J. BIOL. ENVIRON. SCI.,
2011, 5(15), 195-202

A GIS-based Method for Shallow Lake Eutrophication Assessment

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ABSTRACT

Because of the rapidly increasing pollution in Lake Uluabat, which is one of the significant shallow lakes of Turkey and has been announced to be a Ramsar Area, eutrophic state evaluation based on geographic information system was performed. The eutrophication level of the lake is determined with the help of a 0 – 100 scale based on TSI calculations and secchi disc depth (SD), chlorophyll-a (Chl-a), total phosphorus (TP) and total nitrogen (TN) parameters. Between 0 - 30 represents oligotrophic level, 30 – 40 represents lower mesotrophic level 40 – 50 mesotrophic, 50 – 60 upper mesotrophic, 60 – 70 eutrophic, 70 – 80 hypereutrophic and 80 – 100 extremely hypereutrophic. The TSI maps of four parameters were created using the Inverse Distance Weight (IDW) interpolation method. The final map showing the spatial distribution of trophic level was generated by synthesising the thematic maps of each indicator on the cell basis with the overlay technique. From the final map, the trophic level of the entire lake was characterised as eutrophic or more in all seasons studied during the year.

Keywords: Eutrophication, Geographic Information System, Shallow Lake

INTRODUCTION

Eutrophication is defined as turbidity in the water and reduction of light permeability and dissolved oxygen as a result of the overall increase of several microorganisms, especially protista containing chlorophyll (algae), which are enriched by nutrients (nutrient salts) released into the environment by human activities (man-made, artificial, or cultural eutrophication) or natural events (natural eutrophication) (Karaer and Akdeniz 2003, Mason 1991).

This situation causes deterioration in the quality of water that affects its intended use and harms aquatic life forms. Since 1960-70's many studies have been performed to determine trophic levels. In this study, calculations based on a single variable that is an indicator of eutrophication or a multi-parameter approach have been used. The single-variable parameters as an indicator of tropic level are analysed in two groups. First of these groups is a non-biological parameters category, which include nutrients (phosphorus and nitrogen), oxygen demand and light transparency (Secchi depth). The other group is represented by the biological parameters. The behaviour of plankton living in rivers and lakes is also an environmental indicator which is used in explaining the eutrophication level. Chlorophyll-a, plankton cell counts, number of species and biomass are often used as trophic level indicators. Many parameters like these have been used to explain the trophic level (oligotrophic, mesotrophic, eutrophic, and others) (Ludovisi and Poletti 2003, Xu et. al. 2001).

Determining the eutrophication level in a lake system depends not only on the vast data obtained, but also on the distribution of data throughout the lake system. Therefore, appropriate methods and tools are needed to reveal this distribution. Geographic Information System (GIS) applications have the exact features to satisfy this requirement. GIS is a kind of information system which can perform functions such as collecting, storing, processing, and analysing the graphical or non-graphical information obtained with location-based observations, and it presents to the user the information as a whole. The most significant advantage of GIS is that it provides the resulting desired map by superposing the distribution maps created with different parameters within a particular database. For this reason, GIS is used in many studies related to the management of natural resources, especially the management of surface water resources. (Xu, et. al., 2001, Akdeniz 2005, Küçükballı et al. 2005, Karaer and Küçükballı 2006).

In our study, main focus was eutrophication as the most considerable problem for the Uluabat lake, and it was included in Ramsar Convention in May, 1999. The trophic level of the lake, differences in the trophic levels between regions, and the pollution sources that cause this condition were argued at the end of the convention.

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MATERIALS AND METHODS

Study Area

Uluabat Lake is located 34 km away from the city center of Bursa, and is within the boundaries of Mustafakemalpaşa and Karacabey districts. The lake is located between 40° 10′ north and 28° 35′ east coordinates. The lake's length is approximately 22 km in the east-west direction and its width is 10,5 km in the north-south direction. It is a large fresh water lake including eight islands, where the area size ranges from 0.25 ha (Heybeli Adası) to 190 ha (Halilbey Adası). The altitude of the lake is approximately 9 m (Katip 2010, Anonymous 2002, Karacaoğlu 2000).

The average depth of Uluabat Lake is 3 m. The depth of the lake changes significantly every year, and between the summer and winter time. In fact, the depth decreases 0.5-1 m in the summer (Anonymous 2002, Karacaoğlu 2000).

The vast majority of the lake basin is located within the boundaries of Bursa, Kütahya, Balıkesir, and Bilecik covers a small portion of the lake basin as well, about 10500 km2 (Anonymous 2002). The Mustafakemalpaşa Stream basin, which feeds the lake, has a drainage area of 10756 km^2. Near Camandar Village it joins the Emet Stream south of the lake and the Orhaneli Stream south-east of it. The basin of Uluabat Lake is shown in the Figure below. There are sixty-seven residential centres present in the MKP (Mustafakemalpaşa) Stream basin. The Tavşanlı sewage system, which has no treatment plant, is one of the most important pollution sources of the region. . Poluted waters from Tunçbilek Thermal Power Plant and lignite processing plant are also being discharged to the Orhaneli Stream, after becoming subjects to physical treatment. The sewage system of MKP village, the organised leather industry district and other untreated wastewaters from 27different dairies and slaughterhouses are discharged in to the MKP Stream. There are 16 settlements on the lake coast. Domestic and industrial wastewater of Akçalar, which is the one of those settlements, is discharged to Uluabat Lake via the Akçalar Creek (Dalkıran et al. 2006, Katip 2010).

In addition to its organic contaminants, the MKP Stream contains high amounts of suspended solids.

The topographic maps of the lake surface area and volume created by Landsat-5 TM satellite imagery and the ILWIS 1.4 program in 1984, 1993 and 1998 have shown a 12 % reduction in the lake surface area and volume. It is indicated that the reason for this reduction is lignite processing plants and sand pits (Aksoy and Özsoy 2002).

Sampling

To be able to determine the seasonal variations, samples were collected bimonthly. Between May 2002 and May 2003, water samples were taken from five sampling stations that have shown pollution the best. The coordinates of the five stations (as seen in Figure 1) were determined with GPS, and they were mapped with these data by the Uludag University, Faculty of Agriculture, Department of Soil Science, Remote Sensing (RS) and GIS Centre. The first station (Station 1) is located on the outlets of Uluabat Lake which is on the northwestern side of the lake. The station's coordinates are 40° 12.457′ north and 28° 28.294′ east. The coordinates of the second station (Station 2) are 40° 10.134′ north and 28° 34.009′ west, and the station is located south of Halilbey Island, which is the largest island in the lake. Station 3 near Eskikaraağaç Village, which is located on the north side of the lake, is to the southwest of Mutlu Island. The coordinates of this station are 40° 09.616′ north and 28° 37.186′ east. The coordinates of Station 4 are 40° 09.511′ north and 28° 40.042′ east. This station is located in the region between Mutlu Island and Gölyazı Village. Station 5 is located around Akçalar Village at the east end of the lake, and the coordinates of the station are 40° 10.356′ north and 28° 42.170′ east.

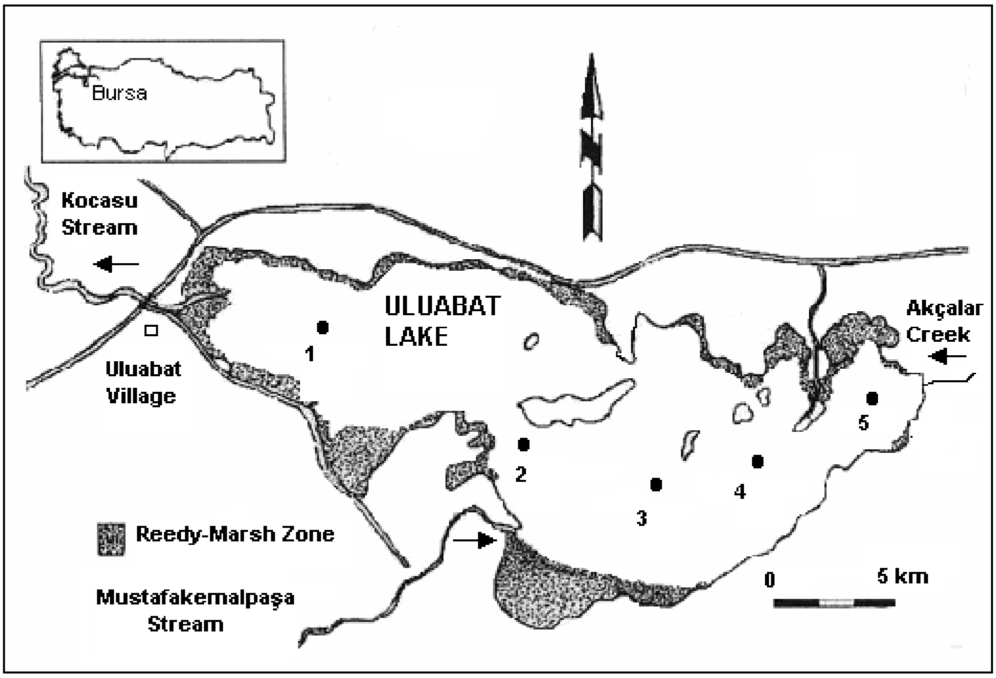

Figure 1. Location of Uluabat Lake Sampling Stations

Water samples were collected by using a Van Dorhn (Alpha Bottle) sampler, and was placed in dark polyethylene two-litre bottles (USEPA 1990, APHA 1998). They were stored in dark coloured bottles, according to standard methods, at + 4^0C up to a week (APHA 1998). To specify the pollution condition of the lake, and to determine conditions like trophic level, temperature (T), electrical conductivity (EC), pH, dissolved oxygen (DO), secchi depth (SD), total nitrogen (TN), total phosphorus (TP) and chlorophyll-a (Chl-a), samples were measured. For the Chl-a, despite the changing water depth, the samples were collected along the water column with the help of a large-scale plastic hose.

Determination of water properties

For the parameters measured in the water samples; pH, temperature, electrical conductivity and dissolved oxygen were measured by using the HACH Sension 156, during the sampling. Likewise, secchi depth and the depth measurement were also measured computed, during the sampling. Total nitrogen (TN) was measured with water steam distillation like Bremner and Mulvaney (1982) reported, total phosphorus (TP) was measured at the 880nm wavelength by spectrophotometer using the ascorbic acid method in Standard Methods (APHA 1998). Chlorophyll-a (Chl-a) values were measured by extraction in acetone like Parson and Strickland (1963) reported and then the Chl-a values were determinated at the 665, 645 and 630 nm wavelengths by spectrophotometer in laboratory conditions.

Assessment of Lake Trophic State and constituting of eutrophication scales

By using the results obtained in the sampling, the trophic level of the lake was calculated. It was compared with the trophic level values of OECD formed by the statistical evaluation of data from many studies (USEPA 2000). Similar to the determination of the OECD standards, the Probability Distribution Graphic in Trophic Classification was used and with these graphics, an evaluation could be made by examining the total phosphorus and chlorophyll-a concentration obtained by others (Reckhow and Chapra 1983, USEPA 2000). Additionally, trophic classification was made using the Trophic State Index (TSI) developed by Vollenweider in 1975 (Chapra 1997) and Carlson in 1977 (USEPA 2000).

Eutrophication GIS applications were used especially to determine the distribution of the parameters examined in Lake Uluabat. For this a 0-100 numeric classification from Carlson, Walker and others was used because it seems to be the most suitable and acceptable method to be used, and because it is based on the TSI with the help of biological, chemical and physical indicators (Thiemann and Kautan 2000, Xu et. al. 2001). First, the scale shown in Table 1, which was developed by Carlson (1977) and Paecella (1980) was created. The scale was created for SD, Chl-a, TP and TN. On the scale which ranges between 0 – 100, a value from 0

– 30 represents oligotrophic, from 30 – 40 represents lower-mesotrophic, from 40 – 50 represents mesotrophic, from 50 – 60 represents upper-mesotrophic, from 60 – 70 represents eutrophic, from 70 – 80 represents hypereutrophic and from 80 – 100 represents the extremely hypereutrophic (Xu et. al. 2001).

Table 1. The TSI scale prepared for SD, Chl-a, TP and TN

TSI	SD (m)	Chl-a (μg L^{-1})	TP (μg L^{-1})	TN (mg L^{-1})
0	64.31	0.04	0.75	0.02
10	32.13	0.12	1.5	0.05
20	16.05	0.34	3	0.09
30	8.02	0.94	6.01	0.18
40	4.01	2.61	12.01	0.37
50	2	7.23	24.04	0.73
60	1	20.02	48.09	1.47
70	0.5	55.5	96.21	2.94
80	0.25	153.8	192.49	5.87
90	0.12	426.26	385.11	11.75
100	0.06	1181.35	770.48	23.49

Calculation of eutrophication levels and generation of thematic maps

The following expression was used to calculate the eutrophication levels for each of the parameters (Xu et. al. 2001).

$$TSI_i = [\, TSI_{k-1} + [(C_i - S_{i,k-1}) / (S_{i,k} - S_{i,k-1})] \times (TSI_k - TSI_{k-1}) \,]$$

where Ci is the measured concentration of the i-th indicator (i=TP, TN, SD, Chl-a), TSI_k and TSI_{k-1} are the k-th and ($k-1$)-th scales of the i-th indicator, $Si_{,k}$ and $Si_{,k-1}$ are the evaluation standards of k-th and ($k-1$)-th scales of the i-th indicator (see Table 1).

To generate the four eutrophication maps, inverse distance weight (IDW) interpolation method was utilised (Xu et. al. 2001). All maps have the resolution of 300 x 300 m, and Ilwis 3.1 GIS program is used for generating the maps (Anonim 2001).

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$$f(x, y) = \left[\sum_{i=1}^{N} w(d_i) z_i \right] \div \left[\sum_{i=1}^{N} w(d_i) \right]$$

where $f(x, y)$ is the interpolated value at point (x, y), $w(di)$ is the weighting function, zi is the data value at point i, and di is the distance from point (x, y). The interpolated values of all points within the dataset are bounded by min (zi) < $f(x, y)$ < max (zi), as long as $w(di) > 0$ (Lam 1983). The IDW interpolation method has been widely used on many types of data because of its simplicity in principle, speed in calculation, easiness in programming and credibility in interpolating surfaces (Xu et. al. 2001).

The overlay of the thematic maps

The function of the overlay technique that is widely used for GIS applications is to generate an eutrophication final map, after synthesising the thematic maps that were created for each indicator. To synthesise the thematic maps, the following steps were used.

1. For the different trophic levels between 0 – 100, a TSI scale was developed. (Table 1)
2. The scale was applied to all of the cells in the maps.
3. The thematic maps that were generated for each indicator (SD, TN, TP and Chl-a) were synthesised or combined on the basis of each cell. The resulting final map showed the spatial distribution of eutrophication conditions. The expression used for overlapping the thematic maps is:

$$TSI = TSI_{SD} * W_{SD} + TSI_{Chl\text{-}a} * W_{Chl\text{-}a} + TSI_{TP} * W_{TP} + TSI_{TN} * W_{TN}$$

TSI values show the trophic levels of the SD, Chl-a, TP and TN parameters. W values are weight factors for the indicator parameters. In our study, W values were determined to be 1/4 for each parameter (Xu et. al. 2001). In the figure 2, GIS application utilised at Lake Uluabat is shown.

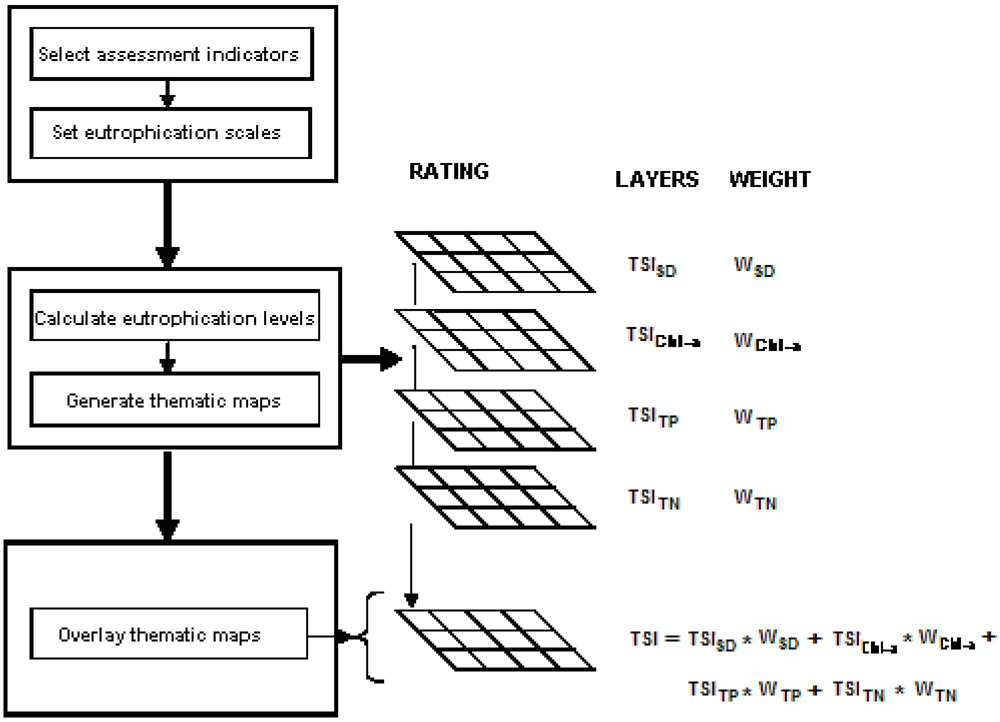

Figure 2. GIS application utilised at Lake Uluabat

RESULTS AND DISCUSSIONS

Using the annual average values of TSISD, TSIChl-a, TSITP and TSITN and using thematic maps generated by the IDW interpolation method and eutrophication scale, different final maps of trophic level distributions were produced.

The trophic level distribution map, which was obtained from the annual average secchi depth values measured in the lake, is in Figure 3 (a). The map shows that a large section of the lake is at eutrophic level (TSISD 60-70). However, the east part of the lake, which is greatly affected by the northern winds is at the hyper-eutrophic level. The prevaling winds at Lake Uluabat are from the North, and is the reason for the higher trophic level at the east part of the lake. The winds make the water turbid by pulling up sediment from the bottom, which causes the depth of the secchi disc to read lower.

The trophic level distribution map generated utilising the annual average values of chl-a is shown in Figure 3 (b). As indicated, the trophic level, compared to chlorophyll-a, reached the eutrophic level (TSIchl-a 60-70) at the east part of the lake, and especially in the Akçalar Gulf. The rest of the lake remained at a uppermesotrophic level (TSIChl-a 50-60). The circumstances shown in Figure 3 were observed during the field work. Moreover, that part of the lake becomes more greenish because of the dense algal population, especially during the summer. Higher trophic levels in the region may be caused by not being mixed as much with other parts of the lake. Another reason may be, around the Akçalar Gulf, the settlements and industrial establishments discharge directly into the lake and as a result cause the eutrophication.

The trophic level distribution map created using the annual averages of the TP parameter, which is one of the significant indicators of trophic level is shown in Figure 3 (c). The map indicates that the situation is much more serious with respect to the total phosphorus. Furthermore, except the western end of the lake, the majority of the lake is at the hypereutrophic level (TSITP 70-80). The western end of the lake, however, reaches the extreme hypereutrophic levels (TSITP 80-100). This reveals that there is serious pollution in Lake Uluabat, with respect to the total phosphorus. We conclude that the phosphorus is the limited nutrient for Lake Uluabat.

Uluabat reached the described levels of polution, which is enough to see what kind of problems will be faced in the future. It has been determined that a great deal of total phosphorus loading dispersed into Lake Uluabat has a tendency to settle down (Akdeniz 2005). Therefore, the already high phosphorus levels in the sediment rises every year. Even if the external sources entering the lake are improved in the coming years, it will only cause a delayed reaction of the lake with the amount of phosphorus increasing in the sediment (Portielje and Molen 1998). The higher trophic level at the western end of the lake is not only caused by water coming back from Kocasu Stream in the summer, but also because this part of the lake is close to the mixing zone.

Finally, TN was applied to determine the trophic state distribution. Figure 3 (d) indicates the distribution map of the trophic state based on annual averages of TN. As shown, the trophic level of the western part of the lake is characterised as hypereutrophic (TSITN 80-100). The hypereutrophic level (TSITN 70-80) extends to the rest of the lake. Clearly, there are many similarities between the trophic level distribution map based on annual averages of TN values and the map generated for TP. On both maps, the trophic level of the lake is consistant between the regions. The western end of the lake reaches extremely high levels, which emphasises that there can be some reversal in the lake.

The final map (Figure 3-e) showing the spatial distribution of lake eutrophication based on overlay technique was generated by comparing all the distribution maps of the trophic level, based on annual averages values for each parameter in the GIS environment. The map shows that the trophic level of the eastern end near the outlet of Lake Uluabat is characterised as hypereutrophic (TSI 70-80). Other regions of Uluabat Lake are eutrophic (TSI 60-70). The results prove that Lake Uluabat is under severe pressure. It should be considered that if precautions are not taken, the trophic level could increase even more.

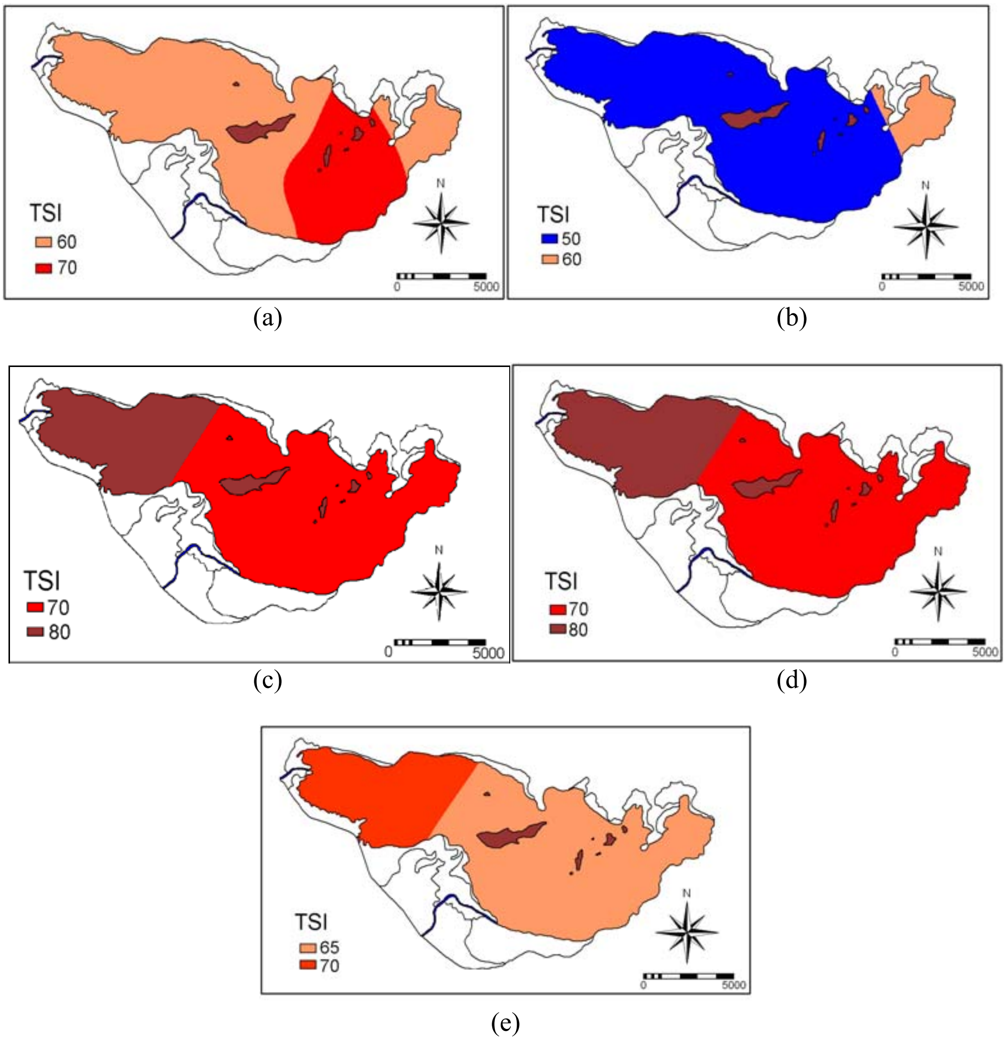

Figure 3. Spatial distribution maps of SD(a), Chl-a(b), TP(c) and TN(d) parameters and the final map of the lake eutrophication based on overlay technique

CONCLUSIONS

A GIS-based IDW interpolation method was used to generate thematic maps indicating the spatial distribution of each TSI. An overlay technique within the GIS framework was applied to analyse the information from the thematic maps, to develop a final map illustrating the spatial distribution of eutrophication conditions in the lake. This study shows the principal advantage of the proposed methodology, compared to other methods based on a multi-parametric classification and assessment of lake trophic trends.

In all of the seasons that was studied during the year, the trophic level of the entire lake was characterised at the eutrophic level or higher. This situation indicates how poor the lake's current situation is. Therefore, essential measures and plans must be implemented without any delays. The sewage and industrial wastewaters of the settlements, especially around the lake and in the watershed, must be treated. In addition, new institutions should be evaluated for their environmental effects, and inappropriate ones should not be established. Over-fertilising should be avoided in agricultural areas. The best method for these measures, is to establish protection zones around the areas in the watershed of the lake. This protection must not allow any activity within the region.

ACKNOWLEDGEMENT

The financial support of Uludag University Research Committee is acknowledged. Project no: 2000-50.

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