	1.60	0.52	0.06	6.88	0.00	1.63	16.97	6.06	1.52	0.07	0.23	0.92
P11	12.24	0.1	5.42	45.46	0.19	0.14	4.43	10.59	1.37	0.08	0.33	0.35
P12	2.77	0.67	0.10	10.86	0.10	0.07	14.43	5.81	1.11	0.06	0.26	0.85
Mean	**6.09**	**0.44**	**6.35**	**15.69**	**0.13**	**4.94**	**14.88**	**7.38**	**1.49**	**0.07**	**0.27**	**0.82**

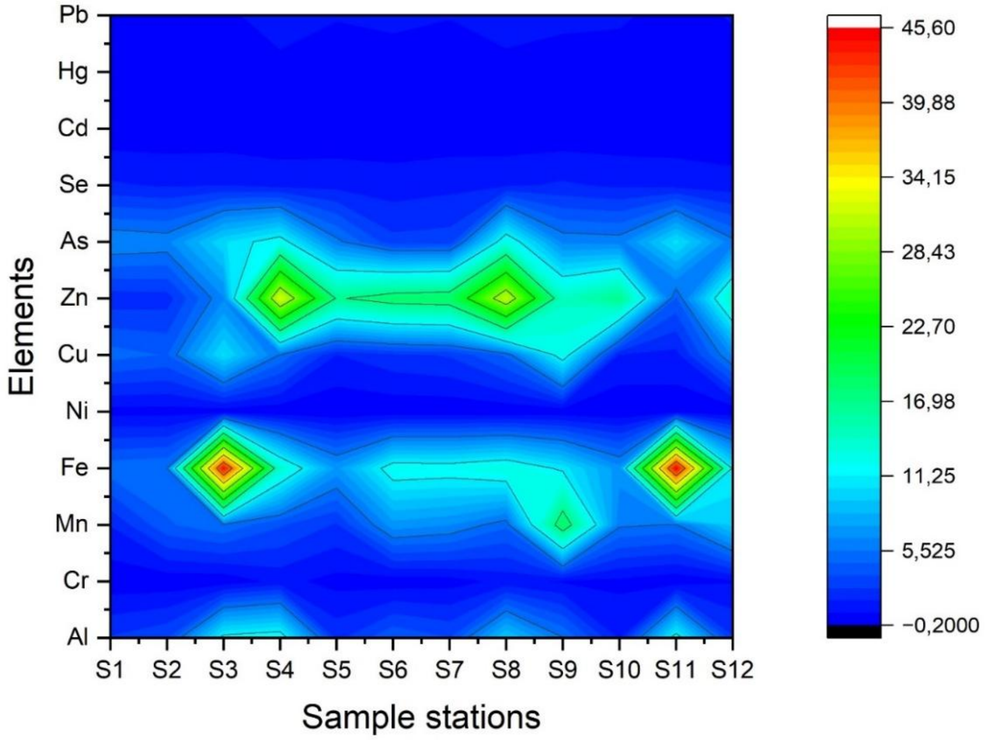

Figure 2: Heat map of PHE levels (µ/L) at 12 stations observed in Damsa Dam

Geographic information system (GIS) techniques were used in the study to look at patterns of spatial pollution distribution and pinpoint possible pollutant sources. The thematically spatial evaluation map showing the accumulation of PHEs (Al, Cr, Zn, As, Mn, Fe, Se, Cd, Ni, Cu, Hg, Pb) in the surface water of the dam is given in Fig. 3. As seen in Figure 3, Mn, Se and Cu concentrations in the northern part of the dam are relatively high in spring mixing period. During the sampling period, relatively high Cr, Zn, As and Pb concentrations were observed in the southeastern part of the lake, while the highest Hg values measured were in the southern regions, similarly high Ni values were measured in the west of the lake, and it is observed from thematic maps that Cd metal contents determined with relatively low concentrations are distributed throughout the lake.

Table 2. USEPA, WHO, and Türkiye Standard Institute surface water rules' permissible limits for surface waters

PHEs (µg/L)	This Study (mean)	World Health Organization (2017)	U.S. Environmental Protection Agency (2009)	Türkiye water quality standards provided drinking water (T.C. Resmi Gazete, 2019)			Türkiye surface water regulations (T.C. Resmi Gazete, 2015)				Turkish drinking water regulations (Turkish Standards Institute, 2005)
				A1	A2	A3					
As	1.08	10	10	10	40	100	≤20	50	100	>100	10
Co	0.72	–	–	800	-	2600	≤20	50	200	>200	-
Cr	3.71	50	100	50	500	1000	≤20	50	200	>200	50
Cu	16.49	2000	1000	2000	5000	20000	≤300	1000	5000	>5000	2000
Cd	1.37	3	5	5	15	50	≤100	500	1000	>3000	5
Mn	85.71	400	50	50	100	250	≤20	50	200	>200	50
Ni	2.83	70	–	20	30	200	≤10	20	50	>50	20
Pb	15.24	10	15	10	50	100	≤200	500	2000	>2000	10
Fe	591.78	300	300	200	1000	2000			100	>100	200
Al	475.11	200	200	200	500	2000					200
Zn	11.43	5000	5000	3000	6000	12000					3000
Hg	0.51	6.0	2	1	2.5	5					1

Table 3: Comparison of average metal concentrations detected during the study period with similar research results

Water Supplies	Cr	Mn	Fe	Ni	Cu	Zn	As	Se	Cd	Hg	Pb	Reference
Damsa Dam, Türkiye	0.44	6.35	15.69	0.13	4.94	14.88	7.38	1.49	0.07	0.27	0.82	This study
Batman Dam, Türkiye	16.5	-	57.66	15.96	9.08	-	0.71		0.04	-	-	(Varol, 2013)
Bitter Lake, Egypt	-	-	-	-	7.06	7.56	-	-	0.05	-	2.20	(Shetaia et al., 2023)
Chaohu Lake, China	0.71	-	-	0.51	0.41	2.11	0.67	-	0.01	-	0.46	(Chen et al., 2024)
Damsa Dam, Türkiye	-	-	18.3	-	0.6	0.4	-	-	-	-	-	(Kalipci et al., 2017a)
Damsa Dam, Türkiye	6.28	6.46	-	2.08	230	2.46	8.24	-	0.02	0.09	0.09	(Findik & Aras, 2023)
Dicle Dam, Türkiye	18.58	-	62.07	15.86	2.12	-	1.61	-	0.03	-	-	(Varol, 2013)
Kızılırmak River, Türkiye	8.71	84.9	33.2	15.27	0.74	12.51	28.15	-	1.22	0.05	0.05	(Cüce et al., 2022a)
Kor River, Iran	20.63	-	-	7.63	8.95	37.93	11.12	-	6.12	-	-	(Mokarram et al., 2020)
Yeşilırmak River, Türkiye	1.1	12.5	260.9	1.7	3.09	29.8	3.1	0.3	0.02	0.01	0.5	(Üstün-Odabaşı & Ceylan, 2023)
World average	0.70	34.0	66	0.80	1.48	0.60	0.62	-	0.08	0.08	0.08	(Gaillardet et al., 2003)

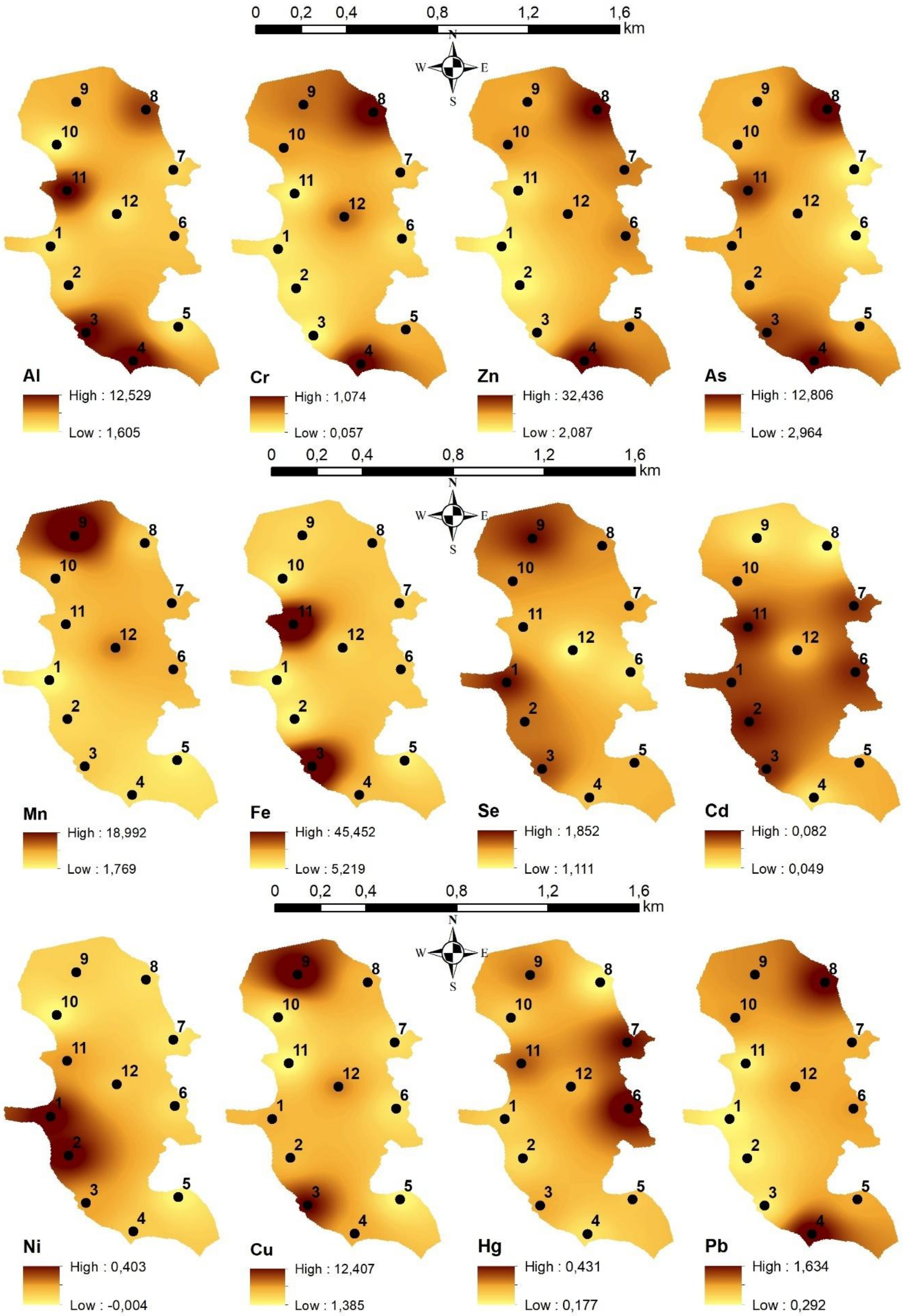

Figure 3: Spatial distribution map of PHEs levels (µ/L)

3.2. Assessment of Indexical Analysis

In recent years, various indices have been used to comprehensively assess pollution levels and ecological risk in lentic ecosystems. Pollution indices used in this study include the Water Quality Index (WQI), the Heavy Metal Pollution Index (HPI), and the Heavy Metal Evaluation Index (HEI). When assessing the acceptability of water quality for human consumption based on metal contamination and interpreting the harmful effects of water given its absolute nature regarding heavy metals, researchers might use the preliminary information gained from these indices.

The Water Quality Index (WQI) is a tool that synthesizes an array of factors into a concise statement, thereby facilitating an integrated and comprehensive assessment of water quality (Wang et al., 2017; Bilgin, 2018; Varol, 2020; Cüce et al., 2025). The weighted arithmetic water quality index is calculated using the following formula, Eq.1:

$$WQI = \sum \left[W_i \times \left(\frac{C_i}{S_i}\right) \times 100 \right] \quad (1)$$

According to Xiao et al. (2019), the water quality status was also classified using the WQI into the following categories: excellent (WQI < 50), good (WQI = 50-100), poor (WQI = 100-200), extremely poor (WQI = 200-300), and water unfit for drinking and irrigation (WQI > 300).

The Heavy Metal Pollution Index (HPI) is a valuation approach that considers the collective impact of each heavy metal on total water quality. It has been employed by the majority of scientists to comprehensively assess overall water quality. In this study, the HPI was calculated using Eq. 2, which were proposed by Mohan et al. (1996) as follows:

$$HPI = \frac{\sum_{i=1}^{n}(Q_i W_i)}{\sum_{i=1}^{n} W_i} \quad (2)$$

In the formula, Wi represents the unit weight of metals, Qi denotes the sub-index of the potentially toxic metal, Si specifies the reference values of the factorial result, Mi signifies the screened values of potentially toxic metals, and n denotes the number of factors taken into account. Accordingly, when HPI is less than 100, it can be inferred that the heavy metal pollution in question is not of a level that is likely to be responsible for severe health risk situations (Saleh et al., 2019).

The Heavy metal evaluation index (HEI) is a useful tool for examining water quality in terms of heavy metal pollution. It can be used to interpret the degree of pollution of water (Edet & Offiong, 2002). In the present study, the HEI was calculated based on the following the formula (Eq. 3).

$$HEI = \sum_{i=1}^{n} \frac{H_C}{H_{MAC}} \quad (3)$$

The maximum permissible concentration (MAC value) for each variable is represented by the Hmac value, whereas the Hc value represents the concentration of each individual factor in the formula (World Health Organization, 2017). High metal concentrations in MAC further deteriorate water quality (Goher et al., 2014; Yüksel et al., 2021). In general, water should not be used if the concentration of a single heavy metal exceeds the MAC value (HEI > 10). Although the results of WQI, HPI and HEI analyses showed that the reservoir water was not significantly polluted by heavy metals (average index values; 11.44, 12.75 and 1.22, respectively), the Cu and As metal data indicated that this agricultural irrigation reservoir water showed pollution levels of heavy metals ranging from mild to severe (Figure 4).

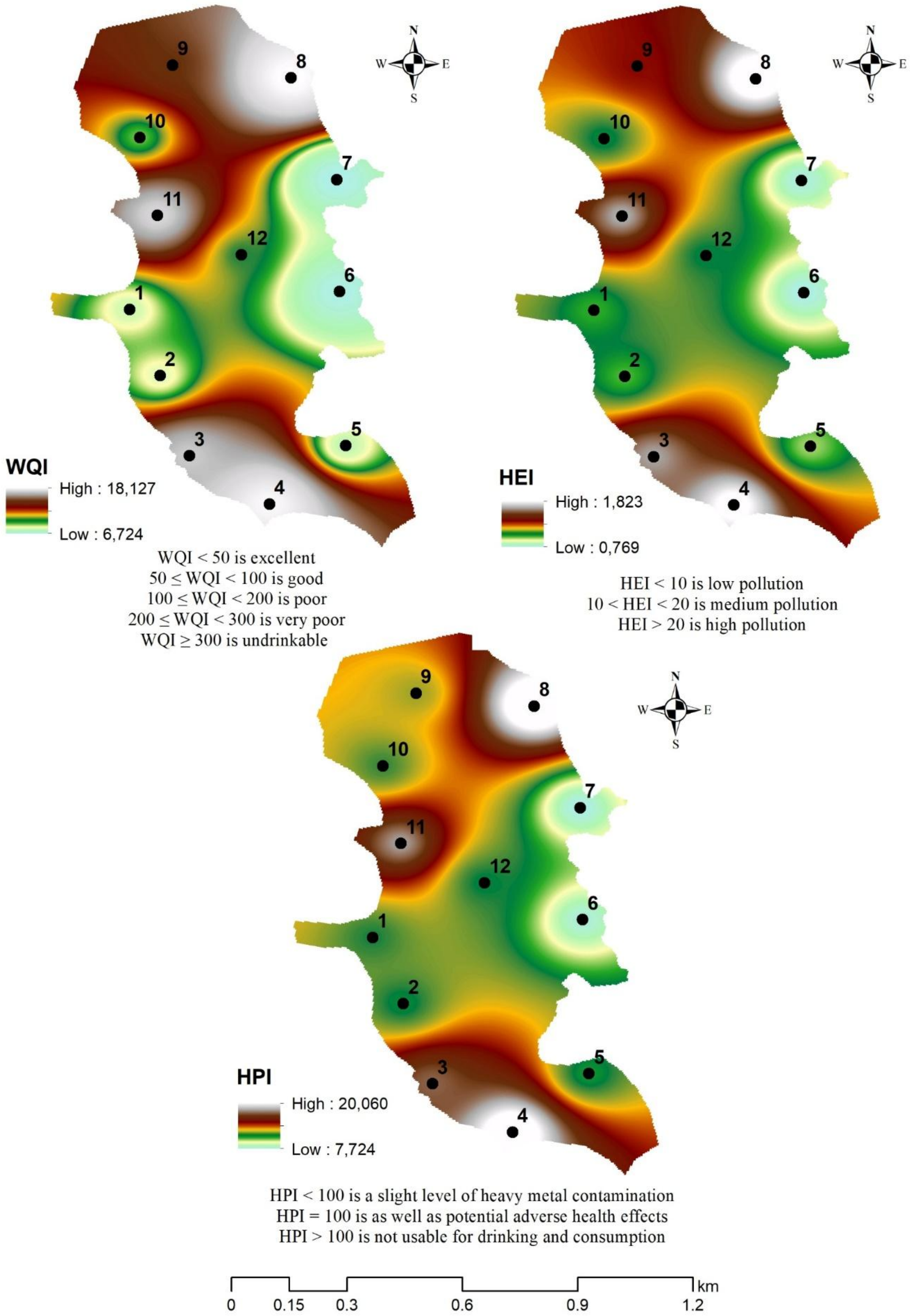

Figure 4: The map of indexical analysis of heavy metal pollution detected in Damsa Dam

3.3. Assessment of Correlation Analysis

Additional methods, like multivariate statistical analyses, have been employed to find possible heavy metal sources in order to improve the analysis's effectiveness and evaluation's power. The analysis of sources of heavy metals can facilitate an understanding of their distribution (Chai et al., 2017; Jiang et al., 2019; Huang et al., 2020). In this study, Pearson correlation analysis was therefore employed. The Pearson correlation coefficients for PHEs in surface water sampled at 12 different measurement stations on the dam lake are presented in Figure 5. In general, high positive correlation levels were detected among the measured metal(loid)s, Al, Fe and As (approximately r=0.8) due to the known geogenic rock structure of the region. According to Suresh et al. (2011), a high correlation coefficient across variables suggests that they have a common source, are dependent on one another, and behave identically when being transported. The highest positive correlation rates were found among Cd, Pb and Zn (approximately 0.9), while the relatively moderate positive correlation of Se metal with Ni and Cd can be considered as an indicator of the possibility of anthropogenic pollution. This finding is compatible with the results of the theme spatial analysis map of PHEs generated by GIS, which shows the accumulation distribution of the selected metals in the sample stations. Furthermore, these results are consistent with the PCA and HCA results (Figure 6-7).

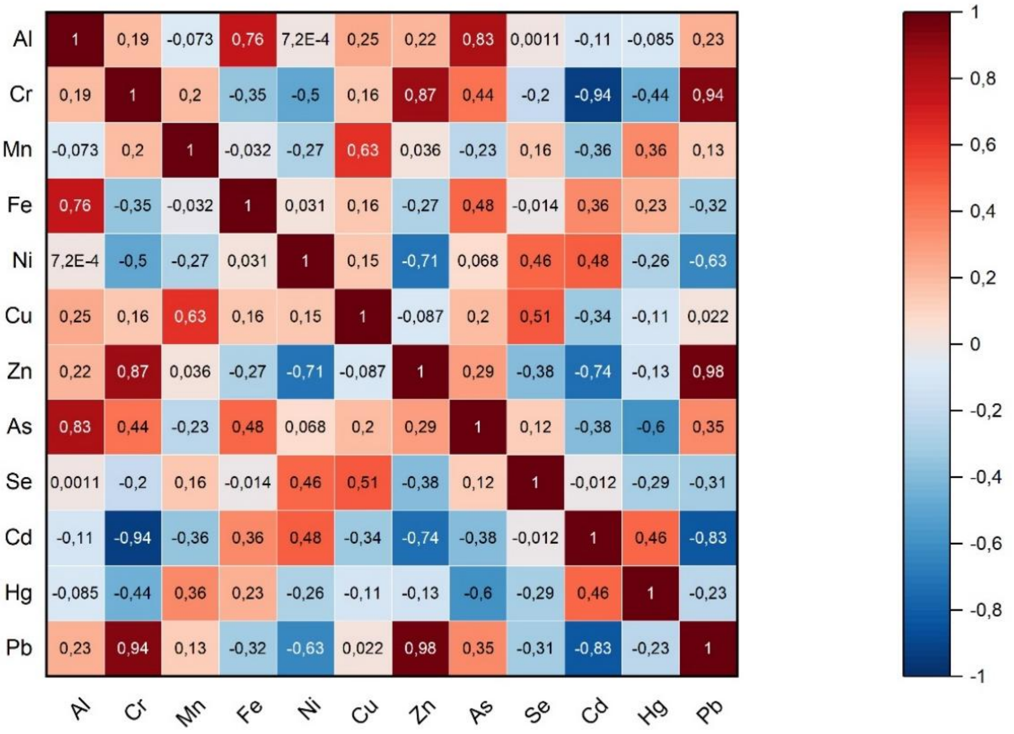

Figure 5: Correlations between heavy metal (loid)s detected in surface water samples

3.4. Assessment of Cluster and PCA Analysis

The principal component analysis (PCA) was used to observe whether the metal concentrations in the dam lake water were related to each other. The application of varimax rotation to the results of the aforementioned investigations enabled the determination of the factors that affected water quality. The diagram of the PCA results is presented in Figure 6. The significant connection between specific metals in surface water may be indicative of a shared source of contamination. As can be understood from Figure 6, Cr, Pb and Zn sources are quite close to each other in terms of origin according to the 1st principal component (PC1). The same situation is valid for As and Al metals. It can be said that other metals have contamination sources close to each other according to the 2nd principal component (PC2).

In this study, cluster analysis was performed to reveal the relationship network between the stations and both groups determined by PCA analysis. It can be said that the index based thematic map of PHEs produced with GIS and the two-way clustering analysis results are compatible with each other and there is a high similarity between them and the PCA results. Hierarchical clustering algorithm divides data into different clusters according to their similarity. Data similarity is measured by distance and correlation coefficient. Distance-based similarity indicates that two data points with a small distance have a large similarity, mainly including Euclidean distance, Mahalanobis distance, Minkowski distance. Hierarchical clustering algorithms include single linkage, complete linkage, average linkage, center point linkage and Ward's method (Cohen-Addad et al., 2019).

The Ward linkage technique and the Euclidean distance metric were used to create a cluster heat map and dendrogram of metal(loid)s findings of surface water sampled at stations (Figure 7). By forming a cluster of similar samplings, various samplings are placed in separate cluster packages, which helps to determine the pollution degree of surface waters with the same PHE concentration (Hossain et al., 2018). As seen in Figure 7, the dendrogram presented main cluster packages in the vertical section. The analysis results were grouped into two main clusters in terms of similar source distribution among heavy metals. Cluster 1 of these includes Al, As, Fe, Cr, Zn and Pb, while Cluster 2 includes other metals. Two main cluster structures were observed in the clusters made to reveal the similarity or closeness between the stations. The first main cluster includes stations S3 and S11. The other cluster forms two large categorical distributions within itself; While S1 and S2 are separated under the first subcluster, the predominant stations of this subcluster are S4-S8/S5-S10 and S6-S7/S9-S12 (Figure 7). In other words, the metal levels at stations S1 and S2 are close to each other. Again, there is no difference in terms of metal levels between S4 and S8 and between S5 and S10. The metal levels measured at S6, S7, S9 and S12 also show high similarity.

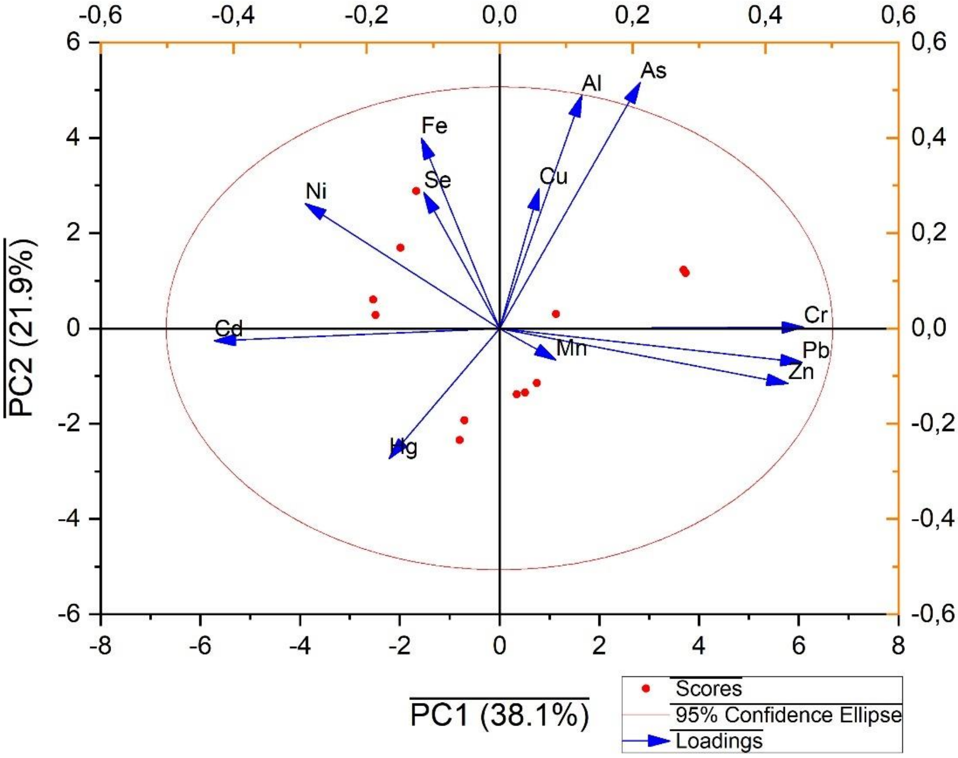

Figure 6: PCA analysis results of PHEs in lake water sampled stations

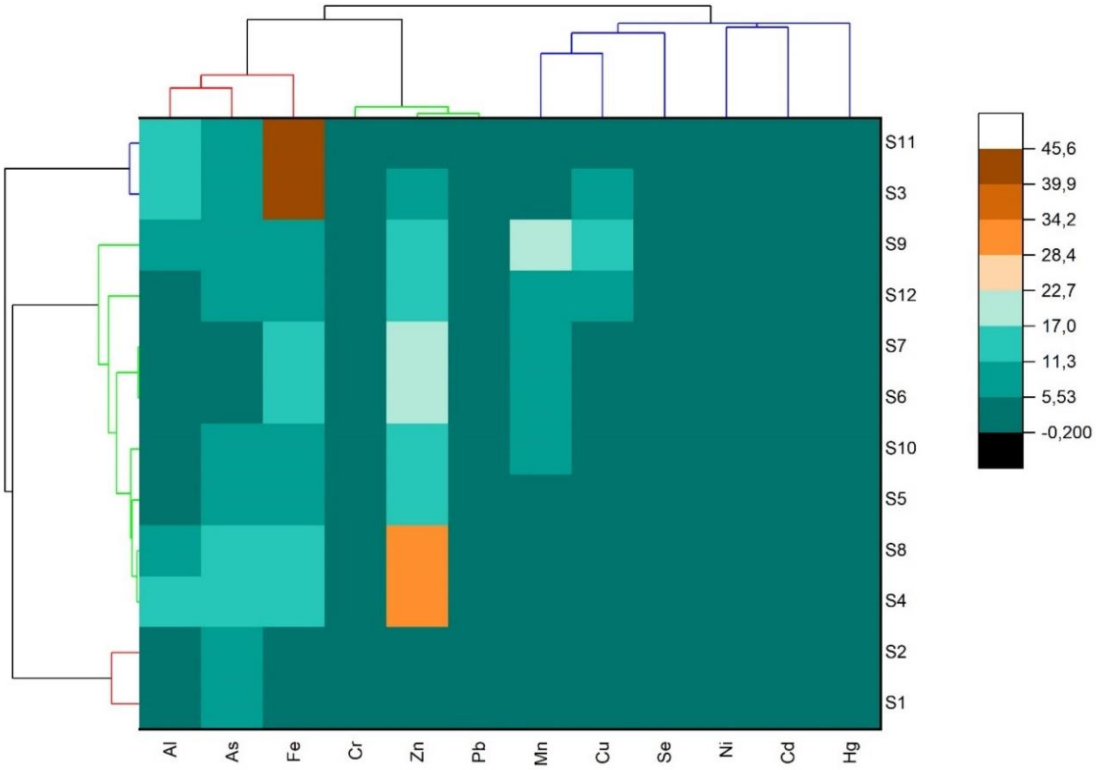

Figure 7: Two-way hierarchical cluster heat map of PHEs in lake water sampled stations

4. Conclusion

This study examined the direct metallic toxic effects of point and diffuse pollutant sources in the Damsa Dam in the Cappadocia region. The presence of possible climatic changes in water quality was considered, and multivariate statistical methods, principal component and cluster analysis, as well as water quality assessment indices, were used to address this issue. In this research, when the measured potential harmful elements (PHEs; Al, Cr, Mn, Fe, Ni, Cu, Zn, As, Se, Cd, Hg, Pb) levels were evaluated, the surface water of Damsa Dam was classified as 1st class water according to Türkiye surface water regulations. The indexical assessment results indicated that Damsa Dam Lake exhibited a low risk profile with respect to surface water quality. The WOI values, calculated based on metal measurement results obtained from 12 stations, demonstrated that the dam water was of excellent quality. However, the HPI and HEI values indicated a relatively low level of heavy metal contamination and low pollution, respectively. Source identifications made with PCA and HCA methods confirm that the metals in Damsa Dam Lake mainly originate from the drainage waters mixed with Damsa Stream that feeds the lake as a result of agricultural and small industrial activities carried out in the area. While the observation of high levels of Fe, Al and As elements is considered as a natural situation due to the formation that presents an example of the rock structure of the region, the presence of toxic elements of industrial origin such as Pb indicates that there may be serious contamination in the basin.

The findings of the present study may prove beneficial for the advancement of the dam lake and its surrounding environment. It is thought that the heavy metal pollution originating from industrial and agricultural waste obtained in this study originates from the main source feeding the dam (Damsa Stream) and other anthropogenic diffuse pollutant sources. Considering that the amount of sediment transported to the dam varies in the meteorological drought and sudden excessive rainfall conditions of the region, it should not be neglected that point heavy metal pollution may be the result of geogenic sediment transport. Although protecting water quality results in high costs for local governments, the best outcome is to expect benefits such as recreational and sustainable water abundance from investments made in protecting water quality, especially with the correction of eutrophication effects. Consequently, it is imperative to implement measures that can prevent the influx of heavy metals into the dam lake through direct discharge or agricultural drainage, as well as the entry of wastewater into drainage channels. This can be achieved by establishing dedicated systems for the collection and removal of these substances, thereby safeguarding the aquatic life within the lake and extending its lifespan. In addition, cost-effective, environmentally friendly adsorbents, remediation methods such as phytoremediation and bioremediation, and tools such as biosensors should be included in the dam lake management plans to reduce anthropogenic hazards.

In light of the recent dredging activities that have been conducted on the dam, it is imperative to monitor the water and sediment quality in order to ascertain the environmental status of the area. The monitoring of the dam water and sediment will provide insights into the changes that have occurred as a result of the dredging activities, which have altered the sediment structure. Such investigations must be repeated on a regular basis in terms of ecosystems due to the persistence of pollution elements and their dynamic structure with changes in quality. Determining the water quality criteria of water resources is crucial for guiding decision-making processes and ensuring efficient water management. This information will serve as a foundation for future studies (such as integrating GIS with multi-criteria assessment approaches and planning sustainable land and water resources using machine learning models and the Analytical Hierarchy Process (AHP) method) and will contribute to the understanding of the environmental impact of such activities.

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