Assessing Water Quality in the Beysehir Lake (Turkey) by the Application of GIS, Geostatistics and Remote Sensing

Bilgehan Nas¹, Hakan Karabork², Semih Ekercin³ and Ali Berktay
Selcuk University, Dept. of Environmental Engineering, 42075, Konya, Turkey
E-mail: bnas@selcuk.edu.tr and aberktay@selcuk.edu.tr,
Aksaray University, Dept. of Geodesy and Photogrammetry Engineering, 68100, Aksaray, Turkey.
E-mail: hkarabork@hotmail.com, ekercin@itu.edu.tr

ABSTRACT

The Beysehir lake is the most important drinking and irrigation water source for the Central Anatolia. The lake has an area of approximately 656 km² with an average depth of 5 meters. The purposes of this investigation were to (1) provide an overview of present water quality in the Beysehir Lake, Turkey and (2) to determine spatial distribution of water quality parameters in the lake surface area using GIS, Geostatistics and Remote Sensing techniques. The water samples were collected from 40 stations. Physical, chemical parameters (pH, Dissolved Oxygen, Secchi disk depth (SDD), Turbidity, Conductivity, TSS, Alkalinity, COD, BOD, TN, TP, NO₃, NH₄) and chlorophyll-a (chl-a) values were determined in the Beysehir Lake in August 19, 2005. According to water quality values (TP, SDD, chl-a) the trophic level of the lake was determined. Based on chl-a concentrations, the lake is classified as mesotrophic and based on TP and SDD, the lake seem to be a eutrophic lake. In order to analyze the data determining water quality, a GIS software package ArcGIS 9.0 and ArcGIS Geostatistical Analyst extension were used. An interpolation technique called “ordinary kriging” was used to produce the spatial distribution of water quality parameters over the lake. Spatial distribution maps of TN, TP, Turbidity, Secchi disk depth and chlorophyll-a were produced for the lake surface area. Terra ASTER satellite image is used as remote sensing data source for water quality mapping in addition to simultaneously performed in-situ measurements. Ground data is collected simultaneously with the ASTER overpass on June 09, 2005 over the Beysehir Lake. The results indicate that simultaneous ground and satellite remote sensing data are highly correlated (R²>0.86). Image processing procedure and the evaluation of results were carried out using Erdas Imagine© software package.

Keywords  Beysehir Lake; GIS; Geostatistics; Remote Sensing; Water quality mapping

INTRODUCTION

The Beysehir Lake is the largest freshwater lake and drinking water reservoir in Turkey. Although it has some protected statues and it is important for water flow and fishing, the lake has a number of problems such as variations in water level due to inappropiate water policy and aquatic macrophytes overgrowing in the lake ecosystem, and uncontrolled fishing, urbanization, and water pollution.

Geographical Information Systems (GIS), Geostatistics and Remote Sensing can be used to provide a large-scale understanding of lake change and in developing lake management strategies.

Applications of geostatistics can be found in very different disciplines ranging from the classical fields mining and geology to soil science, hydrology, meteorology, environmental sciences, agriculture, even structural engineering. Kriging is widely used in geology, hydrology, environmental monitoring and other fields to interpolate spatial data (Stein 1999). Among the various forms of kriging, ordinary kriging has been used widely as a reliable estimation method (Yamamoto 2000). Ordinary Kriging is most commonly adopted for environmental studies (Poon et al. 2000; Buttner et al. 1998; Kravchenko and Bullock 1999; Lin et al. 2001; Tranchant and Vincent 2000). A more detailed explanation of the kriging method is given by Stein (1999), Yamamoto (2000), Gringarten and Deutsch (2001), McGrath and Zhang (2003), Cressie (1990).

Traditional water quality monitoring methods can be precise, but are usually expensive and time consuming, especially for the large area of water body like Beysehir Lake. A solution could be to optimise our efforts and more frequently base our surveillance on remote sensing techniques to improve the information content and limit the costs (Östlund et al. 2001). Today, there are many satellites which have high enough resolution for use in water quality monitoring studies (Bilge at al. 2003). Many research projects have examined for estimating water quality parameters in inland, estuarine and near-shore ocean waters using various satellite imagery (Baban 1993; Nellis et al. 1998; Thiemann and Kaufmann 2000; Wang and Ma 2001; Koponen et al. 2002; Östlund et al. 2001; Hellweger et al. 2004; Hedger et al. 2001; Lillesand et al. 1983; Kloiber et al. 2002a and 2002b).
The purposes of this investigation were to (1) provide an overview of present water quality in the Beysehir Lake, Turkey and (2) to determine spatial distribution of water quality parameters (TN, TP, Turbidity, SDD, and chlorophyll-a) in the lake surface area using GIS and Geostatistics techniques.

This paper also presents an application of water quality mapping through real-time satellite and ground data. Terra ASTER satellite image is used as remote sensing data source for water quality mapping in addition to simultaneously performed in-situ measurements. The spatial distribution map is developed by using multiple regression (MR) technique for water quality parameter, which is chlorophyll-a (chl-a).

METHODS

Study area

The Beysehir Lake is placed in the southern part of Konya Basin that is the largest closed basin in Anatolia. Its surface covers an area of approximately 656 km² with an average depth of 5 meters (8 meters maximum). There are 33 islands where most of are important for wintering, waterfowl and breeding birds. The Beysehir Lake has 1st degree Natural SIT protection status (a national site protection status of the Turkish Ministry of Culture) since 1991. The lake is completely surrounded by two National Parks since 1993 namely Beysehir and Kızıldağ National Parks. It is located between 31° 17′ and 31° 44′ E and 37° 34′ and 37° 59′ N in the Central Anatolia, Turkey (Figure 1).

A tectonic lake shaped by karst formations, the lake is fed by water coming from the western Toros Mountains. Apart from the two streams, the lake is fed mainly by groundwater. The lake is the most important drinking and irrigation water source for the Central Anatolia. In addition to its function as a water reservoir for irrigation in the Cumra Plain, the lake is used for transportation, generates a lot of wetland products and has scenic and wildlife values.

Data collection and analyses

The water samples were collected from 40 stations with a vertical point water sampler at 50 cm below the surface (Figure 2). The locations of the stations were obtained by using a hand held Global Positioning System (GPS) receiver. Physical, chemical parameters and chlorophyll-a values were determined in the Beysehir Lake in August 19, 2005. Water quality parameters (pH, Dissolved Oxygen (DO), Conductivity, Turbidity, COD, BOD, TN, TP, NO₃, NH₄, TSS, Alkalinity, and Chlorophyll-a) were analyzed in the laboratory according to the methods given in Standard Methods (APHA, AWWA, WEF 2005). NO₃ and NH₄ were analyzed with Orion 710A advanced ion selective meter. DO, conductivity and pH measurements were performed by using the WTW Multiparameter 340i. All laboratory analyses were carried out within 24 h following sample collection. Secchi disk depths (SDD) were measured with a 20 cm diameter disk with alternating black and white quadrants. The extraction and measurement of the chlorophyll-a concentrations were made with acetone following the SM 10200 H- spectrophotometric method (APHA, AWWA, WEF 2005). In this study, in order to analyze the data determining water quality, a GIS software package ArcGIS 9.0 and ArcGIS Geostatistical Analyst extension were used. An interpolation technique called “ordinary kriging” was used to produce the spatial distribution of water quality parameters over the lake.
Lake water quality monitoring using ASTER data

For this study, a cloud-free Terra ASTER (Advanced Spatial-borne Thermal Emission and Reflection Radiometer) image data acquired on June 09, 2005 is used as the satellite image data for mapping water quality in the lake. ASTER is a moderate resolution sensor developed by the Japanese Ministry of Economy, Trade and Industry (METI). The ASTER instrument has three spectral bands in the visible near-infrared (VNIR), six bands in the shortwave infrared (SWIR), and five bands in the thermal infrared (TIR) regions, with 15, 30, and 90 meters ground resolution respectively. However, only VNIR and SWIR bands (first four bands 0.52-1.70µm) were used to correlate remotely sensed data and water quality parameters. Image processing procedure and the evaluation of results were carried out using Erdas Imagine© and ArcGIS© 9.0 software packages.

Image Processing

Raw images usually contain such significant systematic and non-systematic (geometric) distortions that they cannot be used as a map (Jensen 2000; Sabins 1996; Toutin 2003). Therefore in this study, ASTER image data was geometrically corrected as a first stage of the image processing procedure.

The ASTER scene acquired on June 09, 2005 was rectified using a set of 40 ground control points (GCPs) extracted from 1:25 000 scale maps. A first-order polynomial transformation was used to create the output images with 15m ground resolution, because the study area presents an almost flat topography and the study includes analysis of the surface water in a lake (Metternicht and Zinck 1998). The root mean square error (RMSE) of the transformation was not permitted to exceed ±0.5 pixel. ASTER image data was registered to Universal Transverse Mercator coordinates zone 36, WGS 84 Datum, and resampled to 15m by nearest neighbour interpolation method (Almeida-Filho and Shimabukuro 2002).

In Situ Data and Laboratory Analysis

The field work involving water sampling and ground truth was carried out on June 09 of 2005. It was simultaneously performed with the overpass of the Terra ASTER instrument (09/06/2005). Taking into account the distribution of sample points, it was decided to collect water samples at twenty three points for this case study covering the Beysehir Lake. In order to make the distribution of sample points homogeneous over the lake surface, the locations of points were checked and recorded by using a hand held GPS.

Correlating image data and water quality parameters. In this study, the average digital number of pixels (a 3x3 window) surrounding the sample pixel is used to perform multiple regression technique. Following multiple regression equation is widely used in water quality researches relating to remote sensing (Hellweger et al., 2004).

\[
\text{Water Quality Parameter (WQP)} = a + b \times \text{Band 1} + c \times \text{Band 2} + d \times \text{Band 3} + e \times \text{Band 4} \quad (1)
\]

RESULTS AND DISCUSSION

Physical, chemical parameters and chl-a values were determined in the Beysehir Lake in August 19, 2005. The statistical evaluation of water quality parameters can be seen in Table 1.

Table 1. Statistical evaluation of water quality parameters for the Beysehir Lake, Turkey (n=40)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mini.</th>
<th>Max.</th>
<th>Mean</th>
<th>Median</th>
<th>Standard deviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>8.1</td>
<td>9.6</td>
<td>9.0</td>
<td>9.0</td>
<td>0.318</td>
</tr>
<tr>
<td>DO (mg/L)</td>
<td>3.3</td>
<td>13.2</td>
<td>8.1</td>
<td>8.1</td>
<td>0.633</td>
</tr>
<tr>
<td>Conductivity(µS/cm)</td>
<td>246</td>
<td>344</td>
<td>267.5</td>
<td>264</td>
<td>18.15</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>0.7</td>
<td>18.8</td>
<td>5.5</td>
<td>3.7</td>
<td>4.622</td>
</tr>
<tr>
<td>COD (mg/L)</td>
<td>6.1</td>
<td>43</td>
<td>20.5</td>
<td>18.4</td>
<td>8.88</td>
</tr>
<tr>
<td>TN (µg/L)</td>
<td>284</td>
<td>1890</td>
<td>911</td>
<td>871</td>
<td>407</td>
</tr>
<tr>
<td>TP (µg/L)</td>
<td>44</td>
<td>155</td>
<td>88.4</td>
<td>87.5</td>
<td>26.305</td>
</tr>
<tr>
<td>NO3 (mg/L)</td>
<td>0.1</td>
<td>1.69</td>
<td>0.8</td>
<td>0.8</td>
<td>0.337</td>
</tr>
<tr>
<td>NH4 (mg/L)</td>
<td>0.3</td>
<td>0.521</td>
<td>0.3</td>
<td>0.3</td>
<td>0.050</td>
</tr>
<tr>
<td>TSS (mg/L)</td>
<td>0.4</td>
<td>27.2</td>
<td>4.3</td>
<td>2.8</td>
<td>0.860</td>
</tr>
<tr>
<td>SDD (cm)</td>
<td>45</td>
<td>585</td>
<td>299.1</td>
<td>170</td>
<td>153.65</td>
</tr>
<tr>
<td>Chl-a (µg/L)</td>
<td>0.6</td>
<td>21.68</td>
<td>4.8</td>
<td>3.3</td>
<td>4.988</td>
</tr>
</tbody>
</table>

The concentration of chl-a in the water is often taken as an index of the biomass of algae present and, together with total phosphorus and water transparency (SDD) has been used to classify the trophic status of lakes (Table 2). The OECD classification system is based on the limnological trophic state of lakes (OECD 1982). According to the Table 2, based on chl-a concentrations, the lake is classified as mesotrophic. Based on TP concentrations and SDD, the lake seem to be a eutrophic lake according to August 19, 2005 samples. Eutrophication can be defined as the enrichment of waters by inorganic plant nutrients. The ratio of nitrogen and phosphorus in the water can also provide useful information. If the N:P ratio exceeds 16:1, phosphorus is likely to be limiting to algal growth; if the ratio is less than 16:1, nitrogen may be limiting. In the Beysehir Lake, the N:P ratio is 10.3:1 and nitrogen is limiting to algal growth. The discharge of nutrient-rich sewage and animal wastes into lakes is often the major source of enrichment problems, while detergents are often the most important sources of phosphorus in wastewater.
Table 2. OECD boundary values for fixed trophic classification system (Mason 2002)

<table>
<thead>
<tr>
<th>Trophic category</th>
<th>TP</th>
<th>Mean Chl-a</th>
<th>Mean SDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultra-oligotrophic</td>
<td>&lt; 4.0</td>
<td>&lt; 1.0</td>
<td>&gt; 12.0</td>
</tr>
<tr>
<td>Oligotrophic</td>
<td>&lt; 10.0</td>
<td>&lt; 2.5</td>
<td>&gt; 6.0</td>
</tr>
<tr>
<td>Mesotrophic</td>
<td>10-35</td>
<td>2.5-8.0</td>
<td>6-3</td>
</tr>
<tr>
<td>Eutrophic</td>
<td>35-100</td>
<td>8-25</td>
<td>3-1.5</td>
</tr>
<tr>
<td>Hypertrophic</td>
<td>&gt; 100</td>
<td>&gt; 25</td>
<td>&lt; 1.5</td>
</tr>
</tbody>
</table>

Spatial interpolation of water quality parameters

Ordinary kriging was used to obtain the spatial distribution of groundwater quality parameters over the area. The water quality data has been checked by a histogram tool and normal QQPlots to see if it shows a normal distribution pattern. For each water quality parameter, an analysis trend was made and the eleven different semivariogram models were tested. Prediction performances were assessed by Cross Validation.

Examining the distribution of the data: Kriging methods work best if the data is approximately normally distributed. In ArcGIS Geostatistical Analyst, the histogram and normal QQPlots were used to see what transformations, if any, are needed to make the data more normally distributed. Normal QQPlots provides an indication of univariate normality. Histogram and normal QQPlots analysis were applied for each water quality parameter and it was found that only the TN and TP parameters showed a normal distribution. It was determined that Turbidity, SDD and Chlorophyll-a concentrations do not show normal distributions. For those parameters a log transformation has been applied to make the distribution closer to normal.

Examining the global trend through trend analysis: For each water quality parameter, an analysis trend was made and it was determined that there is global trend for TN, TP, Turbidity, SDD and Chlorophyll-a parameters. Global trend was removed from all of parameters.

Semivariogram models: In this study, the semivariogram models (Circular, Spherical, Tetraspherical, Pentaspherical, Exponential, Gaussian, Rational Quadratic, Hole effect, K-Bessel, J-Bessel, Stable) were tested for each water parameter data set. Prediction performances were assessed by Cross Validation. Cross Validation allows determination of which model provides the best predictions. For a model that provides accurate predictions, the standardized mean error should be close to 0, the root-mean-square error and average standard error should be as small as possible, and the root-mean square standardized error should be close to 1. When the average estimated prediction standard errors are close to the root-mean-square prediction errors from cross-validation, then you can be confident that the prediction standard errors are appropriate (ESRI 2001).

After applying different models for each water quality parameter examined in this study, the error was calculated using cross validation and models giving best results were determined. Table 3 shows the most suitable models and their prediction error values for each parameter. Table 3 also shows that for different parameters different models may give better results. For water quality parameters, RMSS range from 0.771 to 1.115. Table 4 shows semivariogram /covariance modeling and its associated parameter values, which are called the nugget, range, and partial sill.

Ordinary kriging interpolation for water quality parameters (TN, TP, Turbidity, Secchi disk depth and Chl-a) in the Lake surface area were taken. Figure 4 shows spatial distribution maps of TN, TP, Turbidity, Secchi disk depth and chl-a concentrations in the study area, respectively.

Figure 3. Regression model for chl-a with ASTER, 2005 image data
Table 3. Fitted parameters of the theoretical variogram model for water quality parameters.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Models</th>
<th>Mean</th>
<th>Root-Mean-Square</th>
<th>Average Standard Error</th>
<th>Mean Standardized</th>
<th>Root-Mean-Square Standardized</th>
</tr>
</thead>
<tbody>
<tr>
<td>TN</td>
<td>Pentaspherical</td>
<td>-4.054</td>
<td>419.5</td>
<td>419.4</td>
<td>-0.01151</td>
<td>1.005</td>
</tr>
<tr>
<td>TP</td>
<td>J-Bessel</td>
<td>0.1852</td>
<td>27.17</td>
<td>24.23</td>
<td>0.004478</td>
<td>1.115</td>
</tr>
<tr>
<td>Turbidity</td>
<td>Pentaspherical</td>
<td>0.5032</td>
<td>5.178</td>
<td>8.918</td>
<td>-0.05439</td>
<td>0.7886</td>
</tr>
<tr>
<td>Chlorophyll-a</td>
<td>Stable</td>
<td>0.287</td>
<td>4.95</td>
<td>5.368</td>
<td>-0.1122</td>
<td>1.027</td>
</tr>
<tr>
<td>SDD</td>
<td>Hole Effect</td>
<td>14.84</td>
<td>158.5</td>
<td>215</td>
<td>-0.04008</td>
<td>0.771</td>
</tr>
</tbody>
</table>
Figure 4 shows that the high TN, TP, Turbidity, SDD and chl-a concentrations occur coast of the lake in general. The concentration of phosphorus in the lake can be related readily to SDD and chl-a concentrations from relationships obtained from a large number of lakes. Since photosynthesis depends fundamentally on light, significant changes in light penetration in a lake will produce a variety of direct and indirect biological and chemical effects. Significant changes in lake transparency are most often the result of human activities, usually in association with land use activities in the watershed. Phosphorus enters water bodies not only as inorganic phosphate ions but also in inorganic polymers, organic phosphorus compounds, living microorganisms and dead detritus. Nitrogen has a similar array. Only some of these forms are immediately available for plant and algal growth, but others may become so through microbial activity (Moos 1998).

Table 4. Semivariogram/Covariance modeling and its associated parameter values

<table>
<thead>
<tr>
<th>Models</th>
<th>TN</th>
<th>TP</th>
<th>Turbidity</th>
<th>Chl-a</th>
<th>SDD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7.8584<em>Pentaspherical(6692.2)+81987</em>Nugget</td>
<td>18.975<em>Bessel(6203.9,0.01)+486.13</em>Nugget</td>
<td>0.26814<em>Pentaspherical(10433)+0.6431</em>Nugget</td>
<td>0.062916<em>Stable(38658,21577,351,3)+0.30696</em>Nugget</td>
<td>0.29197<em>Hole Effect(10011,7640.3,19.8)+0.16228</em>Nugget</td>
</tr>
<tr>
<td>Major range</td>
<td>6692.2</td>
<td>6203.9</td>
<td>10433</td>
<td>38658</td>
<td>10011</td>
</tr>
<tr>
<td>Sill</td>
<td>7.8584</td>
<td>18.975</td>
<td>0.26814</td>
<td>0.062916</td>
<td>0.29197</td>
</tr>
<tr>
<td>Nugget</td>
<td>81987</td>
<td>486.13</td>
<td>0.64311</td>
<td>0.30696</td>
<td>0.16228</td>
</tr>
</tbody>
</table>

Figure 4 shows that the high TN, TP, Turbidity, SDD and chl-a concentrations occur coast of the lake in general.

Spatial distribution of Chl-a using ASTER data

In the application, the multiple regression is adopted as having five input (independent variables) and one output (dependent, prediction) parameter, WQP. The results of multiple regression technique show that in situ data and remotely sensed data are in good agreement with a R2 value of over 0.86. Table 5 shows the constant coefficients (a, b, c, d, e) and determination coefficient of multiple regression equation for water quality parameter. It is obvious that the multiple regression model predictions of WQP (calculated values) are consistent and reliable (Figure 2). Application of our regression equation for calculation of chl-a from remote sensing reflectance resulted in a distribution map of chl-a (Figure 4f). As can be seen Figure 4f, the highly chl-a zones are appearing in green colour. The areas showing high concentration of chl-a are the areas receiving untreated sewage from villages of adjoining areas of the lake.
Table 5 Multiple regression analysis of chlorophyll-a concentration and spectral reflectance.

<table>
<thead>
<tr>
<th>Water Quality Parameter (WQP)</th>
<th>Regression equation</th>
<th>Determination Coefficient ($R^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll-a (Chl-a)</td>
<td>Chl-a = -1.024 + 0.0086<em>Band1 - 0.013</em>Band2 - 0.096<em>Band3 + 0.367</em>Band4</td>
<td>0.863</td>
</tr>
</tbody>
</table>

CONCLUSIONS

In the Beysehir Lake basin, most of the settlements are discharging their wastewater to the lake and streams which are feeding the lake without any treatment. Agricultural runoff is also another threat for the lake. The concentration of phosphorus in the lake can be related to the SDD and chl-a concentrations. In the Beysehir Lake, the N:P ratio is 10.3:1 and nitrogen is limiting to algal growth. The ordinary kriging interpolation method was used for generating thematic maps indicating the spatial distribution of TN, TP, Turbidity, SDD and Chlorophyll-a concentrations.

The geostatistical approach allows the investigator to determine the number of observations required to achieve a tolerable accuracy. This can be determined prior to the actual survey. In this study, the water quality data were checked by a histogram and normal QQPlots. For each water quality parameter, an analysis trend was made and the eleven different semivariogram models were tested. Anisotropy was checked and prediction performances were assessed by Cross Validation.

Spatial distributions of surface chlorophyll-a were determined from remotely sensed images. As a result, Terra/ASTER data proved to be useful for mapping water quality.

ACKNOWLEDGMENTS:

This study is supported by The Scientific and Technological Research Council of Turkey (TUBITAK) with project No: 105Y086 and Selcuk University Scientific Research Fund with project No: 2004/102.

REFERENCES


