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GIS-based assessment for trace metal pollution: case study on lake Uluabat

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Abstract

This study was carried out to investigate distribution of Cr and Ni concentrations in water and sediment of Lake Uluabat, in Bursa (Turkey). The samples were collected from 10 sites and monitored monthly from August 2013 to July 2014. Data were mapped in ArcGIS 10.1 software and metals in water were assessed according to Turkish Water Pollution Control Regulations (TWPCR), while in sediment were assessed according to American National Oceanic and Atmospheric Administration's (NOAA) criteria. As a result, Lake Uluabat was determined 4th class water, in terms of dissolved forms of Cr, while the lake was determined 3th class water quality in terms of dissolved Ni forms. Trace metals monitored were found above upper threshold value in the lake sediment. These results showed the importance and the need for hard control of pollution loads for the protection of the Lake's sediment and water quality. It is recommended to control and monitor all pollutant sources for ecological sustainability in the lake.

Keywords: Trace Metals, Geographic Information Systems (GIS), TWPCR, Uluabat Lake, NOAA

Introduction

Great amount of trace metals are being discharged into the ecosystems with the rapid industrial and economic development (Liu et al. 2014). Also mining and geochemical structure of soil compose eventual sources of heavy metal pollution into the ecosystems. Trace metals may accumulate up to toxic concentration and result in ecological damage, in these environmental conditions (Hu et al. 2011, Castillo et al. 2011). Trace metal contamination has become a topic of many studies in recent literatures because of the rapid development of industrialization and urbanization (Liu et al. 2018, Gür and Özan 2017, Liu et al. 2014, Yang et al. 2014, Gao and Li 2012, Varol and Şen 2012, Katip et al. 2012). These toxic metals be formed in water systems in soluble, in suspension, in colloidal and in bottom sediments. Geochemical structure of bottom sediment is a very useful indicator for surface water quality, principally regarding heavy metal contents. Also physicochemical composition of lake water is the same significance (Katip 2010). Lake Uluabat forms a significant part of the Susurluk Basin in Marmara Region (42°12′ N, 28°40′ E), where economy, industry and population are developing quickly (Figure 1). The Lake is also one of Turkey's richest lakes in terms of aquatic plants as well as birds and fish populations. Lake Uluabat is under natural and anthropogenic pressure due to its position (Katip et al. 2013).

Consequently, Lake Uluabat has been contaminated for many years by anthropogenic sources such as domestic, agricultural, industrial waste waters, contaminated rain water, etc. The results of many studies that have been made Lake Basin indicate that erosion, eutrophication and heavy metal pollution continues in the lake (Aksoy and Özsoy 2002, Elmacı et al. 2007, Kazancı et al. 2010, Katip 2010, Akdeniz et al. 2011, Katip et al. 2013, Liu et al. 2018). This situation preoccupies the effectiveness of the management plan for the basin which was completed in 2002. To increase the effectiveness of current management plan, GIS utilized from different management plan tools, which widely used in the management of water quality recent years. This paper describes research undertaken

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to explore the degree of metal pollution in Lake Uluabat. Cr and Ni elements were found to be important in previous studies in the lake (Katip 2010, Katip et al. 2012, Katip et al. 2016), therefore in this study these metals were studied.

Materials and Methods

Study Site and Sampling Strategy

Lake Uluabat is a freshwater lake in the city of Bursa, west part of Turkey (42°12' N and 28°40' E). The lake is important part of Susurluk basin. It is a large lake, covering an area of between 135 and 160 km^2 depending on the water level, but very shallow, being only 3 m deep at its deepest point. The lake is fed by the Mustafa Kemal Paşa Brook from the southwest. Water leaves the lake by way of the Kocasu Brook in the northwest. A map of Lake Uluabat showing sampling sites is presented in Figure 1. The locations of the sampling sites determined using global positioning system tool (GPS). Water and sediment samples were taken from ten different sites in the lake. Samples were taken monthly and synchronously for a year, from Aug 2013 to July 2014.

Water samples were taken from 0.5 m below the water surface by using a Hydro-Bios brand standard sampler. The samples were transferred to dark polythene bottles (APHA 1998, Burton and Pitt 2002). Sediment samples were taken from the 5 cm layer of the surface sediment by Ekman grab sampler. The samples were carried into the laboratory in plastic bags, and then air-dried for 4 days for stable weighing. Water samples were filtered through a milipore filter paper with preweighed 0.45 µm pore-size. The filtered water samples were acidified with 0.2% (v/v) concentrated HNO_3 and kept in glass bottles. The filter papers containing the suspended solids were air dried and reweighed again. They were digested with 4/1 (v/v) HNO_3/HCl mixture using a microwave device. After cooling, digestions were diluted to 30 ml with mili-Q water. Sediment samples were air dried and then sieved through a 0.2 mm mesh. These samples were digested with Aqua Regia solution 3/1 (v/v) HCl/HNO_3 in microwave device. Then diluted to 50 ml with mili-Q water. Samples were placed in teflon cups and digestion operations were performed in a CEM brand Mars 5 model microwave device (Katip et al. 2013). Trace metals (Cr and Ni) were determined using the VISTA-MPX model of the VARIAN brand ICP-OES device.

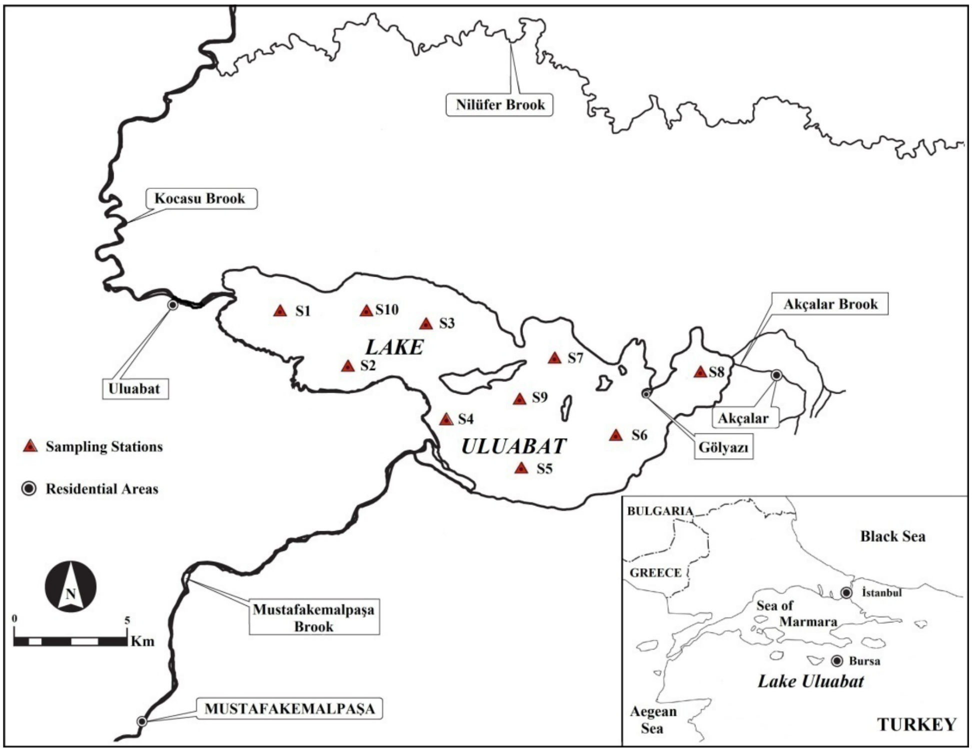

Figure 1. Sampling Sites in Lake Uluabat

Mapping Study

ArcGIS is a worthful tool for interpreting spatial diversity and environmental monitor. Interpolation is used to predict the values of cells at locations that lack sampled points. Inverse distance weighting (IDW) and kriging are two interpolation methods applied widely to clarify spatial variation and distribution of many parameters including heavy metals (Liu et al. 2018). Kriging interpolation refers to a group of spatial interpolation methods for assigning a value of a random field to an unsampled location based on the measured values of the random field at nearby locations (Li and Heap 2008, Xie et al. 2011). IDW assumes that the predictions are a linear combination of available data, and greater weighting values are assigned to values closer to the interpolated point (Hacısalihoğlu et al. 2016). The formula for the IDW method is presented below;

$$z(x_0) = \frac{\sum_{j-1}^{m} z(x_j) d_{ij}^{-k}}{\sum_{j-1}^{m} d_{ij}^{-k}} \quad \text{(Eq.1)}$$

$z(x_0)$: The linear interpolator weights the interpolated data,
$z(x_j)$: The using parameter at the location j,
m : The number of neighboring sampling locations,
x_0 : Non-sampling location,
k : The distance influence coefficient, which is usually 1 or 2,
d_{ij} : The distances between the unsampling location $i(x_0)$ and the sampling locations $j(x_j)$ (Hacısalihoğlu et al. 2016, Mantzafleri et al. 2009).

ArcGIS 10.1 software, spatial analyst extension, and IDW interpolation methods were applied in this study. The locations of the sampling sites determined with global positioning system tool (Magellan XL-GPS) using the Europe 1950 UTM coordinate system. The annual average results of trace metals were recorded vector maps attribute tables. These results were interpolated by the method of IDW and were created layers of grid format. In this way the data point transformed into spatial map data and the distribution of pollution maps in the lake have been obtained (Mantzafleri et al. 2009). These maps were evaluated in comparison with national and international standards.

Results and Discussion

The ranges and mean concentrations of trace metals obtained as a result of the study were given in Table 1. The accumulation order of these metals was found to be Cr>Ni for dissolved form, Ni>Cr for metals in the particulate form and Ni>Cr for those in sediment as seen on Table 1. As shown in Table 1, in particulate and sediment form of Ni while the maximum, in dissolved, concentration of Cr is maximum. These elements had high concentrations in summer and in September, also low concentrations in spring and in winter. Because concentration was diluted during rainy periods.

Table 1.Trace Metal Concentrations of Lake Uluabat

Metal	Mean-SD	Maximum-Minimum
Dissolved form (mg/l)		
Cr	0.022 ± 0.03	0.249 – 0.0
Ni	0.012 ± 0.01	0.091 – 0.0
Particulate form (mg/kg)		
Cr	10.53 ± 8.50	42.2 – 0.95
Ni	20.77 ± 32.1	159.3 – 1.2
Sediment(mg/kg)		
Cr	119.74 ± 34.70	210.52 – 1.02
Ni	196.27 ± 52.32	310.28 – 2.05

Spatial distributions of pollution are effective method to identify 'hot points' areas with high contents (Zhou et al. 2007). The concentrations of Cr and Ni are not uniform at all sites. Distribution patterns of Cr and Ni in dissolved, particulate, sediment forms are presented in Figure 2. As shown in Figure 2, dissolved metal concentrations are very high in the site 1st.When the particulate metal distribution maps are analyzed, pollution has been observed intensively in Brook Mustafa Kemal Paşa (MKP) and Brook Kocasu where it is input-output of the Lake. At the sites 6th, 7th and 8th which are more stable regions, metal pollutions are very low. The maximum concentrations of Cr and Ni were detected at 2nd, 4th and 5th sites. This is due to the fact that the area where these stations are located is exposed to too much wind causing water turbulence. In water column, winds cause vertical mixing of bottom sediment. This situation encourage bonding between dissolved trace metals and particulates (Singh et al. 2008).When the sediment metal distribution maps are analyzed, the maximum values of Cr were observed at the 2nd and 3rd sites, respectively. Katip et al. (2016) were found that Cr and Ni concentrations are higher than the other metals such as As, Cu, Zn, Pb etc. Additionally, the high concentrations of Ni are based on the configuration of soil (Başar et al. 2004).

After the creation of metal pollution distribution maps, water pollution of the Lake was assessed in conformity with TWPCR, sediment pollution of the Lake was assessed in according to NOAA international criteria. TWPCR are generally used in Turkey as a pragmatic technique for following the pollution problem in water. The measured parameters were classified according to "Quality Classification of Continental Surface Water (Water Quality Index)" tables in standard. The standard was given in Table 2. According to Table 2, 1st class water refers to high quality water, 2nd class water refers to less contaminated water, 3rd class water refers to dirty water and 4th class water refers to very dirty water.

Table 2 valid for dissolved metals in water. The annual average values of the measured metals were used to decide quality classes depending on metal concentrations. Spatial distribution maps of these metal classes were given in Figure 3.

Table 2. Turkish Water Pollution Control Regulation, Quality Classification (Water Quality Index) (Anonymous, 2004)

(mg/l)	TWPCR				This Study
Metals	Class I	Class II	Class III	Class IV	Mean – SD
Cr	0.02	0.05	0.2	> 0.2	0.0848 ± 0.2092
Ni	0.02	0.05	0.2	> 0.2	0.0304 ± 0.0416

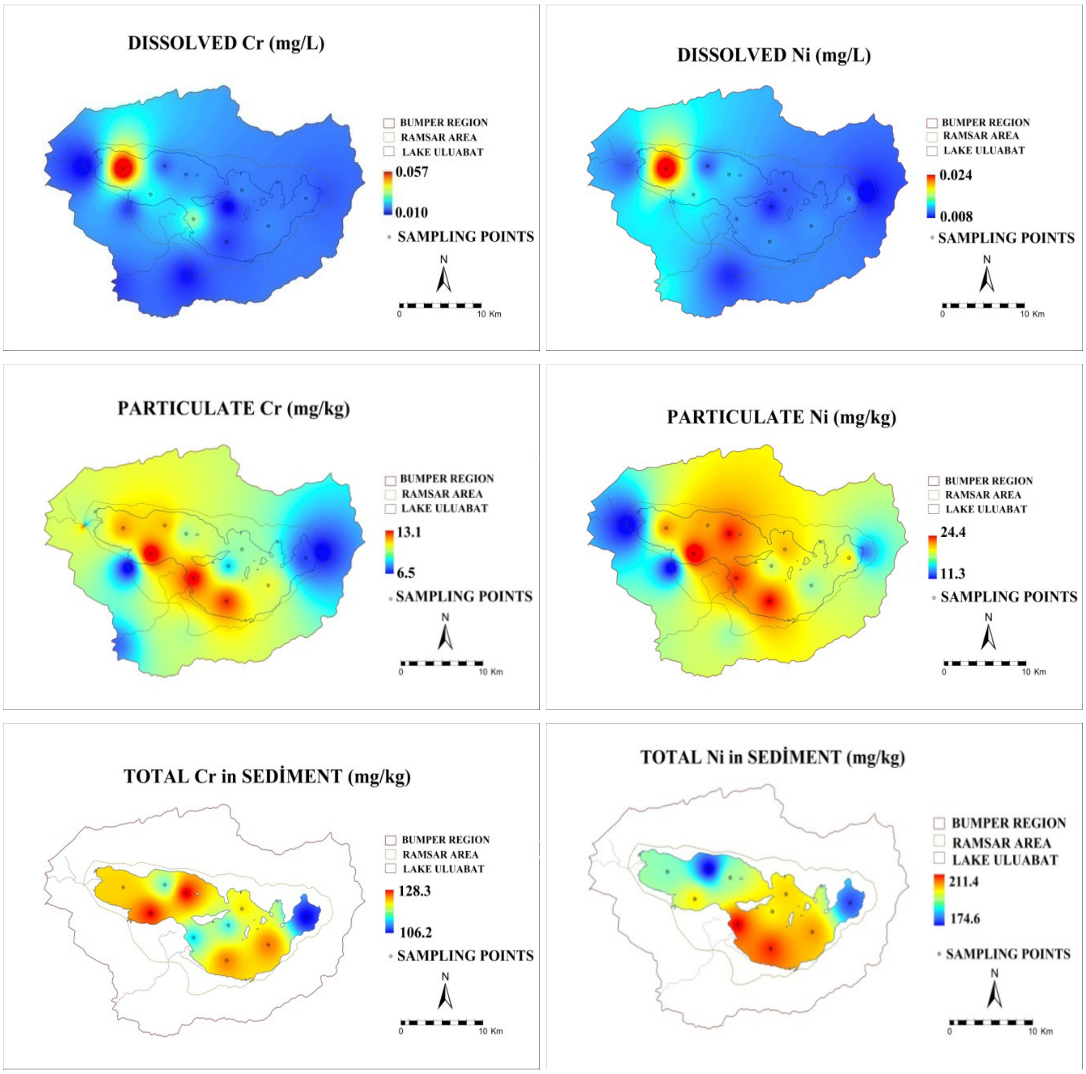

Figure 2. Pollution Distribution Maps of Trace Metals in Lake Uluabat

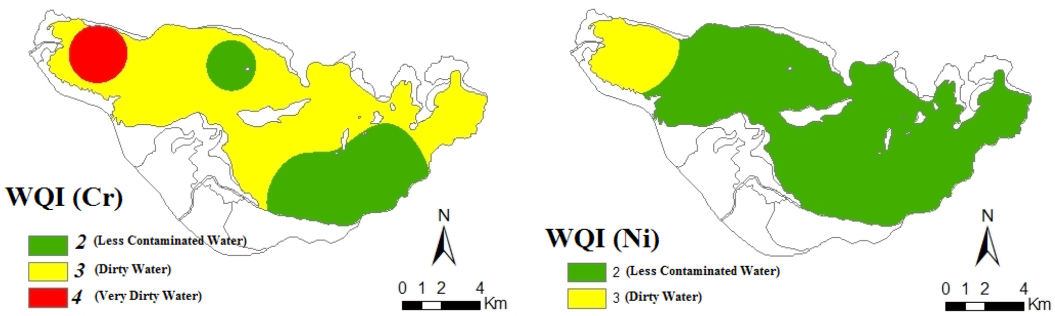

Figure 3. Spatial distribution maps of Cr and Ni according to WQI (in dissolved form)

According to Figure 3, the study area was classified into three zones according to Cr values, that is, class 2 (3rd, 5th, 6th sites), class 3 (2nd, 4th, 7th, 8th, 9th, 10th sites), class 4 (1st site). Also, the lake was classified into two zones according to Ni concentrations, that is, class 3 (only 1st site) and class 2 (all sites). The two metals were determined higher at site 1 than all of the lake, which is closest to the lake exit. Some another pollutant sources enter the Lake, such as reverse current. This current occurs in the Kocasu Brook, because its rate of flow is raised by rainfall during winter (Katip et al. 2013). Another sources of pollutant is Creek Akçalar, which carries domestic and industrial wastewaters of Akçalar village. The irrigation canals of the General Directorate of State Hydraulic Works, which drains wastewaters from agricultural irrigation and neighboring industries are some of the other pollutant sources (Katip et al. 2012). Sediment is an important layer in which water contaminants can be caught like heavy metals. The level of pollution in water resources can be measured by detailed analysis of water, sediment and aquatic organisms living in that area (Goher et al. 2014). Sediment quality guidelines are important tools for assessing the level of contamination in biologically important water resources (Hacısalihoğlu and Karaer 2016, Zhou et al. 2007). Sediment pollution of the Lake was assessed in according to American National Oceanic and Atmospheric Administration (NOAA) international criteria. This criteria was given in Table 3.

Table 3. Concentrations of metals in Lake Uluabat sediment and the toxicological reference values for sediments according to NOAA (Burton and Pitt, 2002)

	Limits	Cr	Ni	
(mg/kg) dryweight	PEL	90	36	PEL : Probable Effect Level
	SEL	110	75	SEL : Severe Effect Level
	TET	100	61	TET : Toxic Effect Threshold
	ERM	145	50	ERM : Effect Range-Median
	UET	95 H	43 H	UET : Upper Effect Threshold
This Study		131.627	220.032	H : Hyalella azteca test

As seen in Table 3, according to the guideline, Cr and Ni values were defined above from all levels (PEL, SEL, TET, ERM, UET). These metals were determined to be higher than upper effect threshold (UET) concentrations. The accumulation of heavy metals in environmental samples affects both human health and the entire ecosystem through the food chain (Castillo et al. 2011). Also, industrial activities, traffic emissions, air pollution can cause contamination of water bodies by heavy metals. Furthermore, rain water coming from runoff carries heavy metals in water resources. These metals, which are found in surface waters, are deposited in the sediment layer. (Katip et al. 2012). In a study conducted by Başar et al. (2004), it was found that the concentrations of Cr, Pb and Ni metals in the soils in the South Marmara Region exceeded the relevant limits. It is possible that these metals deposits in sediment after runoff from the basins of MKP Brook. In addition, the high Ni concentration is due to the general structure of the soil (Başar et al. 2004). Although the metals may remain in the sediment for a long time, they may become free by degradation under oxidizing conditions. This is explained by the fractions of metals. According to the NOAA criteria metal distribution maps for Cr and Ni in sediment was given in Figure 4.

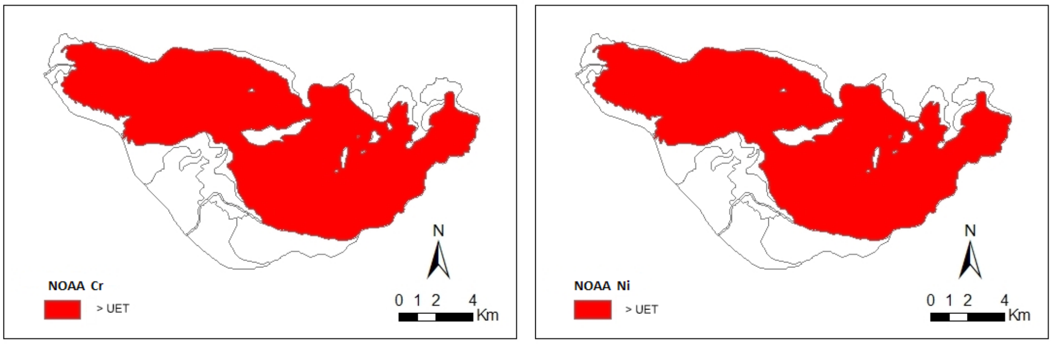

Figure 4. Spatial distribution maps of Cr and Ni according to NOAA (in sediment)

As shown in Figure 4, metal concentrations of the lake sediment were found higher than UET (upper effect threshold) limits. The two metals were determined very high all of the lake sediment. Difference methods have been produced for the risk assessment of heavy metals in sediment; one of them is pollutant load index (Goher et al. 2014). Ecological risk management supply systematic methods that can apprise decision making. Heavy metals are non-biodegradable pollutants. These pollutants do not remove by self purification, on the contrary they cause accumulation, finally enter the food chain (Goher et al. 2014).

Conclusions

Contamination of toxic metals has attracted global notice owing to its persistence, bioaccumulation, and toxicity. The results of this research provide valuable data about Cr and Ni contents of water and sediment from different sites on Lake Uluabat. The concentrations of these metals in water and sediment undergo seasonal changes. Especially concentrations are generally higher during summer. In addition, the quality status of the lake was determined by overlapping water and sediment quality indices with GIS. GIS is widely used for water resources management as well as for many purposes. Using GIS modeling software spatial distribution of numerous water and sediment quality parameters were prepared and analyzed. More intense pollution load were observed at the sites of 1st and 5th. The present situation of the lake compared with WQI for dissolved metals in water and compared with NOAA for metals in sediment. The results show that according to Cr concentrations the lake was classified three zones; class 2 (less contaminated water), class 3 (dirty water), class 4 (very dirty water). Also according to Ni concentrations the lake was classified into two zones that is, class 3 (dirty water) and class

2 (less contaminated water). The two metals were determined higher at site1 than all of the lake, which is near the outlet of the lake. In the Lake sediment, heavy metals were found to be over upper effect threshold value. Lake Uluabat which its importance is high lightened at the global status, have been exposed to heavy metal pollution. So, this study suggested that heavy metals should be monitored regularly in the water and sediment of the lake. Domestic, industrial and agricultural discharges in the lake should be avoided, considering the danger of metals to human health and ecosystem.

Finally, if the necessary precautions are not taken, these metals will participate the human food chain and affect human health.

Compliance with Ethical Standards

Conflict of interest

The authors declare that for this article they have no actual, potential or perceived the conflict of interests.

Author contribution

The contribution of the authors is equal.
All the authors read and approved the final manuscript.
All the authors verify that the Text, Figures, and Tables are original and that they have not been published before.

Ethical approval

Not applicable.

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Data availability

Not applicable.

Consent for publication

Not applicable.

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