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Evaluation of water quality in the Kızılırmak River (Central Anatolian) using physicochemical parameters and process proposal for ımprovement in water quality – a case study

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ABSTRACT

This study investigates the pollution status of the Kızılırmak River in winter. The Kızılırmak River Basin covers a big area in Turkey. Water samples for the study were taken from two stations along the Kızılırmak River located in Kırıkkale city. Physico-chemical parameters and major ions of the river water such as pH, dissolved oxygen(DO), temperature(T), electrical conductivity(EC), 5-days biochemical oxygen demand (BOD_5), suspended solids (SS), chemical oxygen demand (COD), phosphate (PO_4), color (Pt-Co), hardness (^{0}dH, CaO), some elements (calcium (Ca^{+2}), magnesium (Mg^{+2}), chloride (Cl^-)), and some compounds (sulphate (SO_4^{-2}), ammonium (NH_4–N), nitrite (NO_2^-), nitrate (NO_3^-)) and trace metals, such as Pb, Al, Zn, Cd, Ni, and Cr (IV) were also measured to determine the overall water quality of the river. Comparative tables were used to evaluate low, medium, and high values of the parameters. Three evaluation methods were used as evaluation criteria: Turkish Water Pollution Control Regulations (WPRC), Surface Water Quality Regulatıon (SWQR), and Environmental Protection Agency (EPA). When the pollution parameters of the Kızılırmak River are examined, water quality can be classified as I, II, III, and IV Class (Grade) due to variations in pollution parameters. The order of concentrations of metals in Kızılırmak River from high to low was Cr(IV) < Ni < Cd < Pb < Al < Zn for Dam point and Pb < Cd < Cr (IV) < Ni < Al < Zn Hacıbalı point, respectively. The study suggests the use of absorbents to remove the pollutants such as (heavy metals) in the river sample for the improvement of water quality.

Keywords: Kızılırmak; River; Water quality class; Heavy metal; EPA

1. Introduction

Water is the most important element of all ecosystems [1]. All living creatures in the aquatic and terrestrial ecosystems, for instance, need water to sustain their lives. In addition, water resources provide living space and food source for many species and help ecological plant development [2,3]. Besides drinking and using, water resources are very important in various economic sectors, such as agriculture, livestock production, forestry, hydropower production, industrial production, and tourism [4].

Over 70% of the Earth's surface is covered by water but most of it is unsuitable for human consumption. Around 97.5% of the world's water is in the oceans and the remaining 2.5% is fresh water present in the atmosphere, ice mountains, freshwater lakes, rivers, and ground water [5]. For this reason, water resources are divided into two categories as salty (sea water) and fresh water (e.g., aquifers, lakes, and rivers) [6]. Among these, rivers are the most important freshwater resource for human beings. Unfortunately, the physicochemical properties and microbiological quality of river waters are deteriorating due to untreated sewage, industrial wastes, and some other human activities [7].

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In surface water quality, assessment of seasonal changes is an important aspect for evaluating temporal variations of river pollution because of natural or anthropogenic inputs [8]. These natural factors (precipitation variability, erosion, weathering of crustal materials) and anthropogenic factors (urban, industrial, and agricultural activities, increased water consumption) deteriorate water quality and damage their use for drinking, industrial, agricultural, recreation, or other purposes [9,10]. Agricultural, industrial, and urban activities are considered as major sources of chemicals, nutrients, and heavy metal to aquatic ecosystems. In addition, some elements (e.g., nitrogen) in the atmosphere, can be a source of pollution in surface water [11].

The contamination of aquatic and terrestrial ecosystems with heavy metals is another environmental problem. Some of these metals are potentially toxic or carcinogenic at sufficient concentrations and thus can be dangerous for human beings as they can cause serious health problems when these metals enter the food chain [12]. Today, the inorganic-chemical (e.g., heavy metals) contamination of river waters has become an urgent problem in the world [13,14], because heavy metal pollution of rivers is a major threat to ecological health and a factor in geochemical cycling of metals [15]. Pollution of the aquatic environment, especially rivers and lakes, with metals is a major factor posing a serious threat to the survival of aquatic organisms [16,17].

This study has examined a list of water parameters related to surface water quality management, such as pH, dissolved oxygen (DO), temperature (T), electrical conductivity (EC), 5-days biochemical oxygen demand (BOD5), suspended solids (SS), chemical oxygen demand (COD), phosphate (PO_4), color (Pt-Co), hardness (^{0}dH), some elements (calcium (Ca^{+2}), magnesium (Mg^{+2}), chloride (Cl^-)), and some compounds (sulphate (SO_4^{-2}), calciumoxide (CaO), ammonium (NH_4–N), nitrite (NO_2^-), nitrate (NO_3^-)) and some heavy metal contents (Pb, Al, Zn, Cd, Ni, and Cr (IV)). The samples were taken during the winter season because it was thought that the heavy metal content would be the least during the winter season. In this season, farmers do not use fertilizers and pesticides, and in addition, agricultural traffic pollution is very low. This allowed the researcher to study the river when the outer factors are the least effective. This study aims to: (1) identify the sources of seventeen physical and inorganic-chemical parameters and six heavy metals contaminations in the Kızılırmak River; (2) propose the formation and use of real-time monitoring of primary trace metal elements in times to come; (3) make comparisons according to the freshwater assessment regulations.

2. Materials and methods

The Kızılırmak River Basin covers an area of about 78,180 km^2, which means about 11% of the country's territory [18], and has the longest river called the Kızılırmak (Red River, in English). It is also a very important water resource for drinking, irrigation, energy, and other purposes in the basin [19,20]. For example, Ankara is the capital city and the Kızılırmak River has been used as Ankara's drinking water source for approximately 1.5 years [21]. Kızılırmak, which is the longest river (1,355 km) within the borders of Turkey, flows within the Central Anatolian Plateau (CAP) and slowly incises into lacustrine and volcaniclastic units before finally reaching the Black Sea [22].

The river begins from the southern slopes of Kızıl Mountain (3,025 m) in Sivas, and it is discharged at 41.72°N and 35.95°E to the Black Sea. There are three different basins over the Kızılırmak River, which are called lower, upper, and middle. The lower basin is under the effect of Black Seaclimate, where the terrestrial climate affects middle and upper basins. Over the middle basin, the value of precipitation amount drops and the average rainfall is observed around 315 mm. Between July and February, the river's flow rate happens to be at its lowest level. Around March, the flow rate starts increasing, and reaches to its maximum level in April [23]. According to the 35 years of observation, the average flow rate of the river is 184 m^3/s. On the other hand, the river's lowest flow rate was marked as 18.4 m^3/s, whereas the maximum flow rate was marked as 1,673 m^3/s [24]. The net total water potential of the Kızılırmak river basin is roughly 6.544 billion m^3/year. Most parts of the basin are covered with agricultural regions and forests or with semi-natural areas. Agricultural regions, forests, and semi-natural areas, wetlands and surfaces covered with water and artificial areas of the basin cover about 54.68%, 42.74%, 0.34%, 0.94%, and 1.3%, respectively [19,20]. Locations of the Kızılırmak river are shown in Fig. 1.

The Kızılırmak river receives substantial loads of nutrients, heavy metals, and other compounds, resulting from anthropogenic activities within its river basin [26]. The study area is located in Kırıkkale city (Fig. 2).

The water samples were collected at three spots from two different stations (first and second points in Fig. 2) as a single season. Two stations, Dam (entrance to Kırıkkale) and Hacıbalı (exit from Kırıkkale) were sampled along the Kızılırmak River located in Kırıkkale city. The GPS coordinates of this study in Kızılırmak were saved as 39°44′20.6″N 33°29′05.3″E and 39°55′01.8″N 33°25′24.7″E. Water samples were taken with 1 L precleaned polyethylene bottles 0.5 m below the water surface for all parameters. Several in situ physical parameters were recorded by using Hach Lange HQ40d Multimeter probes simultaneously. Sampling, protection, and carrying of the water samples to the analysis laboratory were as per standard methods [27]. Water samples were stored at 4°C before other analysis. Data for physico-chemical parameters of water samples were used as mean values and analyzed using descriptive analysis.

Mean value, min-max, and standard deviation of pollutants are given in the tables. The standard deviation was calculated by the formula [28]. All physico-chemical parameters of surface water were analyzed in both Selcuk University, Environmental Technologies laboratory, and in a special measurement laboratory. Water samples were determined by Spectroscopy, after being filtered by 0.45 μm filter paper.

The analytical data accuracy was ensured through careful standardization, procedural sample measurements, sensitive, and double samples. pH, temperature (T), dissolved oxygen (DO) and conductivity (EC) were measured with multi-parameter analyzer (Hach HQ 40d) at the sampling location. Analyses of physico-chemical parameters such as SO_4^{-2}, PO_4^{3-}, NH_4–N, NO_2^-, NO_3^-, COD, BOD were carried out in accordance with standard methods [27]. All metals were determined by direct measurement of the sample solution

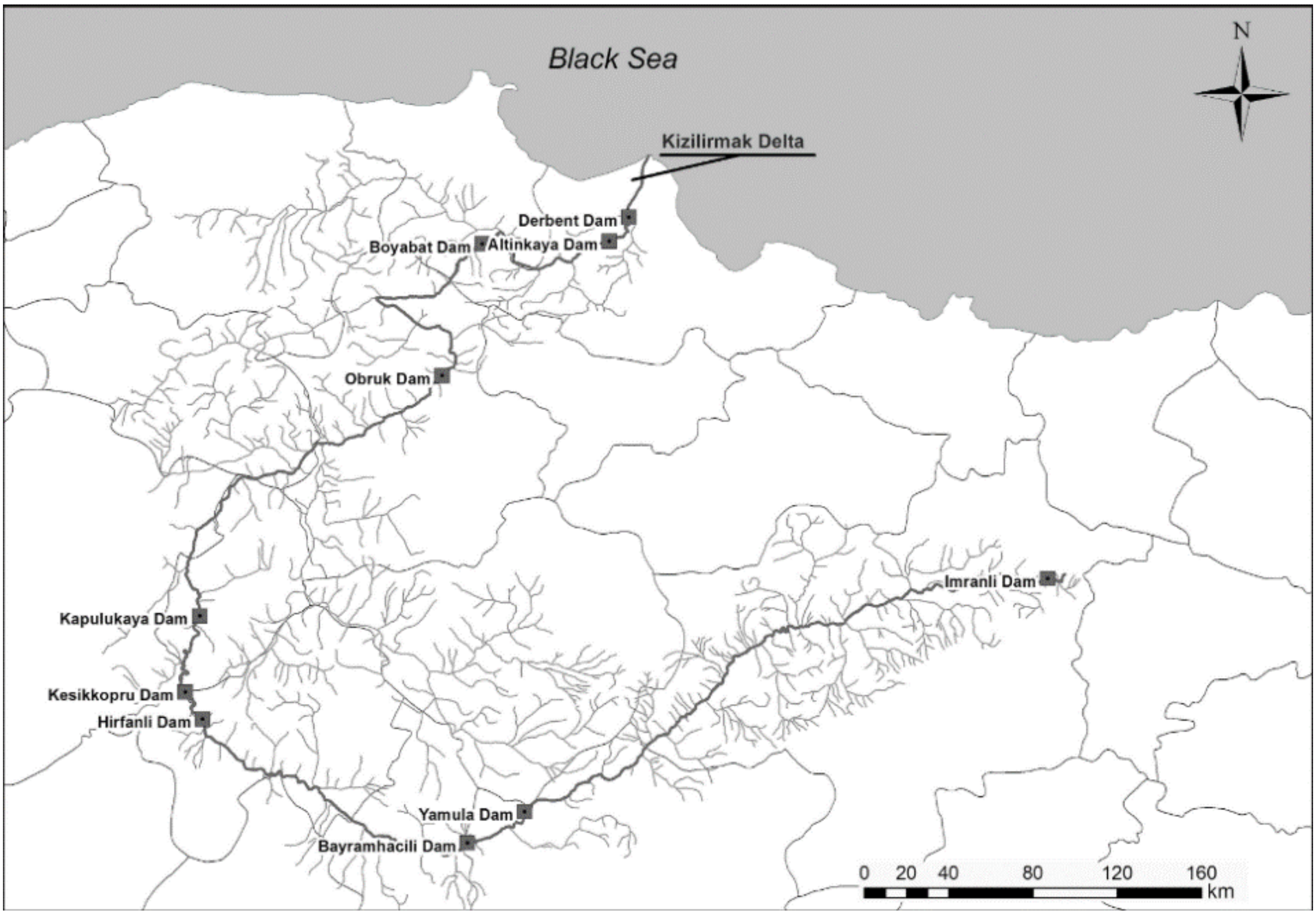

Fig. 1. Positions of the dams situated on the stem of the Kızılırmak River in Turkey [25].

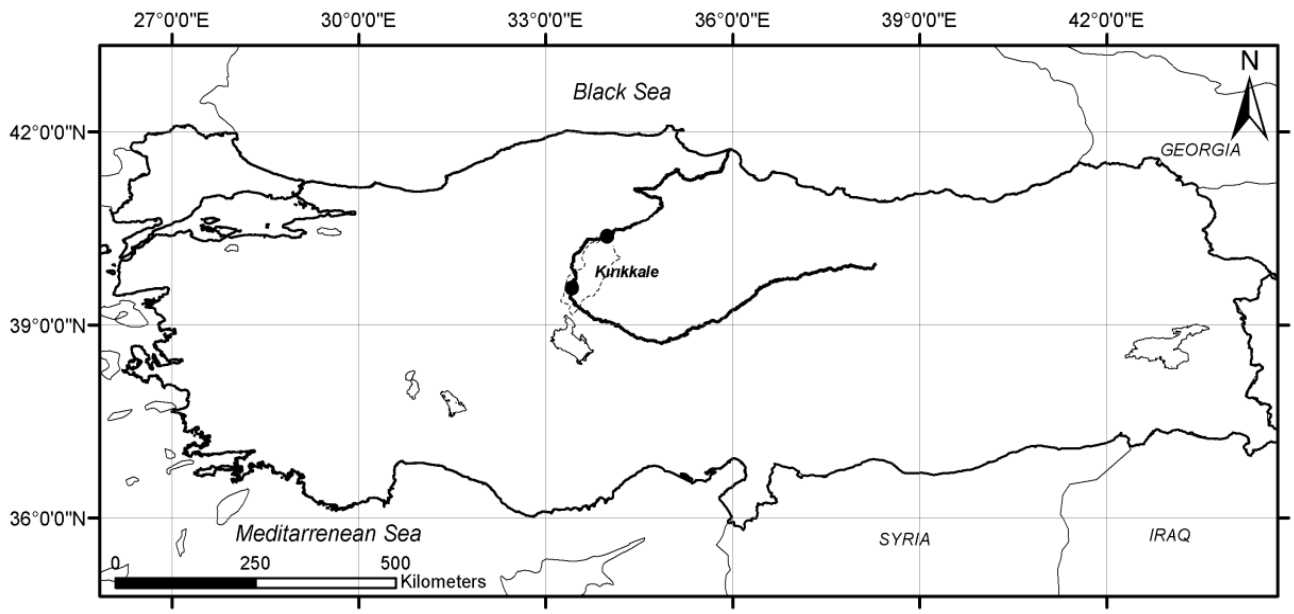

Fig. 2. The latitude and longitude of Turkey (locations of the Kızılırmak River, Kırıkkale city, and first and second sample point).

into ICP-MS/OES [29]. All the different water quality parameters, their units, and the results of the analysis are shown in Tables 1 and 2. After all the pollution parameters have been analyzed according to standard methods, three evaluation methods were determined as evaluation criteria: (1) Turkish Water Pollution Control Regulations (WPRC), (2) Surface Water Qualıty Regulatıon (SWQR), and (3) Environmental Protection Agency (EPA).

3. Results and discussion

The evaluation of the physical, organic, and inorganic-chemical and heavy metal results are based on WPCR [30], SWQR [31], and EPA [32], and they are shown in Tables 3–7. Between Tables 3 and 7 contains the most up-to-date criteria for aquatic life ambient water quality criteria for EPA. Aquatic life criteria for toxic chemicals are the highest concentration of specific pollutants or parameters in the water that are not expected to pose a significant risk to the majority of species in a given environment or a narrative description of the desired conditions of a water body being "free from" certain negative conditions [32]. The table below lists EPA's recommended aquatic life criteria.

The water quality class gives us information on the purpose for which the water can be used. Class I "Very Good" category indicates that water quality is good, and its potential of being used as drinking water, swimming water, and trout production is high. Class II "Good" category indicates that the quality of the water is almost as good as the Class I water (recreational, except for trout production, etc.). While Class III corresponds to "Polluted Water", Class IV corresponds to "Very Polluted Water" [31]. The water sample analyses taken from the Kızılırmak River are given in Tables 3 and 4. Although WPRC has an average limit value of 25°C, there is no limit value in SWQR and EPA for temperature. Since WPRC did not provide a limit value for conductivity, SWQR's

Table 1
Concentrations of the physical and inorganic-chemical parameters in the water according to the stations by the mean value, min–max, and standard deviation

Source		Parameters												
		pH	DO (mg/L)	T (°C)	EC (µS/cm)	BOD_5 (mg/L)	SS (mg/L)	COD (mg/L)	PO_4^{3-} (mg/L)	Cl^- (mg/L)	SO_4^{-2} (mg/L)	NH_4–N (mg/L)	NO_2^- (mg/L)	NO_3^- (mg/L)
Dam	Min	7.92	8.67	8.8	1,716	5.1	10.8	12.1	0.008	271.9	113.28	0.029	0.006	0.394
	Mean	8.11	8.69	9.3	1,719	5.7	11.26	12.8	0.012	273	113.85	0.031	0.007	0.395
	Max	8.27	8.71	9.7	1,721	6.2	11.8	13.2	0.018	274.3	114.67	0.034	0.008	0.401
	SD	0.144	0.016	0.37	2.16	0.454	0.41	0.49	0.004	0.98	0.594	0.002	0.0008	0.004
HacıBallı	Min	7.8	8.77	8.9	1,761	14.3	15.7	29.4	0.123	276.3	117.4	0.493	0.089	0.936
	Mean	7.81	8.8	9.46	1,763	14.8	16.7	30.4	0.126	277	117.8	0.502	0.095	0.945
	Max	7.92	8.82	9.8	1,765	15.5	17.5	31.8	0.13	278.3	118.01	0.507	0.096	0.95
	SD	0.086	0.216	0.402	1.63	0.509	0.74	1.01	0.003	0.846	0.282	0.006	0.004	0.006

Note: pH, dissolved oxygen (DO), temperature (T), electrical conductivity (EC), 5-days biochemical oxygen demand (BOD_5), suspended solids (SS), chemical oxygen demand (COD), phosphate (PO_4^{3-}), chloride (Cl^-), and some compounds (sulphate (SO_4^{-2}), ammonium (NH_4–N), nitrite (NO_2^-), and nitrate (NO_3^-)).

Table 2
Concentrations of the inorganic contamination, color, and hardness parameters in the water according to the stations by the mean value, min–max, and standard deviation

Source		Parameters								
		Pb (µg/L)	Al (µg/L)	Zn (µg/L)	Cd (µg/L)	Ni (µg/L)	Cr (IV) (µg/L)	Color (Pt-Co) (mg/L)	Hardness (^{0}dH)	Ca/Mg
Dam	Min	114	128	299	121	118	75	5.921	32.5	3.52
	Mean	119	135	312	123.3	121	83	5.932	34.2	3.63
	Max	123	143	323	125	125	92	5.942	37.1	3.71
	SD	3.69	6.16	9.8	1.7	2.94	7.43	0.008	2.06	0.08
HacıBallı	Min	111	375	475	124	195	184	7.002	42.9	11.45
	Mean	116	383	511	127	210	194.6	7.029	44.6	11.77
	Max	124	391	563	130	228	209	7.064	46.4	11.9
	SD	5.44	6.55	37.6	2.48	13.5	10.53	0.0259	1.43	0.187

Note: some trace metal contents (Pb, Al, Zn, Cd, Ni, and Cr (IV)) and hardness (^{0}dH), color (Pt-Co), rate of some elements (e.g., calcium(Ca^{+2}), magnesium(Mg^{+2})).

Table 3
Physical and inorganic-chemical parameters in the water according to the stations and mean value

Parameters	Mean value		EPA, freshwater	WPRC: Turkish Water Pollution Control Regulations (μg/L)			
	Dam	Hacıbalı		Class of water resources			
			CAS number and CMC, μg/L	I	II	III	IV
Temperature	8–10	8–10	–	25	25	30	>30
Conductivity	1,719	1,763	–	–	–	–	–
Dissolved oxygen, DO	8.69	8.8	7782447	8	6	3	<3
pH	8.11	7.81	–	6.5–8.5	6.5–8.5	6.0–9.0	6.0–9.0 except
NH_4–N	0.031	0.502	7664417	0.2	1	2	>2
NO_2^-	0.007	0.095	–	0.002	0.01	0.05	>0.05
NO_3^-	0.395	0.945	–	5	10	20	>20
PO_4^{3-}	0.012	0.126	–	0.02	0.16	0.65	>0.65
SO_4^{-2}	113.85	117.8	–	200	200	400	>400
Cl^-	273	277	16887006–860000	25	200	400	>400
Color (Pt-Co)	5.932	7.029	–	5	50	300	>300
Hardness, ^{0}dH	34.2	44.6	–	–	–	–	–
Ca/Mg	3.63	11.77	–	–	–	–	–

CMC: criterion maximum concentration (acute).
For all physicochemical parameters (except pH, conductivity, and temperature), the measuring unit is mg/L; for conductivity μS/cm; for temperature °C.

Table 4
Conductivity parameters in the water according to the stations and mean value

Water quality parameters	Mean value		SWQR: Water quality class (Grade)			
	Dam	Hacıbalı	I (very good)	II (good)	III (middle)	IV (low)
Conductivity (μS/cm)	1,719	1,763	<400	1,000	3,000	>3,000

Table 5
Organic parameters in the water according to the stations and mean value

Parameters	Mean value		EPA, freshwater	WPRC: Turkish Water Pollution Control Regulations (mg/L)				SWQR: Surface Water Qualıty Regulatıon (mg/L)			
	Dam	H.balı	CAS Number and CMC, μg/L	I	II	III	IV	I	II	III	IV
BOD_5	5.7	14.8	–	4	8	20	>20	<4	8	20	>20
COD	12.8	30.4	–	25	50	70	>70	<25	50	70	>70

CMC: criterion maximum concentration (acute).
For all physicochemical parameters, the measuring unit is mg/L.

result was taken into consideration and considering the information mentioned in Table 4, the water quality obtained from Dam and Hacıbalı point was found to be Class III "Middle" grade water. Distributions of physico-chemical and heavy metal parameters by stations are displayed in Tables 1 and 2. The study results for the two stations show that the waters are nonacidic (7.8 ≤ pH ≤ 8.27), hard (hardness 32.5–46.4 as °dH), fresh (conductivity < 1,765 μs/cm) and dissolved oxygen (>8.67). In addition, the mean values of the major cations (e.g., Ca^{2+}, Mg^{2+}) and anions (e.g., SO_4^{2-}, Cl^-) are within the WPRC and EPA standards. Chloride concentrations varied between 271.9 and 278.3 mg/L (Tab. 1). Some of the scientific investigations showed that chloride concentrations possessed a good positive relationship with most anions and cations [33]. However, the correlation between anions and cations was not investigated in this study. Phosphorus and nitrogen are important to all living organisms. However, excessive phosphorus causes algae blooms, which are harmful to aquatic life. They may cause a decrease in the DO levels of the water, gas formation, and temperature rise [18,26]. The anion chemistry showed that more than 90% of the samples analysed belong to $Cl^- > SO_4^{-2} > NO_3^- > PO_4^{-3} > NO_2^-$. The results of nitrite

Table 6
Inorganic contamination parameters in the water according to the stations and mean value

Parameters	Mean value		EPA, Freshwater		WPRC: Turkish Water Pollution Control Regulations (μg/L)			
	Dam	Hacıbalı	CAS Number	CMC, μg/L	I	II	III	IV
Ni	121	210	7440020	470	20	50	200	>200
Pb	119	116	7439921	65	10	20	50	>50
Zn	312	511	7440666	120	200	500	2,000	>2,000
Cr (IV)	83	194.6	18540299	16	not measurable	20	50	>50
Cd	123.3	127	7440439	1.8	3	5	10	>10
Al	135	383	7429905	750	300	300	1,000	>1,000

CMC: criterion maximum concentration (acute).
For all physicochemical parameters, the measuring unit is μg/L.

Table 7
Comparison of aluminum limits in freshwaters for water quality criteria[a] [32]

Version	Freshwater acute (1-day, total aluminum)	Freshwater chronic (4-day, total aluminum)
2017 Draft AWQC Criteria (MLR normalized to pH = 7, hardness = 100 mg/L, DOC = 1 mg/L)	1,400 μg/L	390 μg/L
1988 AWQC Criteria (pH 6.5–9.0, across all hardness and DOC ranges)	750 μg/L	87 μg/L

[a]Values are recommended not to be exceeded more than once every three years on average.
Note: Values will be different under differing water chemistry conditions as identified in this document.

showed low levels during the investigation of the river. This might be attributed to the fast conversion of NO_2^- to NO_3^- ions by nitrifying bacteria [33]. Discharge of domestic wastewater and untreated sewage of agricultural activities in the region, industrial activity, and a sizable decrease of water flow rate, are principal reasons of anions pollution increase [34].

The cation and heavy metal concentrations of the water samples can be arranged from the highest to lowest values as Zn > Al > Cd > Ni > Pb > Cr(IV) > NH_4 for the first point and Zn > NH_4 > Al > Ni > Cr(IV) > Cd > Pb for the second point. Ammonium accounted for the major proportion of total soluble inorganic nitrogen. It showed a slight increase from the dam to the hacıbalı point, but without seasonal trends. Cation and heavy metal ion concentrations of river basins depend not only on industrial and household waste inputs but also on the geochemical composition of the area [35]. Moreover, it is seen that the water pollution from heavy metal increases gradually from south to north in which the river flows. It may be noted that in the downstream area, the increased concentration of cations is an indication of anthropogenic activities. Effluents from industries, fertilizers, and pesticides from agricultural run-off and the domestic sewage directed into the river increase the concentration of pollutants in the river water. In addition, there are three different organized industrial zones in Kırıkkale city. One of them is the machinery and chemical industry [36]. It is thought that if the wastewater is discharged without treatment, it may contribute to the heavy metal pollution in the river.

The hardness parameter can be used to determine whether water is suitable for use in different areas, such as drinking water, surface water, boiler water, and process control. The measuring range of calcium and magnesium levels are given in Table 2 that were determined with the cuvette test LCK 327 residual hardness. Measurement unit of water hardness is German hardness (°dH). One degree of German hardness (°dH) means 10 mg CaO/L in water hardness procedure of Hach-Lange.

In terms of dam surroundings: When the pH, DO, NH_4–N, NO_3^-, PO_4^{3-}, SO_4^{-2}, and COD values are taken into consideration, the river is in Class I grade water category. With regard to the obtained values of NO_2^-, color (pt-co) and BOD_5, the river is in Class II grade water category. In terms of chloride (Cl^-) value, the river is a freshwater source in the category of Class III grade water. According to concentration ranking of inorganic contamination, the order of samples (in terms of metal concentration) taken from the point of Dam in Kızılırmak River from high to low is Zn > Al > Cd > Ni > Pb > Cr(IV). In terms of Al value, the river is in the category of Class I grade water. In terms of Zn value, it is in the category of Class II grade water. With regard to Ni value, it is in the category of Class III grade water. With regard to Pb, Cr(IV), and Cd values, it is in the category of Class IV grade water.

In terms of Hacıbalı surroundings: When the pH, DO, and SO_4^{-2} values are examined, the river is in Class I grade water category. When NH_4–N, NO_2^-, NO_3^-, PO_4^{3-}, Color (pt-co), and COD values are taken into consideration, the river is in Class II grade water category. The Kızılırmak River is in Class III grade water category according to the concentration levels of chloride (Cl^-) and BOD_5. The order of the inorganic contamination (in terms of heavy metal) concentration of the samples taken from the district of the Hacıbalı is as follows: Pb < Cd < Cr (IV) < Ni < Al < Zn. In terms of Al and Zn values, the river is in the category of Class III grade water. With regard to Ni, Pb, Cr(IV) and Cd values, it is in the category of Class IV grade water.

EPA limits were surpassed in terms of Ni, Pb, Zn, Cr, and Cd concentrations. The highest concentration value surpassing the EPA limit belongs to cadmium metal. The river is in a good condition in terms of aluminum concentration when the data from Table 7 is evaluated. In terms of heavy metal concentration levels, aluminum and nickel have the highest amounts.

Low, medium, and high values of the parameters were evaluated with comparative tables. Three evaluation methods were used as evaluation criteria: (1) Turkish Water Pollution Control Regulations (WPRC), (2) Surface Water Qualıty Regulatıon (SWQR), and (3) Environmental Protection Agency (EPA). When the pollution parameters of the Kızılırmak River are examined, water quality class can be of Class I, II, III, or IV grade due to variations in pollution parameters. The order of concentrations of trace metals in Kızılırmak River from high to low was: Si > Fe > Al > Mn > As > Ni > Se > Cd [21], Al > B > Cu > Mn > As > Ni > Zn > Cr > Se > Hg = Pb = Cd = Sb [18], Pb > Ni > Cr [26]. In this study, the order of concentrations of metals in the Kızılırmak River from high to low was Cr(IV) < Pb < Ni < Cd < Al < Zn for Dam point and Pb < Cd < Cr (IV) < Ni < Al < Zn for Hacıbalı point, respectively.

3.1. Process proposal for improvement in water quality

Adsorption is most commonly applied for the removal or low concentrations of nondegradable organic compounds from groundwater, drinking water preparation, process water or as tertiary cleansing after, for example, biological water purification [37]. I suggest the adsorption process for the removal of some contaminants in the river sample for the change of quality class. This is because adsorption processes are widely used in water treatment. It is widely used to remove organic substances from different types of water such as drinking water treatment, urban wastewater treatment, industrial wastewater treatment, swimming-pool water treatment, groundwater remediation, treatment of landfill leachate, aquarium water treatment, and so on [38]. If the water of the river of the Kızılırmak River is treated by adsorption, we can partially reduce the amount of some heavy metals (e.g., copper and cadmium) [39]. There are criteria to be considered when treating surface water. If the adsorption process is to be carried out with an agitated incubator, some optimization criteria must be taken into consideration such as mixing speed, contact time, pH, adsorbent dosage, and temperature. There are many studies that have used adsorption for pollutant removal on water and wastewater treatment, such as removal of chromium with waste material [40], color removal with pomace [41], removal of total organic carbon from drinking water using polypropylene and titanium dioxide nanocomposite [42], removal of arsenic from Songhua river [43], and adsorption of Ni^{2+}, Hg^{2+}, Pb^{2+}, Cr^{3+}, and Co^{2+} on iron oxide nanoparticles [44]. As adsorption process reduces the many pollutant (e.g., heavy metal ions) concentrations to very low levels from waters and because of using various low-cost adsorbent materials including biosorbents, clays, activated carbons, zeolites, and metal oxides, it has major advantages [45]. Depending upon the nature of forces existing between adsorbate molecules and the adsorbent, the adsorption can be classified into two types as physi-sorption and chemi-sorption [46]. The pollution parameters in the water of the Kızılırmak River can be removed by adsorption technique. Both physical and chemical adsorption can take place during this treatment.

4. Conclusions

When the results are analyzed and interpreted, it is not possible to say that the Kızılırmak River belongs to Class I category in terms of all parameters. However, it is evident that there might be an improvement in the water quality when an advanced treatment process such as adsorption is carried out. As can be seen from the analysis results of the water samples, it has been determined that the quality of the water decreases while proceeding to the Hacıbalı point from the dam point of the Kızılırmak River. When we consider the fact that some industrial, mining, and domestic/sewage activities [26], agricultural wastes [18], and geochemical composition of the area [35] are mixed in the Kızılırmak River, we can say that they are the most important pollutants causing pollution in the river. The highest values of pollution observed in the Kızılırmak are concentrations of chloride (Cl^-), SO_4^{-2}, NO_2^-, and PO_4^{3-}. Among the concentrations of heavy metals detected in the river sample, the highest levels of pollution belong to nickel, lead, chromium, and cadmium. Firstly, wastewater discharge points should be determined and then it is necessary to prevent untreated wastewater discharges into the river. The river water needs to be monitored with samples more often for a longer period. Class I suggests the adsorption process for the removal of some contaminants in the river sample so as to lead to a change in the quality class. Both physical and chemical adsorption can take place during this treatment. In addition, the recommendations and findings of this study have major ecotoxicological, agronomic, and aquatic life importance to policy makers and can serve as useful references for future reclamation and remediation efforts in the areas of water use.

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