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RESEARCH ARTICLE

Development of a water quality index for Lake Aygır in Bitlis, Turkey

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ABSTRACT

Water quality indices help to develop correct policies using water quality data. In this study, a useful and reliable method was determined for water quality management of Lake Aygır. For this, monthly water quality measurements were made from Lake Aygır between May 2015 and May 2016. Expert opinions and literature were used in the selection of parameters. Temperature, dissolved oxygen, electrical conductivity, pH, ammonia, alkalinity, hardness, fluorine, and arsenic parameters were selected for the calculation of the water quality index of Lake Aygır for drinking (AG-$WQI_{drinking}$), as it is more effective on human health. Temperature, dissolved oxygen, electrical conductivity, pH, ammonia, alkalinity, hardness, and turbidity were selected for the calculation of the water quality index of Lake Aygır for fisheries (AG-$WQI_{fisheries}$) as they are the parameters to which fish is most affected. Water quality indices of Lake Aygır were found AG-$WQI_{drinking}$ as 149.41 and AG-$WQI_{fisheries}$ as 76.11. The most effective parameters were hardness and alkalinity in the AG-$WQI_{drinking}$ calculations; and ammonia and dissolved oxygen in the AG-$WQI_{fisheries}$ calculations. Hence, it expresses numerically the suitability of Lake Aygır in terms of drinking and fishing.

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Introduction

Water is a material that covers three-quarters of the earth, and it is an indispensable source of life for living things (Bulum, 2015). Lakes and reservoirs are major resources as they contain approximately 90% of the world's surface freshwater (Karmakar & Musthafa, 2013). The water quality of the lakes is the center of human and economic development. For this reason, the assessment and prediction of water quality levels are crucial for social and economic development (Li et al., 2016). Water quality is affected by natural and human effects (Gray, 1994). In general, the most important natural impacts in a basin

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are geological, hydrological, and climatic factors (Scheffer & van Nes, 2007), while anthropogenic effects stem from agricultural irrigation, industrial pollution, and municipal use, among other factors (Cosgrove & Rijsberman, 2000).

Conventional water quality assessment can be a complex application as many parameters are individually evaluated. At the same time, determining water quality is an expensive and time-consuming process (Poonam et al., 2013). Moreover, many efforts have been made to manage water quality (Karmakar & Musthafa, 2013). Additionally, water quality indices (WQI) are approaches that greatly reduce data volume and simplify the expression of water quality status (Poonam et al., 2013). Therefore, involvement with the use and development of WQI methods, in general, is increasing all over the world (Ou et al., 2014). However, each water source has its own characteristics, so water quality parameters vary according to the source. Thus, the relative weight values of the parameters for each source should be determined in WQI calculations. Otherwise, consistent results may not be obtained (Alver, 2019).

Typically, Lake Aygır is an important part of locals' total potable and irrigation water supply. Therefore, the main objective of this study was to create a water quality index (WQI) for water quality evaluation and classification in Lake Aygır.

Material and Methods

Study Area

Lake Aygır (Bitlis) is in the Lake Van Basin, Bitlis, Turkey. The lake, which has an area of approximately 1.4 km^2 and a maximum depth of 43.4 m, is located at an altitude of 1938 m. The lake has been used markedly for the purposes of drinking, fisheries, recreation, and irrigation. In addition, the lake water is stored by means of a regulator and used as a reservoir (Güllü & Güzel, 2006; Elp et al., 2014; Doğu & Deniz, 2015; Çavuş, 2018) (Figure 1).

Water Quality Analysis

Water samples were taken monthly between May 2015 and May 2016. The samples were taken from the surface (-20 cm), -15 m depth, and lake bottom with a Nansen bottle.

To determine the quality of water samples, chlorine (Cl) and salinity by Mohr-Knudsen method, calcium (Ca), magnesium (Mg), total hardness by EDTA method, carbonate (CO_3), bicarbonate (HCO_3), total alkalinity by hydrogen chloride (HCl) titration method were analyzed by titrimetric analysis solutions (Greenberg et al., 1992), total suspended solids (TSS), aluminum (Al), chromium (Cr), cyanide (CN), ammonium (NH_4), ammonia (NH_3), nitrite (NO_2), nitrate (NO_3), sulphate (SO_4), orthophosphate (o-PO_4), potassium (K), zinc (Zn), copper (Cu), fluorine (F), manganese (Mn), silver (Ag), boron (B), nickel (Ni), cobalt (Co), bromine (Br), iodine (I), molybdenum (Mo), iron (Fe), silicon (Si), chemical oxygen demand (COD) parameters with a HACH DR 5000 Spectrophotometer (HACH, 2010), arsenic (As) and cadmium (Cd) with ICP-OES spectrometer; boron (B) with ICP-MS spectrometer; sodium (Na) with AAS spectrometer (Thompson & Wood, 1982; Hill et al., 1995; Morales-Rubio & De la Guardia, 1999; Kmiecik et al., 2016). In addition, fecal coliform was determined using a membrane filter set (TS EN ISO 9308-1) (TSE, 2014; Tekbaş & Oğur, 2005).

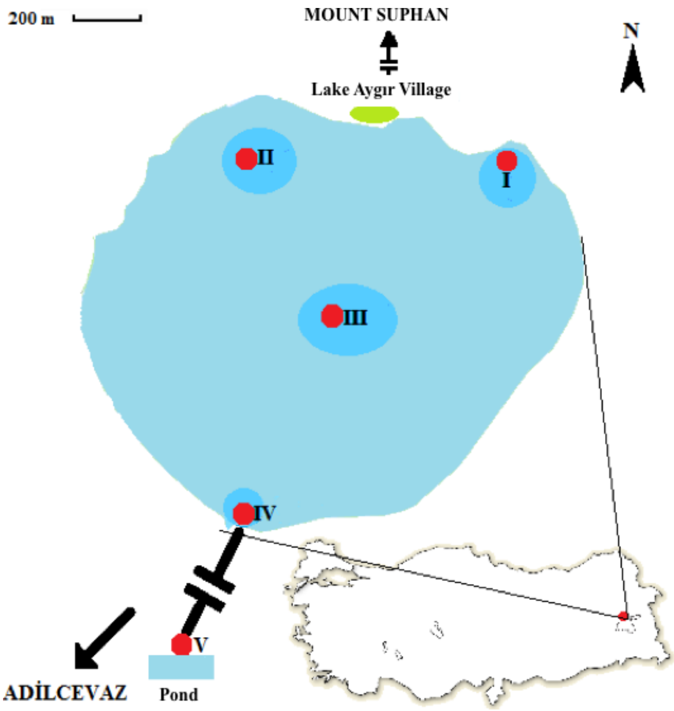

Figure 1. Location of Lake Aygır and sampling points; I. station (38° 50′ 18.00″ N, 42° 49′ 29.7″ E), II. station (38° 50′ 28.56″ N, 42° 49′ 14.82″ E), III. station (38° 50′ 6.66″ N, 42° 50′ 22.92″ E), IV. station (38° 49′ 54.36″ N, 42° 49′ 10.98″ E), V. station (38° 49′ 18.12″ N, 42° 50′ 11.7″ E).

Calculation of WQI

The water quality index has been developed using Horton (1965), Brown et al. (1970), Brown et al. (1972), and Ravikumar et al. (2013). The formulae are as follows:

$$AG - WQI = \sum SI_i \quad (1)$$

$$SI_i = W_i q_i \quad (1.1)$$

$$q_i = \frac{C_i}{S_i} \times 100 \quad (1.2)$$

$$W_i = \frac{w_i}{\sum w_i} \quad (1.3)$$

SI_i: water quality sub-index; W_i: relative weight; q_i: quality rating scale; C_i: concentration in the water sample; S_i: standard value set by legislation, literature, or experts. They are EEC and WHO (Tebbutt, 1998), WPC (2004), TSE (2005 and 2014), WHC (2005), APRAR (2006), Emre & Kürüm (2007), and PWTC (2014) for drinking and fisheries. w_i: weighting. Each of the physical and chemical parameters was selected by means of experts and literature. They should be weighted by the weight of their importance for their intended use from 2 to 5.

Finally, the calculated water quality index values are classified into categories as excellent (<50), good (<100-50≤), poor (<200-100≤), very poor (<300-200≤), unsuitable for using purpose (≥300) (Ravikumar et al., 2013).

$$Ew_i = \frac{SI_i}{WQI} \times 100 \quad (2)$$

In addition, the effective weights (Ew_i) of each water quality parameter were calculated to determine the water quality parameter that had the greatest impact on the WQI results. where Ew_i is the effective weight of the ith parameter (Equation 2). W_i is compared with Ew_i, reflecting the importance of each parameter with respect to other parameters used in WQI calculations (Şener et al., 2017).

Results

In this study, analyses were carried out monthly between May 2015 and May 2016 from the Aygır Lake and the irrigation pool. Water quality parameters used in AG-WQIs were found as DO: 0.41-13.14 g.L^{-1}, EC: 222.30-507.40 µS.cm^{-1}.

Average water quality parameters were found as oxygen saturation: 76.6%, SPC: 435.0 µS.cm^{-1}, salinity: 0.21‰, TDS: 0.2881 g.L^{-1}, transparency: 5.8 m, Cl: 17.3 mg.L^{-1}, Ca: 54.3 mg.L^{-1}, Mg: 40.6 mg.L^{-1}, CO_3: 9.8 mg.L^{-1}, HCO_3: 256.9 mg.L^{-1}, NO_2: 17.8 µg.L^{-1}, NO_3: 1.2 mg.L^{-1}, NH_4: 0.06 mg.L^{-1}, SO_4: 11.7 mg.L^{-1}, o-PO_4: 21.7 µg.L^{-1}, K: 1.72 mg.L^{-1}, Al: 1.13 µg.L^{-1}, Zn: 0.22 µg.L^{-1}, Cu: 3.7 µg.L^{-1}, Mn: 3.2 µg.L^{-1}, Ag: 0.15 µg.L^{-1}, Cd: 1.1 µg.L^{-1}, Pb: 0.21 mg.L^{-1}, B: 0.01 mg.L^{-1}, Br: 0.12 mg.L^{-1}, I: 0.16 mg.L^{-1}, Na: 27.0 mg.L^{-1}, Mo: 1.69 mg.L^{-1}, CN: 1.19 µg.L^{-1}, Si: 5.74 mg.L^{-1}, SiO_2: 24.27 mg.L^{-1}, TSS: 3.8 mg.L^{-1}, and fecal coliform: 0.5 colony.100 mL^{-1}. Cr, Co, Ni, COD and BOD were not found in water samples. Total Fe (0.018 mg.L^{-1}). was found only in IV. station.

All values in water samples were interpreted and evaluated by experts. Temperature, DO, EC, pH, NH_3, alkalinity, hardness, F, and As parameters were selected for AG-$WQI_{drinking}$ as drinking water. As a result, Lake Aygır, used as drinking water, has been found to be of medium quality with 149.41 (Table 1).

Table 1. Water quality index developed for drinking water

Parameter	Unit	Weight (w_i)	Relative weight (W_i)	Desirable limit* (S_i)	Min-Max	Mean±SE (C_i)	q_i	SI_i	Ew_i (%)
Temperature	°C	2	0.06	25	3.7-21.5	9.9±0.5	39.59	2.40	1.6
DO	mg.L^{-1}	3	0.09	8.0	0.41-13.14	8.15±0.4	101.88	9.26	6.2
EC	µS.cm^{-1}	3	0.09	2000	222.3-507.4	353.05±4.1	17.65	1.60	1.1
pH		4	0.12	9.20	7.03-8.73	8.14±0.06	88.44	10.72	7.2
NH_3	mg.L^{-1}	4	0.12	0.50	0-0.19	0.05±0.01	10.0	1.21	0.8
Alkalinity	mg.L^{-1}	3	0.09	50	120-310	235.08±2.9	470.2	42.7	28.6
Hardness	mg.L^{-1}	4	0.12	50	173.3-443.3	302.66±4.79	605.3	73.4	49.2
Fluorine	µg.L^{-1}	5	0.15	1500	0.31-1.82	0.56±0.05	37.33	5.66	3.8
Arsenic	µg.L^{-1}	5	0.15	10	0-43.76	1.59±0.35	15.93	2.41	1.6
Total		33	1.00						
AG-$WQI_{drinking}$								**149.38**	

Note: *The desirable limits were determined according to EEC and WHO (Tebbutt, 1998), WPC (2004), TSE (2005), and WHC (2005).

Table 2. Water quality index developed for fisheries

Parameter	Unit	Weight (w_i)	Relative weight (W_i)	Desirable limit* (S_i)	Min-Max	Mean±SE (C_i)	q_i	SI_i	E_{Wi} (%)
Temperature	°C	5	0.20	21.5	3.7-21.5	9.9±0.5	46.03	9.21	12.1
DO	$mg.L^{-1}$	4	0.16	9.0	0.41-13.14	8.15±0.4	90.56	14.49	19.0
EC	$\mu S.cm^{-1}$	2	0.08	2000	222.3-507.4	353.05±4.1	17.65	1.41	1.9
pH		2	0.08	9.0	7.03-8.73	8.14±0.06	90.41	7.23	9.5
NH_3	$mg.L^{-1}$	4	0.16	0.025	0-0.19	0.05±0.01	198.13	31.70	41.7
Alkalinity	$mg.L^{-1}$	2	0.08	400	120-310	235.08±2.9	58.77	4.70	6.2
Hardness	$mg.L^{-1}$	2	0.08	400	173.3-443.3	302.66±4.79	75.66	6.05	7.9
Turbidity	NTU	4	0.16	10	0.2-7.2	0.82±0.1	8.23	1.32	1.7
Total		25	1.00						
AG-WQI$_{fisheries}$								**76.11**	

Note: * The desirable limits were determined according to APRAR (2006), Emre & Kürüm (2007), and PWTC (2014).

Temperature, DO, electrical conductivity, pH, NH_3, alkalinity, hardness, and turbidity parameters were selected for AG-WQI$_{fisheries}$ for fisheries. As a result, Lake Aygır has been found to be of good quality, with 76.11 in terms of fisheries (Table 2).

The order of anions was HCO_3>Cl>SO_4>CO_3>NO_3>F>I>Br>PO_4>NO_2>CN and cations were Ca>Mg>Na>K>NH_4>Cu>As>Al>Cd>Zn>Ag>Fe≥Cr≥Ni in water samples. The results showed that the highest effective weight value belonged to the hardness (49.2%) and alkalinity (28.6%) parameters compared to the others for drinking. Generally, there is a strong relationship between the major ion contents of water samples and the water-rock interaction (Şener et al., 2017). There was a directly proportional correlation between the effective and the relative weights in terms of temperature, DO, and pH. F and As parameters with high relative weight showed low effective weight (Table 1). This observation was primarily due to the very low concentrations of these measured parameters in water samples. According to calculations, the highest effective weight values belonged to NH_3 and DO parameters with 41.7% and 19.0%, respectively, in the AG-WQI$_{fisheries}$ calculations. There was a directly proportional correlation between the effective and the relative weights in terms of EC. Turbidity with secondary relative weight showed low effective weight (Table 2). This observation was primarily due to the low concentrations of turbidity in water samples.

Discussion

Lake Aygır, used as drinking water, has been found to be of medium quality (Table 1). Our AG-WQI$_{drinking}$ study results are similar to those found by Karakaya & Evrendilek (2010). Lake Aygır has been found to be of good quality, with 76.11 in terms of fisheries (Table 2). Our AG-WQI$_{fisheries}$ study results are similar to those found by Imneisi & Aydin (2016) and Çavuş & Şen (2020).

Water quality indices have some limitations. For example, it may not contain enough information about the actual quality status of the water. Therefore, the parameters were chosen for the AG-WQI. In addition, many uses of water quality data cannot be covered by an index. For this, separate indices such as AG-WQI$_{drinking}$ and AG-WQI$_{fisheries}$ have been developed for each use. However, WQI has more advantages than disadvantages. An index is not a complex forecast model for technical and scientific applications. Thus, it is a useful tool for communicating water quality information to the public and legal decision-makers (McClelland, 1974; Kumar & Dua, 2009).

While Lake Aygır is not polluted and has a suitable quality in terms of drinking, use, fishing and irrigation, it has been determined that it could be adversely affected by the settlements and agricultural activities around it (Çavuş & Şen, 2023).

Scientists doing research on water resources as a priority in Turkey can create a water quality index with the national water quality criteria. The data obtained at the end of the study were compared with the regulations and standards regarding drinking and fisheries (Tebbutt, 1998; WPC, 2004; TSE, 2005; TSE, 2014; WHC, 2005; APRAR, 2006; Emre & Kürüm, 2007; PWTC, 2014). Selected national legislations are "Regulation on Water for Human Consumption", "Water-Water for Human Consumption", and "Regulation on Surface Water Quality Management" for drinking water. The national legislation for fisheries is "Regulation on the Protection and Improvement of Waters Where Trout and Carp Fish Live" and "Water Quality

Criteria for Trout Breeding". In the absence of national water quality criteria, they can use international quality criteria (Tebbutt, 1998). For WQI, meetings can be held with people specializing in water quality, and the data can be presented and discussed. While creating the water quality index, selecting the priority parameters for the basin is an important step in the development of the index. Another important step is the selection of parameters for the intended use. It is very important to have a single method and a single quality scale in choosing WQI. Thus, comparisons between results can be made easily. This WQI should help develop local water management strategies.

The developed index is not in agreement with the other many indices that can be applied for the water quality assessment because the selected parameters in indices are different from each other.

Conclusion

The locals are engaged in agriculture and animal husbandry as well as aquaculture and fishing. It has become one of the most beautiful recreation areas of the region with a trout facility and trout restaurant in the Lake Aygır village and location of the lake. No industrial establishment was found in the region. The water of the lake is transferred to the pool for irrigation in the spring and summer months. Besides, it has been solving the water needs of Aydınlar Town since about 2008. Therefore, the water level of Aygır Lake is gradually decreasing. In order to prevent such changes that will affect the water quality, other water sources can be found in the town. Farmers can be encouraged to use technological irrigation systems that consume less water.

Considering all these observations and AG-WQI, we can say that Lake Aygır is not polluted and is suitable for drinking and fishing. For this suitable water resource, necessary protection measures should be taken regarding the use of lake water. Hence, the AG-WQI can be used in the evaluation of all freshwater resources in the Lake Van Basin.

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Compliance With Ethical Standards

Authors' Contributions

FŞ contributed substantially to the conception and design of the study, interpretation of the results. He provided critical revision of the article, and final approval of the version to publish. AÇ contributed substantially to the acquisition of data. She drafted of the article. AÇ and FŞ agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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