Application of the Heavy Metal Pollution Index for Surface Waters: A Case Study for Çamlıdere

Ağır Metal Kirlilik Indeksinin Yüzey Sularına Uygulanması: Çamlıdere Örneği

Research Article

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ABSTRACT

The objective of this study is to assess the water quality of surface waters feeding Çamlıdere Dam, one of the biggest drinking water source of Ankara, capital city of Turkey, with respect to heavy metal contamination. Water samples at three different branches of Çamlıdere Dam were collected and 20 trace metals were analyzed. The concentrations of the elements in most of the samples were found within the limit values given in the standards. At some points, iron, aluminum, arsenic and barium exceed the limit values. The data obtained were used to calculate the heavy metal pollution index for three branches. It was found that the index values correspond to medium class for each branch and the branches are not fully polluted by trace metals. The heavy metal pollution index which includes many parameters was found useful to assess the overall pollution level with respect to heavy metals in Çamlıdere area.

Key Words
Water quality, pollution, heavy metal, index.

ÖZ

Bu çalışmanın amacı, Türkiyenin başkenti Ankara’nın en büyük içme suyu kaynaklarından biri olan Çamlıdere Barajını besleyen yüzey sularının kalitesinin ağır metal kirliliği açısından değerlendirilmesidir. Çamlıdere’yi besleyen üç farklı koldan numune alınmış ve 20 iz elementin analizi yapılmıştır. Numunelerdeki elementlerin derişimlerinin çoğunun standardlarda verilen sınır değerlerden düşük olduğu bulunmuştur. Bazı noktalarda, demir, alüminyum, arsenik ve baryum değerlerinin sınır değerleri aştığı görülmüştür. Üç kol için de elde edilen veriler ağır metal kirlilik indeksinin hesaplanmasında kullanılmıştır. Üç kol için de indeks değerinin orta sınıfa karşılık geldiği ve yüzey sularının eser elementlerle tamemen kirlenmediği bulunmuştur. Çamlıdere alanında ağır metale göre kirlilik seviyesinin değerlendirilmesinde, bir çok eser elementi içeren ağır metal kirlilik indeksinin kullanımının faydalı olduğu görülmüştür.

Anahtar Kelimeler
Su kalitesi, kirlilik, ağır metal, indeks.

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INTRODUCTION

Water quality is very important for human health and also for aquatic life. Available fresh water is very limited and restricted in the world. In recent years, water quality issues have become a significant concern due to the rapid urbanization and technological and industrial developments [1,2]. Water can be easily contaminated with different pollutants through different ways. Heavy metals are one of the major contaminants among these pollutants because of their non-degradable properties. The existence of the heavy metals in water may cause toxic and harmful effects in aquatic life and also people who consumes it. Metals can accumulate in the human body system and damage the nervous system and internal organs [2]. Thus, proper monitoring, assessment and reporting of the water quality is very important. In this study, the water quality status in Çamlıdere with respect to its heavy metal concentration was evaluated by using heavy metal pollution index (HPI). It is important to note that some of the elements studied in this paper are not classified as heavy metals, however, the general term "heavy metal" will be used throughout the paper for easy expression.

Heavy metal pollution index (HPI) is a method developed by assigning a rating or weightage (Wi) for each parameter that shows the composite influence of individual heavy metal on the overall quality of water. The rating is a value between 0 and 1 and it reflects the importance of individual quality considerations. W_i is inversely proportional to the permissible limit value given in the standard [2-8].

HPI can be calculated in three steps:
1.Determination of the unit weightage for each parameter;
2.The calculation of the sub-indices values (quality rating for each parameter);
3.The summation of sub-indices.

The weightage of each parameter can be calculated by using Equation (1):

$$W_i = k/S_i \qquad (1)$$

where, W_i is the unit weightage and S_i is the permissible value given in the standard for each parameter and k is the constant of proportionality. Sub-indices can be calculated by using the following expression (Equation 2):

$$Q_i = \sum_{i=1}^{n} \frac{\{M_i(-)I_i\}}{S_i - I_i} * 100 \qquad (2)$$

where, Q_i is the sub-index of ith parameter, M_i is the analyzed result of the ith parameter in μg/L and S_i the permissible limit value given in the standard for the ith parameter and I_i the ideal value of the ith parameter. The sign (-) means that algebraic sign will be ignored and only the numerical difference of the two values will be used in the calculation. In this study, the ideal values, I_i, was taken as zero for all element [2-8].
The overall heavy metal index is calculated as follows (Equation 3):

$$HPI = \sum_{i=1}^{n} Q_i W_i \Big/ \sum_{i=1}^{n} W_i \qquad (3)$$

Where, Q_i is the sub-index of ith parameter, W_i is the unit weightage for each parameter, n is the number of parameters [2-8]. This index model is intended for the drinking water [4]. For the categorization of the heavy metal pollution index, a modified scale (Table 1) proposed by Edet and Offiong [5] has been used in this study.

Table 1. Categorization of heavy metal pollution index [5,6].

HPI	Class
<15	Low
15-30	Medium
30>	High

In this paper, the study of overall pollution caused by heavy metals in surface waters near Çamlıdere has been performed. Water quality has been identified with respect to heavy metals by only looking at a single aggregate value and the corresponding scale.

MATERIALS and METHODS

Study Area, Sampling, and Analysis Methods

Çamlıdere is one of the most important area including major drinking water source of Ankara, the capital city of Turkey. Çamlıdere Dam is located in this area with an average water potential of 142 hm^3/year. Çamlıdere Dam and its branches (Acun, Çay, Eşik streams, etc.) are used as a drinking water, agricultural and irrigation purposes. Surface waters around here are open to pollution due to human activities, agricultural activities and livestock and geothermal plants. There are also mining plants for andesite and basalt which are among volcanic rocks and can cause pollution [9].

The sampling process was conducted from April 2009 to October 2012 for each year by sampling 3 stations (Table 2) with a sampling frequency of three months. Water samples were collected below the water surface into 1 L plastic bottles and preserved by adding 1 mL of 1:1 diluted nitric acid (from %65 HNO_3, Merck, Darmstadt, Germany). Bottles were sealed tightly and transported to the DSI, Department of Chemistry, Water Analysis Laboratory in accordance with "Standard Methods 1060 Collection and Preservation of Samples" [10]. Heavy metal analyses were carried out by using 7500a ICP-MS instrument (Agilent, CA, USA) in accordance to the EPA 200.8 method [11]. The analyzed parameters and minimum and maximum values obtained for each parameters are presented in Table 3. Results were evaluated by using the limit values given in TS 266 standard, Turkish Water Pollution Control Regulation and WHO for drinking water quality. The standard values are represented in Table 3 [12-15].

RESULTS and DISCUSSION

Çamlıdere encloses the important drinking water sources of Ankara, the capital city of Turkey. Water samples were collected from three sampling stations (Table 2) in this area for three years' period from April 2009 to October 2012.

Table 2. Names and the coordinates of sampling stations.

Station number	Name	Coordinates	
		North	East
N1	Cay Stream	40° 27′ 30.0″	32° 22′ 17.9″
N2	Acun Stream	40° 24′ 50.1″	32° 25′ 35.2″
N3	Esik Stream	40° 25′ 56.8″	32° 19′ 20.8″

Analysis of 20 trace elements (lead, zinc, chromium, manganese, ion, copper, cadmium, cobalt, nickel, aluminum, mercury, arsenic, molybdenum, antimony, selenium, boron, beryllium, silver, barium and thallium) has been conducted during the experimental period for all water samples and the minimum and maximum values of analysis results are listed in Table 3.

The concentrations of trace elements in water samples were low except iron, aluminum, arsenic and barium at some points.

Iron and aluminum are among the most abundant elements in Earth's crust. Iron is an essential element for all organisms. High concentrations of iron may cause color problem in water and can be slightly toxic. Iron contained water has inky flavor and bitter taste. It may cause also some health problems in humans. Prolonged consumption of drinking water containing iron at high concentration makes the teeth and nail black and weak, stickiness of hair and water and may also cause liver disease. In our study the concentration of Fe ranges from is 2 to 768 μg/L. Limit value for Fe prescribed by TS 266 is 200 μg/L [1,4,5,8,12]. While aluminum can be present in the drinking water naturally, aluminum salts using in coagulation process can increase the concentration of aluminum in the water. High amounts of aluminum can cause Alzheimer disease in human [14,15].

Arsenic is found widely in Earth's crust in the forms of sulfides, metal arsenide or arsenates. Volcanic rocks are one of the reasons that cause the increasing of arsenic in water. Exposure to drinking water containing high amount of arsenic can cause serious health problems in humans.

The effects of barium on human health is related with its solubility. High amounts of barium in water can affect the nervous system, brain and liver and cause serious health problems [14,15].

The obtained results in this study represent temporal and spatial variations. In general, iron and aluminum concentrations measured at the sampling stations exceed the limit levels especially during spring times for all stations.

Table 3. The minimum and maximum values of water quality parameters, corresponding limit values given in the standards and analysis methods.

Water Quality Parameters	N1		N2		N3		Limit values given in standards*
	min	max	min	max	min	max	
Lead, Pb (μg/l)	<0.40	0.70	<0.40	0.52	<0.40	<0.40	10
Zinc, Zn (μg/l)	<4.00	36.48	<4.00	42.62	<4.00	29.00	500[a]
Chromium, Cr (μg/l)	<0.60	26.44	<0.60	21.28	<0.60	13.40	50
Manganese, Mn (μg/l)	<0.15	21.70	<0.15	17.56	<0.15	10.32	50
Iron, Fe (μg/l)	<2.00	730.00	<2.00	767.80	<2.00	715.40	200
Copper, Cu (μg/l)	<2.50	6.32	<2.50	6.04	<2.50	5.47	2000
Cadmium, Cd (μg/l)	<0.06	0.06	<0.06	<0.06	<0.06	<0.06	5
Cobalt, Co (μg/l)	<0.06	0.19	<0.06	0.19	<0.06	0.25	10[a]
Nickel, Ni (μg/l)	<0.20	2.19	<0.20	2.43	<0.20	3.04	20
Aluminum, Al (μg/l)	<1.00	1302.00	<1.00	1042.00	<1.00	823.90	200
Mercury, Hg (μg/l)	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	1
Arsenic, As (μg/l)	4.45	3.45	1.77	61.11	2.32	23.93	10
Molybdenum, Mo (μg/l)	<0.20	4.30	0.23	6.40	<0.20	3.19	70[b]
Antimony, Sb (μg/l)	<1.10	<1.10	<1.10	<1.10	<1.10	<1.10	5
Selenium, Se (μg/l)	<0.30	0.39	<0.30	0.58	<0.30	0.41	10
Boron, B (μg/l)	11.60	824.10	8.15	94.22	5.41	39.57	1000
Beryllium, Be (μg/l)	<0.04	0.10	<0.04	0.09	<0.04	0.07	4[c]
Silver, Ag (μg/l)	<0.65	0.77	<0.65	0.74	<0.65	0.68	100[c]
Barium, Ba (μg/l)	32.44	363.40	27.32	134.20	20.66	51.46	100[a]
Thallium, Tl (μg/l)	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	2[c]

*All limits values were given based on TS 266 except [a](Turkish-Regulation 2012); [b](WHO 2011); [c](EPA 2009).
(The elements given in this table are classified as heavy metals except As, Sb, B are metalloid, Se is non-metal, Al, Be and Ba are metal.)

Table 4. The calculated HPI values with unit weightage (Wi) and standard permissible level (Si).

Parameters	Mean concentration values (g/L)			Unit weightage (Wi)	Standard permissible value (Si)* (g/L)	HPI		
	N1	N2	N3			N1	N2	N3
Lead, Pb	0.42	0.41	0.40	0.0372	10	16	23	16
Zinc, Zn	8.79	8.78	6.51	0.0007	500[a]			
Chromium, Cr	8.04	7.45	4.49	0.0074	50			
Manganese, Mn	5.64	5.12	2.66	0.0074	50			
Iron, Fe	153.69	137.02	104.02	0.0019	200			
Copper, Cu	3.51	2.97	3.01	0.0002	2000			
Cadmium, Cd	0.06	0.06	0.06	0.0744	5			
Cobalt, Co	0.13	0.12	0.09	0.0372	10[a]			
Nickel, Ni	0.77	0.82	0.89	0.0186	20			
Aluminum, Al	298.25	209.24	150.16	0.0019	200			
Mercury, Hg	0.19	0.20	0.20	0.3721	1			
Arsenic, As	13.64	30.75	12.73	0.0372	10			
Molybdenum, Mo	2.08	2.67	1.48	0.0053	70[b]			
Antimony, Sb	1.10	1.10	1.10	0.0744	5			
Selenium, Se	0.31	0.34	0.32	0.0372	10			
Boron, B	270.95	50.19	18.97	0.0004	1000			
Beryllium, Be	0.04	0.05	0.04	0.0930	4[c]			
Silver, Ag	0.66	0.66	0.65	0.0037	100[c]			
Barium, Ba	118.39	78.64	37.56	0.0037	100[a]			
Thallium, Tl	0.10	0.10	0.10	0.1860	2[c]			

*All limits values were given based on TS 266 except [a](Turkish-Regulation 2012); [b](WHO 2011); [c](EPA 2009).

While arsenic concentration is generally high in all stations, barium concentrations exceed limit values at some time periods at stations N1 and N2. In order to calculate HPI, the mean concentrations of all 20 elements were used. Calculated HPI values with unit weightage (W_i) and standard permissible level (S_i) were given in Table 4. The heavy metal pollution index values were found as medium class.

The assessment and interpretation of each water quality parameters in accordance with permissible limit values given in the standards is really time consuming and also difficult. The pollution and quality index models provide easy interpretation of the data. The heavy metal pollution index (HPI) method used in this study has been found to be very useful and easy for the evaluation of the overall pollution levels with respect to heavy metals.

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