Research Article

Submission Date
17 / 10 / 2025
Admission Date
30 / 12 / 2025

Heavy Metal–Based Water Quality and Pollution Indices Assessment of Drinking Waters in Ağrı Province, Türkiye

Ağrı İli İçme Sularının Ağır Metal Bazlı Su Kalitesi ve Kirlilik İndekslerinin Değerlendirmesi

Ufuk MERCAN YÜCEL[1]

How to Cite: Yucel, U. M. (2025). Heavy Metal–Based Water Quality and Pollution Indexes Assessment of Drinking Waters in Ağrı Province, Türkiye, 7 (8), 207-218. DOI: https://doi.org/10.53472/jenas.1805583

ABSTRACT:

In this study, water quality and pollution levels in terms of heavy metals were evaluated in drinking water samples collected from water reservoirs, boreholes, and public fountains belonging to the Ağrı Water and Sewerage Administration in the central neighborhoods of Ağrı Province. For this purpose, water samples were taken from 50 different locations in the central neighborhoods of Ağrı province. Analyses of Cd, Cu, Fe, Hg, Mn, Ni, Pb, Co and Zn in the drinking water samples were performed using atomic absorption spectrophotometry. In this study, the water quality ındex (WQI) was used to evaluate the quality of drinking water, while the heavy metal pollution index (HPI), heavy metal assessment index (HEI), and pollution level (DC) were used to determine the heavy metal pollution of drinking water. As a result of the analyses, Hg was not detected in the water samples. The determined ranges of WQI, HPI, HEI, and DC values were 77.35–101.74, 64.14–93.25, 5.01–6.81, and −2.99 to −1.19, respectively. Except for sampling point N1, WQI values between 50 and 100 indicated that the drinking water samples were classified as good-quality water according to water quality criteria. Based on the HPI results, the ranking of heavy metal concentrations was Pb > Cd > Co > Ni > Mn > Fe > Zn > Cu. The highest HPI and HEI values were observed in water samples collected from region N12. However, since HPI values at all sampling points were below 100, the drinking water samples were considered unlikely to cause adverse health effects. In addition, because HEI values were below 10 and DC values were below 1 at all locations, the water samples were classified as having low pollution levels. Overall, the results indicate that drinking water in the city center of Ağrı Province is generally suitable for consumption. However, due to industrial pollutants, the uncontrolled use of organic and chemical fertilizers, and the application of wastewater and sewage sludge in agriculture, regular heavy metal analysis and pollution monitoring in drinking water are essential for public health.

Keywords: *Water Quality, Pollution Index, Heavy Metal, Drinking Water, Ağrı Province,*

ÖZ:

Bu çalışmada, Ağrı ili merkez mahallelerinde yer alan Ağrı Su ve Kanalizasyon İdaresi Genel Müdürlüğü'ne ait su depoları, sondaj kuyuları ve umumi çeşmelerden alınan içme suyu örneklerinde, ağır metaller açısından su kalitesi ve kirlilik düzeyleri değerlendirilmiştir. Bu amaçla Ağrı ilinin merkez mahallelerindeki 50 farklı noktadan su örnekleri alınmıştır. İçme suyu örneklerinde Cd, Cu, Fe, Hg, Mn, Ni, Pb, Co and Zn ağır metallerinin analizleri atomik absorpsiyon spektroskopisi kullanılarak gerçekleştirilmiştir. Bu çalışmada, su kalite İndeksi (WQI) içme sularının kalitesinin değerlendirilmesinde, ağır metal kirlilik indeksi (HPI), ağır metal değerlendirme indeksi (HEI) ve kirlilik derecesi (DC) ise içme sularının ağır metal kirliliğinin belirlenmesinde kullanılmıştır. Yapılan analizler sonucunda, su örneklerinde Hg tespit

[1] **Corresponding Author:** Van Yüzüncü Yıl Üniversitesi, umercan@yyu.edu.tr, ORCID: 0000-0001-8256-7868

edilmemiştir. Örnekleme noktalarına göre belirlenen WQI, HPI, HEI ve DC değerleri sırasıyla 77,35–101,74, 64,14–93,25, 5,01–6,81 ve −2,99 ile −1,19 aralığında bulunmuştur. N1 örnekleme noktası dışında, içme suyu örneklerine ait WQI değerlerinin 50–100 aralığında olması, bu suların su kalite kriterlerine göre iyi kalite sınıfında yer aldığını göstermiştir. HPI sonuçlarına göre ağır metal konsantrasyonlarının sıralaması Pb > Cd > Co > Ni > Mn > Fe > Zn > Cu şeklinde belirlenmiştir. En yüksek HPI ve HEI değerleri, N12 bölgesinden alınan su örneklerinde tespit edilmiştir. Bununla birlikte, tüm örnekleme noktalarında HPI değerlerinin 100'ün altında olması, içme sularının sağlık açısından olumsuz etki oluşturmadığını göstermektedir. Ayrıca, tüm örneklerde HEI değerlerinin 10'un altında, DC değerlerinin ise 1'in altında olması nedeniyle, sular düşük kirlilik sınıfında değerlendirilmiştir. Sonuç olarak, Ağrı ili merkezindeki içme sularının genel olarak içme amacıyla uygun olduğu belirlenmiştir. Ancak, endüstriyel kirleticiler, organik ve kimyasal gübrelerin kontrolsüz kullanımı, atıksu ve kanalizasyon çamurunun tarımda uygulanması nedeniyle, içme sularında ağır metal analizlerinin düzenli olarak yapılması ve kirlilik düzeylerinin izlenmesi, halk sağlığı açısından büyük önem taşımaktadır.

Anahtar Kelimeler: *Su Kalitesi, Kirlilik İndeksi, Ağır Metal, İçme Suyu, Ağrı.*

1. Introduction

Water accounts for about 60–70% of the human body and is essential for life. It is necessary for humans as well as for all living organisms (Begun et al., 2009). According to the World Health Organization, nearly half of the population in developing countries faces health problems due to the lack of drinking water that meets required quality standards (WHO, 1992). Water pollution is generally classified as organic, inorganic, biological, and thermal pollution (Munsuz & Unver, 1995). Metals are the main sources of inorganic water pollution, and, unlike organic pollutants, they can accumulate in aquatic environments without being degraded (Egemen & Sunlu, 1999).

Heavy metals are commonly found in the environment and include metals and semi-metals with a density of about 5 g/cm³, which is around five times higher than that of water (Hutton & Symon, 1986). Some metals, such as copper (Cu) and zinc (Zn), are essential micronutrients for normal biological functions in humans, animals, and plants. However, other metals, including cadmium (Cd) and lead (Pb), have no known beneficial role in living organisms (Kar et al., 2008; Suthar & Singh, 2008; Wasim Aktar et al., 2010). These metals are not biodegradable and can accumulate in the human body, causing damage to the nervous system and internal organs (Lee et al., 2007; Lohani et al., 2008). Exposure to certain metals in drinking water increases the risk of disease, such as brain and kidney disorders from Pb, liver and neurological problems from Mn (manganese), skin and stomach diseases related to As (arsenic), kidney damage from Cd, Cu, and Hg (mercury), and skin diseases caused by Cr (chromium) (Pehlivan, 2022). Therefore, monitoring toxic metal levels in drinking and domestic water is essential to protect public health (Begun et al., 2009).

Heavy metals can enter aquatic environments due to both natural processes and human activities, causing serious problems in living organisms. Heavy metals can naturally occur in water at low and non-toxic levels because they can enter water naturally through the erosion of rocks, soil leaching, and the dissolution of airborne particles. However, the main anthropogenic sources—industrial and domestic waste, and the use of metal-based fertilizers and pesticides in agriculture—cause increased heavy metal levels and heavy metal pollution in water. Furthermore, activities such as mining, mineral processing, fossil fuel use, radioactive remnants, and volcanic activity also contribute to the release of heavy metals into the environment (Atay & Pulatsu, 2000; Koleli & Kantar, 2005). The use of fossil fuels for heating is also a significant source of heavy metal pollution (Egemen & Sunlu, 1999). According to data from the Ministry of Health, 20.8-25.6% of drinking water samples collected between 2000 and 2004 did not meet chemical quality standards (Anonymous, 2004).

Heavy metals become toxic when their concentration exceeds safe limits. For this reason, the maximum allowable levels of heavy metals in drinking water and food are legally restricted and must be regularly monitored, especially because these resources are consumed continuously (Kahvecioglu et al., 2003). A review of the literature shows that no previous study has investigated heavy metal pollution in drinking water sources in Ağrı province. According to the Ağrı Province Environmental Status Report, domestic wastes and agricultural fertilizers are the main causes of surface water pollution in the region. Sewage is discharged directly into the Murat River, and TÜİK data from 2014 indicate that 8,037 m³ of wastewater per year is released into receiving environments. The absence of wastewater treatment plants, uncontrolled waste discharge into water sources, and inadequate sewage systems lead to the release of untreated wastewater into lakes, streams, and rivers, posing serious risks to human health (Anonymous, 2018). Therefore, this study represents the first assessment of water quality and heavy metal pollution in drinking water samples collected from the central districts of Ağrı province and is important for developing solutions to public health risks related to drinking water quality.

2. Materials and Method

2.1. Working area

The study area is Ağrı Province, which is located in the eastern part of Türkiye, within the Upper Murat–Van section of the Eastern Anatolia Region. The province lies approximately between 38°59′–40°02′ north latitude and 42°15′–44°36′ east longitude and covers an area of 11,376 km² (Kocaman, 2012). In this study, the water sampling locations and sampling points are shown on the map in Figure 1. All sampling points were determined using the WGS 84 UTM coordinate system.

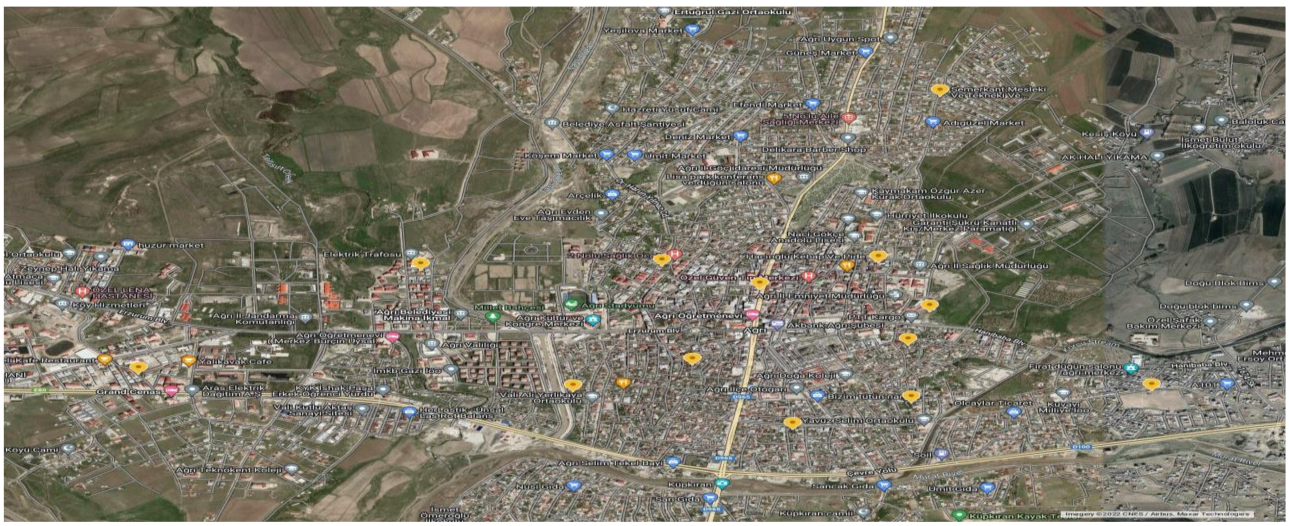

Figure 1. Sampling points (taken from Google Earth).

2.2. Collection and Preparation of Water Samples for Analysis

A sampling study was carried out to identify the neighborhoods supplied with tap water by the Ağrı Water and Sewerage Administration, which operates under the Ağrı Municipality. Sampling points were selected from water reservoirs, boreholes, and commonly used public fountains managed by the administration. Privately drilled boreholes located in residential gardens were excluded from the study. Only boreholes under municipal responsibility were included, as the aim was to evaluate only municipally supplied drinking water.

In May 2018, a total of 50 water samples were collected from the Abide, Alparslan, Cumhuriyet, Fevzi Çakmak, Fırat, Gazi, Hürriyet, Kazım Karabekir, Leylek Pınar, Mehmet Akif Ersoy, Murat, Sıtkıye, and Yavuz neighborhoods in the city center of Ağrı. The samples were collected in 15 mL Falcon tubes that had been washed with 1% diluted HNO_3 and dried. To preserve the samples, 1 mL of 65% HNO_3 was added to each tube. This process prevented microbial activity and changes in metal forms.

All samples were stored at 4 °C until analysis and analyzed within 15 days. Before analysis, 15 mL of each sample was filtered using 0.45 µm Millipore membrane filters. The filtered samples were transferred to beakers, and 5 mL of concentrated HNO_3 was added. The samples were heated until the volume was reduced to 2–3 mL, then evaporated to dryness. Finally, the residue was diluted with deionized water to a final volume of 10 mL for analysis.

Table 1. Number of samples and coordinates of sampling points

Sampling Points	n	Coordinates	
		Latitude	Longitude
N1	3	39,7214	43,0382
N2	3	39,7249	43,0544
N3	4	39,7193	43,0519
N4	3	39,7275	43,0433
N5	5	39,7158	43,0354
N6	5	39,7236	43,0602
N7	6	39,7205	43,0442
N8	3	39,7301	43,0574
N9	3	39,7124	43,0306
N10	6	39,7268	43,0651
N11	3	39,7169	43,0589
N12	3	39,7076	43,0401
N13	3	39,7223	43,0499

13 neighborhoods (N1-N13): Abide, Alparslan, Cumhuriyet, Fevzi Çakmak, Fırat, Gazi, Hürriyet, Kazım Karabekir, Leylek Pınar, Mehmet Akif Ersoy, Murat, Sıtkiye, and Yavuz.

2.3. Heavy metal analysis of water samples

The concentrations of Cd, copper (Cu), iron (Fe), Hg, Mn, nickel (Ni), Pb, Co (cobalt) and zinc (Zn) in the water samples were determined using a Thermo Scientific ICE-3000 Atomic Absorption Spectrophotometer at the Van Yüzüncü Yıl University Central Laboratory. A concentration method was applied during the analyses (Fifield & Haines, 1997). Blank solutions were prepared to identify any interference from chemical reagents during metal determination. Each metal analysis was performed in triplicate, and the reported values represent the mean concentrations obtained from the instrument.

2.4. Determination of water quality index (WQI), Pollution index (HPI, HEI and DC)

2.4.1. Water Quality Index (WQI)

The Water Quality Index (WQI) is a numerical method that combines different water quality parameters into a single value to describe the overall suitability of water for human consumption. It is widely used to assess groundwater quality and its appropriateness for use as drinking and domestic water (Varol & Davraz, 2015).

The calculation of the WQI:

Step 1. Each of the heavy metal parameters that may pose risks to human health was assigned a weight (AW_i) ranging from 1 to 5, based on expert opinions reported in previous studies. A value of 1 represents the lowest importance, while 5 represents the highest importance. The average weight values and related references are presented in Table

Step 2. The relative weight (RW) for each parameter was calculated using the following equation:

$RW = AW / \Sigma AW$ (1)

Step 3:The quality rating (Q_i) was calculated by dividing the measured concentration of each metal (C_i) by the corresponding drinking water standard limit (S_i) defined by the WHO (2011) and multiplying the result by 100:

$Q_i = (C_i / S_i) \times 100$ (2)

Step 4: The sub-index value (SI_i) for each metal was obtained by multiplying the relative weight (RW) by the quality rating (Q_i):

$SI_i = RW \times Q_i$ (3)

Finally, the WQI value was calculated by summing all sub-index values:

$WQI = \Sigma SI_i$ (4)

In this study, Co was not included in the WQI calculation because there is no standard limit value for Co according to WHO (2011) and TS 266 (2005). Hg was also not included in the calculation because it was below the detection limits in the analyzed water samples. The AW and RW values of the evaluated metals are presented in Table 1, and the S_i values were taken from WHO (2011) and TS 266 (2005) standards. Only the limit value for Pb was taken from USEPA

(2009). Weight values were determined based on the review of relevant literature (Abdul Hameed et al., 2010; Ustaoğlu, 2021; Yüksel et al., 2021).

Table 2. Weight values (AW), relative weight (RW) values and standard values (Si) in the drinking water category of the metal parameters evaluated in the study

Heavy metal Parameter	AW	RW	Si, H_{MAC}
Cd	5	0.172	5
Cu	2	0.069	2000
Fe	4	0.138	200
Mn	5	0.172	50
Ni	5	0.172	20
Pb	5	0.172	15
Zn	3	0.103	500
Total AW	29		

Table 3. Water Quality Rating as per Weight Arithmetic Water Quality Index Method (Sahu and Sikdar, 2008)

WQI Value	Rating of Water Quality	Usage Possibilities	Grading
< 50	Excellent water quality	Drinking, irrigation, industrial	A
50 – 100	Good water quality	Drinking, irrigation, industrial	B
100 – 200	Poor water quality	Irrigation, industrial	C
200 – 300	Very Poor water quality	Irrigation	D

In this study, the Heavy Metal Pollution Index (HPI) proposed by Prasad and Bose (2001), the Heavy Metal Evaluation Index (HEI) developed by Edet and Offiong (2002), and the Pollution Degree (CD) defined by Brraich and Jangu (2015) were used to assess the level of water pollution. These indices are commonly applied to evaluate the quality of drinking and irrigation water and to describe the overall impact of heavy metals on water quality.

2.4.2. Heavy metal pollution index (HPI)

The Heavy Metal Pollution Index (HPI) is used to evaluate the effect of heavy metals on overall water quality. For this reason, HPI is commonly applied to assess the contribution of metal parameters to total water quality (Herojeet et al., 2015; Ustaoğlu, 2021). The HPI was calculated using the following equations (1–3), as proposed by Prasad and Bose (2001):

$HPI = \Sigma(Qi \times Wi)/\Sigma Wi$ (1)

$Qi = Ci/Si \times 100$ (2)

$Wi = k/Si$ (3)

where: Qi is the sub-index of each heavy metal, Ci is the measured concentration of the metal (µg/L), Si is the standard permissible limit of heavy metals for drinking water (TS 266, 2005; WHO, 2011), Wi is the unit weight of the metal and is a constant value equal to 1.

2.4.3. Heavy metal evaluation index (HEI)

The Heavy Metal Evaluation Index (HEI) is used to assess water quality based on the level of heavy metal contamination (Edet & Offiong, 2002). The HEI was calculated using the following equation:

HEI=ΣHC/HMAC (4)

where: HC represents the measured concentration of each heavy metal, and HMAC is the maximum allowable concentration of the metal in drinking water, as defined by TS 266 (2005) and WHO (2011).

2.4.4. Pollution degree (DC)

The Degree of Pollution (DC) represents the combined effect of heavy metals that are considered harmful to drinking water. The DC was calculated using the following equations (Brraich & Jangu, 2015):

$$DC = \sum Cfi$$
$$Cfi = Cai/CNi - 1$$

where: Cfi is the contamination factor, Cai is the measured concentration of each heavy metal and CNi is the permissible upper limit for the metal in drinking water.

2.5. Water Quality and Pollution Mapping

Water quality and pollution maps were generated using the Ordinary Kriging (OK) method in ArcMap 10.8. Ordinary Kriging is the most commonly used kriging technique. It is applied when the mean value of the variable changes across the study area, but is assumed to be constant within a local moving window. Because the mean is allowed to vary spatially, the OK method is considered non-stationary. Estimates are calculated as weighted averages of nearby sample values. This method assumes that no overall trend exists in the data (Bostan, 2017).

2.6. Statistical Analysis

Descriptive statistics for the measured parameters were calculated and expressed as mean, median, standard deviation, minimum, and maximum values. All statistical analyses were performed using SPSS software (version 21).

3. Results

In this study, the WQI values of water samples collected from the central neighborhoods of Ağrı province are presented in Table 4 and classified according to the criteria shown in Table 3**.** Mercury (Hg) **was** not detected in any of the analyzed drinking water samples.

Table 4.WQI values of drinking water samples

SamplingPoints	WQI	Classification
N1	101.74	Poor Water Quality
N2	87.33	Good Water Quality
N3	97.68	Good Water Quality
N4	77.35	Good Water Quality
N5	79.68	Good Water Quality
N6	82.29	Good Water Quality
N7	86.50	Good Water Quality
N8	93.20	Good Water Quality
N9	82.78	Good Water Quality
N10	99.77	Good Water Quality
N11	77.73	Good Water Quality
N12	82.31	Good Water Quality
N13	78.77	Good Water Quality
Average	86.70	Good Water Quality

13 neighborhoods (N1-N13): Abide, Alparslan, Cumhuriyet, Fevzi Çakmak, Fırat, Gazi, Hürriyet, Kazım Karabekir, Leylek Pınar, Mehmet Akif Ersoy, Murat, Sıtkiye, and Yavuz.

According to Table 4, the WQI values range from 86.70 to 101.74. The highest WQI value was recorded at sampling point N1. Since the WQI value at N1 is greater than 100, this point falls into the poor water quality category. The lowest WQI value was observed at sampling point N4.

The average concentrations of nine heavy metals (Cd, Co, Cu, Fe, Mn, Ni, Pb, Zn, and Hg) were used to calculate the HPI values. In composite indices such as HPI and HEI, some studies include metals with not detected (ND) or zero concentrations as zero in the calculations (Quansah et al., 2022). Therefore, Hg was included in the HPI and HEI calculations in this study. The details of the HPI calculations are presented in Table 5.

Table 5. HPI calculations based on heavy metals for water samples taken from central neighborhoods of Ağrı province

Heavy metals (µg/L)	Average concentration (Ci)	Maximum allowed value (Si)*, Hmac	Unit weight (Wi= 1/Si)	Sub-index (Qi)	Wi×Qi
Cd	4.04	5	0.2	80.8	16.16
Co	6.11	10[a]	0.1	61.1	6.11
Cu	6.49	2000	0.0005	0.33	0.00017
Fe	60.06	200	0.005	30.03	0.15
Mn	8.96	50	0.02	17.92	0.36
Ni	13.59	20	0.05	67.95	3.40
Pb	44.97	15[b]	0.067	299.8	20.09
Zn	85.45	500[a]	0.002	17.09	0.0034
Hg	0.0	6	0	0.17	0.0
ΣWi = 0.62, ΣQiWi = 46.27 Average HPI = 74.23					

*All limit values except lead and zinc are taken from TS 266 ([a]İSESY 2012, [b]USEPA, 2009)

According to HPI**,** the metals were ranked as Pb > Cd > Co > Ni > Mn > Fe > Zn > Cu**.** Pb was the metal detected at the highest concentration in the drinking water samples. In addition to the average HPI value, HPI, HEI, and DC values were calculated separately for each sampling station to compare heavy metal pollution levels and assess overall water quality (Table 6**).**

Table 6. HPI, HEI and DC values of sampling points

SamplingPoints	HPI	HEI	DC
N1	77.76	6.22	-1.78
N2	70.79	5.36	-2.64
N3	74.03	6.03	-1.97
N4	64.14	5.01	-2.99
N5	70.08	5.40	-2.60
N6	73.11	5.81	-2.19
N7	75.50	5.96	-2.04
N8	69.34	5.99	-2.01
N9	73.92	5.90	-2.10
N10	71.50	6.46	-1.54
N11	71.22	5.53	-2.47
N12	93.25	6.81	-1.19
N13	80.35	5.77	-2.23
Average	74.23	5.87	-2.13

13 neighborhoods (N1-N13): Abide, Alparslan, Cumhuriyet, Fevzi Çakmak, Fırat, Gazi, Hürriyet, Kazım Karabekir, Leylek Pınar, Mehmet Akif Ersoy, Murat, Sıtkiye, and Yavuz.

According to Table 6**,** the HPI values range from 64.14 to 93.25, the HEI values range from 5.01 to 6.81, and the DC values range from −2.99 to −1.19**.** The highest HPI, HEI, and DC values were observed in the drinking water samples collected from region N12**.** In contrast, the lowest values for all three indices were found in the samples collected from region N4**.**

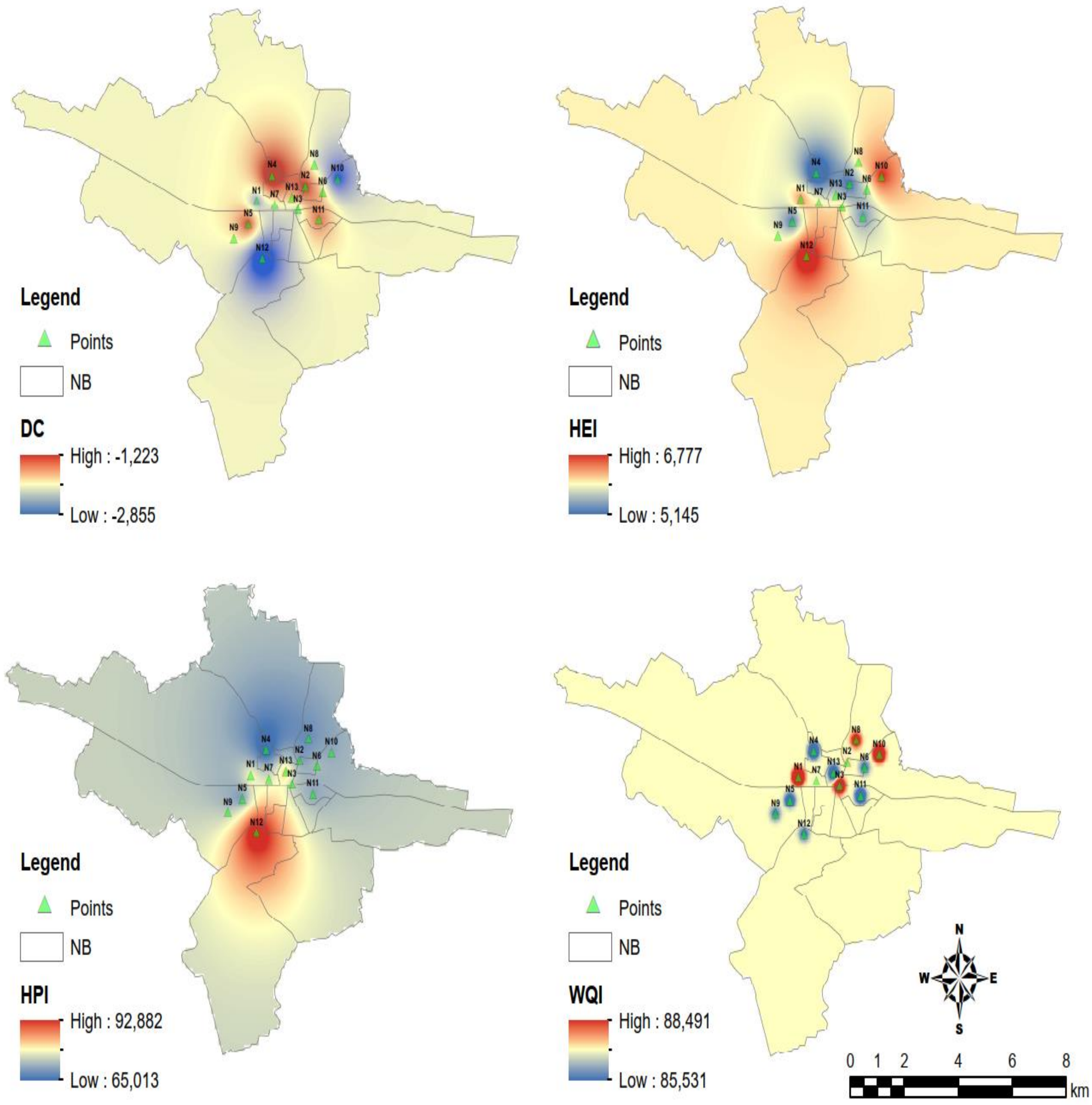

Figure 2. Water quality and regional drinking water pollution distribution maps of Ağrı province 13 neighborhoods (N1-N13)

According to Figure 2, water quality in terms of heavy metals is higher in the water samples taken from regions N1, N3, N8, and N10 compared to the others; the HPI index is higher in region N12; the HEI index is higher in regions N12 and N10; and the DC index is higher in region N12.

Table 7. Classification of sampling points according to HPI (Prasad & Bose, 2001), HEI (Edet & Offiong, 2002) and DC (Brraich & Jangu, 2015) values

HPI Value	Classification	Sampling Points	HEI Value	Pollution Level	Sampling Points	DC Value	Pollution Level	Sampling Points
< 100	Suitable for drinking	N1, N2, N3, N4, N5, N6, N7, N8, N9, N10, N11, N12, N13	< 10	Low	N1, N2, N3, N4, N5, N6, N7, N8, N9, N10, N11, N12, N13	< 1	Low	N1, N2, N3, N4, N5, N6, N7, N8, N9, N10, N11, N12, N13
> 100	Not suitable for drinking	-	10<HEI <20	Medium		1–3	Medium	-
			> 20	High		> 3	High	-

According to Table 7, the HPI values determined of all drinking water sampling points are below 100, the HEI values are below 10, and the DC values are below 1. Based on these results, all water samples are classified as suitable for drinking and show low levels of heavy metal pollution.

4. DISCUSSION AND CONCLUSION

Water is the most essential resource for life, and the human body requires water to maintain its vital functions. For this reason, heavy metals, which are classified as inorganic pollutants, should be regularly monitored in drinking water. In this study, the Water Quality Index (WQI) was used to assess overall water quality, while the Heavy Metal Pollution Index (HPI), Heavy Metal Evaluation Index (HEI), and Degree of Pollution (DC) were applied to evaluate heavy metal contamination in drinking water samples collected from the central neighborhoods of Ağrı province. The results showed that, except for the M1 sampling point, the WQI values ranged between 50 and 100, indicating good-quality water according to Table 2. The M1 sampling point, with a WQI value greater than 100, was classified as poor-quality water. Since the HPI values at all sampling points were below 100, the drinking water was considered suitable for consumption and not likely to cause adverse health effects. Furthermore, since HEI values were <10 and DC values were <1 at all sampling points, the drinking water is classified as having a low pollution level according to Table 7. Overall, the results indicate that the drinking water in the city center of Ağrı is generally suitable for drinking.

Assessing water quality using only point measurements does not fully represent spatial variability. Therefore, combining water quality data through indices and presenting them on maps is important for identifying environmental risks and supporting management decisions (Webster & Oliver, 2007). Based on the water quality and pollution maps produced in this study, water samples from regions N1, N3, N8, and N10 showed lower water quality in terms of heavy metals compared to other regions. In addition, the HPI, HEI, and DC values were notably higher, particularly in region N12**.** These findings indicate that low-level heavy metal contamination is present in the water samples from these regions.

Only a limited number of studies have applied WQI and HPI to evaluate drinking water quality. Dede (2016) used the HPI to assess heavy metal pollution in surface waters feeding the Çamlıdere Dam, one of the main drinking water sources of Ankara. The results showed that the index values of the three tributaries were in the middle class, indicating that the surface waters were not heavily contaminated with trace elements. Varol and Şekerci (2018) evaluated water resources in the Korkuteli district of Antalya using WQI and reported that all samples were classified as poor-quality water, suggesting potential long-term health risks. A study on drinking water quality in Çankırı, Türkiye showed that As, Hg, and Ni levels were higher than the limits set by Türkiye and the WHO, and that the WQI based on heavy metals indicated poor or very poor water quality due to high metal concentrations. Kurt et al. (2022) assessed drinking well waters from ten locations in rural areas of Bursa and classified all samples as excellent quality, with WQI values below 50. They also reported that HPI values below 100 posed no health risk and that very low HEI values (<10) indicated no significant heavy metal pollution. The findings of the present study are closely consistent with the results reported by Kurt et al. (2022).

Ağrı Province is not highly industrialized, and therefore the risk of heavy metal contamination originating from industrial activities is relatively low. However, the metals that most strongly increased the WQI, HPI, HEI, and DC values in this study were Pb and Cd. These metals have many non-industrial sources of contamination. Pb, commonly occurs together with metals such as silver, copper, zinc, antimony, and iron (Guler & Cobanoglu, 1997). It has been widely used in cooking and storage utensils, pesticides, ceramic and porcelain products, solder materials in drinking water distribution systems, weapons, cigarettes, cosmetics, fuel additives, cables, and battery production (Zietz et al., 2001; Kahvecioglu et al., 2003; Asri & Sonmez, 2007; Kahraman, 2007; Akhan, 2014; Poyraz, 2014). In drinking water, Pb contamination often does not originate from the water source, but from materials used in the distribution system. Pb pipes, Pb-based solders, and brass fittings, especially in older networks, play a major role in Pb release into drinking water (EPA, 2014). In addition, low pH, low alkalinity, and long water residence times increase Pb dissolution from pipe surfaces, resulting in elevated Pb levels at the tap even when Pb is absent at the treatment plant outlet (WHO, 2011). Cd is a toxic heavy metal that naturally occurs together with Zn (Kahvecioglu et al., 2003). It can be present in the environment as airborne particles or in dissolved form in water (WHO, 2004). Phosphate fertilizers may naturally contain Cd, and long-term fertilizer use leads to Cd accumulation in soils (Alloway, 2013). This accumulated Cd can be leached into groundwater through rainfall and irrigation (Kabata-Pendias, 2011), increasing the risk of contamination in drinking water wells near agricultural areas (FAO, 2010). In addition, batteries, electronic waste, and metal-containing solid waste are important Cd sources, and landfill leachate can transport Cd into groundwater (ATSDR, 2022; EPA, 2014). Cd can also occur naturally in phosphate rocks, shale, and volcanic rocks (Kabata-Pendias, 2011). Weathering and geochemical processes may allow Cd to enter groundwater from these formations (WHO, 2011). The geology of Ağrı Province is dominated by volcanic formations, including Neogene and Quaternary volcanoes such as Mount Ağrı, Tendürek, and Kösedağ (Anonymous, 2018). Therefore, natural geological conditions may contribute to Cd contamination in the region.

As a result, the fact that drinking water samples collected from the central neighborhoods of Ağrı are suitable for consumption is encouraging from a public health perspective. However, due to industrial pollutants, the uncontrolled use of organic and chemical fertilizers, and the application of wastewater and sewage sludge in agriculture, regular heavy metal analysis and pollution monitoring in drinking water are essential for the protection of public health.

ETHICAL STANDARDS:

Conflict of Interests: There are no potential conflicts of interest.

Ethics Committee Permission: This article does not require ethics committee approval.

Financial Support: No financial support was received for this article.

Acknowledgement: I thank to Nurhayat ATASOY for his valuable help for her comments and corrections.

** This study presented as an oral presentation on the Latin America 4th International Conference on Scientific Researches, November 3-6, 2022, Mexico City.*

REFERENCES

Abdul, H. M., Jawad, A., & Haider, S. A. (2010). Application of water quality index for assessment of Dokan lake ecosystem, Kurdistan region, Iraq. *Journal of Water Resource and Protection,* 2(9), 792-798.

Akhan, M. (2014). *Investigation of heavy metals in naturel mineral waters and spring waters*, PhD. Thesis, İstanbul University, Institute of Health Science, Department of Food Hygiene and Technology, İstanbul.

Alloway, B. J. (2013). *Heavy metals in soils: Trace metals and metalloids in soils and their bioavailability* (3rd ed.). Springer.

Anonymous (2018). Ağrı Province 2017 Environmental Status Report.R epublic of Türkiye, Ağrı Governorship, Provincial Directorate of Environment and Urbanization. http//agr-_2017_cevre_durum_raporu_son-20180910151359.pdf. Access date: 15.08.2025.

Asri, F.O., & Sonmez, S. (2006). The effect of heavy metal toxicity on plant metabolism, *Derim journal*, 23 (2): 36-45.

Atay, D., Pulatsu, S. (2000). *Water pollution and control.* Ankara University Faculty of Agriculture, Fisheries Publication No. 1513, Ankara.

ATSDR. (2022). *Toxicological profile for cadmium*. Agency for Toxic Substances and Disease Registry.

Begun, A., Ramaiah, M., Harikrishna, S., Khan, I., & Veena, K. (2009). Analysis of Heavy Metals Concentration in Soiland Litchens fromVarious Localities of Hosur Road, Bangalore, India, *E-Journal of Chemistry*, 6(1):13-22.

Bostan, P. (2017). Basic kriging methods in geostatistics. *Yuzuncu Yıl University Journal of Agricultural Sciences*, *27*(1), 10-20.

Brraich, O. S., & Jangu, S. (2015). Evaluation of water quality pollution indices for heavy metal contamination monitoring in the water of Harike Wetland (Ramsar Site), India. *International Journal of Scientific and Research Publications*, *5*(2), 1-6.

Caylak, E. (2022). Quality and health risk assessment in drinking water of Cankiri, Turkey. *Pollution and Effects on Community Health*, *1*, 1-13.

Dede, Ö. T. (2016). Application of the heavy metal pollution index for surface waters: A case study for Çamlıdere. *Hacettepe Journal of Biology and Chemistry*, *44*(4), 499-504.

Edet, A. E., & Offiong, O. E. (2002). Evaluation of water quality pollution indices for heavy metal contamination monitoring. A study case from Akpabuyo-Odukpani area, Lower Cross River Basin (southeastern Nigeria). *GeoJournal*, *57*(4), 295-304.

Egemen, Ö., & Sunlu, U. (1999). Water quality. *Ege University Fisheries Faculty Periodicals. Bornova*, *14*, 20-25.

EPA. (2014). *Human health risk assessment for cadmium*. U.S. Environmental Protection Agency.

FAO. (2010). *Cadmium in soils and crops*. Food and Agriculture Organization of the United Nations.

Fifield, F. W., & Haines, P. J. (1997). *Environmental Analytical Chemistry*, Blackie Academic and Professional, London.

Guler, C., & Cobanoglu, Z. (1997). *Chemicals and Environment*, Environmental Health Basic Source Series No: 50, Ankara.

Herojeet, R., Rishi, M. S., & Kishore, N. (2015). Integrated approach of heavy metal pollution indices and complexity quantification using chemometric models in the Sirsa Basin, Nalagarh valley, Himachal Pradesh, India. *Chinese Journal of Geochemistry*, *34*(4), 620-633.

Hutton, M., & Symon, C. (1986). The quantities of cadmium, lead, mercury and arsenic entering the UK environment from human activities. *Science of the total environment*, *57*, 129-150.

İSESY (2012). Regulation on the quality of surface water from which drinking water is obtained or planned to be obtained, R. G. Date: 26.06.2012, R. G. Number: 28338. Ministry of Forestry and Water Affairs. (Web page: https://www.resmigazete.gov.tr/eskiler/2012/06/20120629-9.htm) (Access date: 02.10.2025).

Kabata-Pendias, A. (2011). *Trace elements in soils and plants* (4th ed.). CRC Press.

Kahraman, U.C. (2007). *Comparison of water quality and heavy metal pollution of some selected ground water wells and pipeline network water in Konya Garrison*, Master's thesis, Selcuk University, Institute of Health Sciences, Konya.

Kahvecioglu, O., Kartal, G., Guven, A., & Timur, S. (2003). Environmental Effects of Metals-I, *Metalurji*, 136, 47-53.

Kar, D., Sur, P., Mandai, S. K., Saha, T., & Kole, R. K. (2008). Assessment of heavy metal pollution in surface water. *International Journal of Environmental Science & Technology*, *5*(1), 119-124.

Kocaman S., & Kaya F. (2012). *Administrative Geography Analysis of Ağrı Province*, Atatürk University Faculty of Letters, Department of Geography I. National Geography Seminar Proceedings, 329-345, Erzurum.

Koleli, N., & Kantar, C. (2005). Toxic heavy metals (Cd, Pb, Ni, As) concentration in phosphate rock, phosphoric acid and phosphorus fertilizers, *Ekoloji*, 14, 1-5.

Kurt, A., Kander, S., & Copur, O.U. (2022). Determination of the heavy metal levels of well waters used as drinking waters in the rural areas of bursa city, *Gıda*, 47(2)199-211.

Lee, C. S., Li, X. D., Zhang, G., Li, J., Ding, A. J., & Wang, T. (2007). Heavy metals and Pb isotopic composition of aerosols in urban and suburban areas of Hong Kong and Guangzhou, South China—evidence of the long-range transport of air contaminants. *Atmospheric Environment*, *41*(2), 432-447.

Lohani, M. B., Singh, A., Rupainwar, D. C., & Dhar, D. N. (2008). Seasonal variations of heavy metal contamination in river Gomti of Lucknow city region. *Environmental Monitoring and assessment*, *147*(1), 253-263.

Munsuz, N., & Unver, İ. (1995). *Water quality*, Ankara University, Faculty of Agriculture, Publication No. 1389, Ankara, 1995.

Quansah, A.K., Sam, A., Ohuapo-Agyemang, L., & Nkansah, P.A. (2022). Evaluation of Heavy Metal Pollution Index of Groundwater during Dry Season in Winneba-Ghana. *Elixir Pollution*, 171 (2022), 56502-56506.

Pehlivan, R. (2025). Quality of Bottled Water and Protection of the Consumer www.gidahareketi.org/su/sise_sularinin_kalite.pdf (Access date: 03.10.2025).

Poyraz, B. (2014). Heavy metal analysis of drinking water samples taken from different locations, *Duzce University Journal of Science and Technology*, 2(1): 16-27, 2014.

Prasad, B., & Bose, J. (2001). Evaluation of the heavy metal pollution index for surface and spring water near a limestone mining area of the lower Himalayas. *Environmental geology*, *41*(1), 183-188.

Sahu, P., & Sikdar, P. K. (2008). Hydrochemical framework of the aquifer in and around East Kolkata Wetlands, West Bengal, India. *Environmental geology*, *55*(4), 823-835.

Suthar, S., & Singh, S. (2008). Vermicomposting of domestic waste by using two epigeic earthworms (Perionyx excavatus and Perionyx sansibaricus). *International Journal of Environmental Science & Technology*, *5*(1), 99-106.

The Ministry of Health of Türkiye (2004). Türkiye Health Report, Research, Planning and Coordination Board Health Statistics, Ankara, 2004.

TS 266. (2005). Water intended for human consumption, Turkish Drinking Water Standards TS 266 standard -Turkish Standards Institute –Ankara.

USEPA (2009). National Primary Drinking Water Regulations, Washington: 7. EPA 816-F-09-004.

Ustaoglu, F. (2021). Ecotoxicological risk assessment and source identification of heavy metals in the surface sediments of Çömlekci stream, Giresun, Turkey. *Environmental Forensics*, *22*(1-2), 130-142.

Varol, S., & Davraz, A. (2015). Evaluation of the groundwater quality with WQI (Water Quality Index) and multivariate analysis: a case study of the Tefenni plain (Burdur/Turkey), *Environmental Earth Science*, 73:1725–1744.

Varol, S., & Sekerci, M. (2018). Evaluation of water resources of korkuteli district center (antalya) by water quality index (WQI) method, *Journal of Engineering Sciences and Design*, 6(1), 74-86.

Wasim Aktar, M., Paramasivam, M., Ganguly, M., Purkait, S., & Sengupta, D. (2010). Assessment and occurrence of various heavy metals in surface water of Ganga river around Kolkata: a study for toxicity and ecological impact. *Environmental monitoring and assessment*, *160*(1), 207-213.

Webster, R., & Oliver, M. A. (2007). *Geostatistics for environmental scientists*. John Wiley & Sons.

WHO (1992). Our Planet, Our health, Report of the WHO Comission on health and Environment World Health Organization, Geneva. http://www.who.int/en/.

WHO (2004). *Cadmium in drinking water*, Background Document for Development of *WHO Guidelines for Drinking-Water Quality*.

WHO (2011). *Guidelines for Drinking-water Quality*. WHO Press, World Health Organization, Geneva 27, Switzerland.

Yuksel, B., Ustaoglu, F., & Arica, E. (2021). Impacts of a garbage disposal facility on the water quality of çavuşlu stream in Giresun, Turkey: a health risk assessment study by a validated ICP-MS assay, *Aquatic Sciences and Engineering*, 36(4): 181-192.

Zıetz, B., De Vergara, J.D., Kevekordes, S., & Dunkelberg, H. (2001). Lead contamination in tap water of households with children in Lower Saxony, Germany, *The Science of the total environment*, 275 (1): 19-26.