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Modeling and Mapping Temperature, Secchi Depth, and Chlorophyll-a Distributions of Zinav Lake by Using GIS and Landsat-7 ETM+ Imagery

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Abstract: Temperature, secchi depth, and chlorophyll-a (in relation to secchi depth) of Zinav Lake in Turkey were modeled and mapped by using Geographic Information Systems (GIS) and Remote Sensing (RS). Temperature (^oC), secchi depth (m), and chlorophyll-a (mg/l) field data were collected from geo-referenced 5 stations on the lake between September- 2011 and October-2012 in monthly basis. Secchi depth was measured by Hidrobios brand secchi disc with 25 cm diameter. A multi-measuring device (YSI-556MPS) was utilized to determine temperature values. Chlorophyll-a was measured by using Helios-α model UV-Vis spectrophotometer and monochromatic method. Utilizing geo-referenced field data and the digital number (DN) values of thermal (6.1) band of Landsat-7 ETM+ image (date: 27 April 2012 and pat/row: 175/32), temperature raster map of Zinav Lake was created. Relationships between secchi depth and band1/band3 values of Landsat-7 ETM+ image, and between secchi depth and chlorophyll-a were modeled by curve fit analysis. Running the produced models in GIS, secchi depth, temperature and chlorophyll-a raster maps of Zinav Lake were generated. The results showed that the lake has anoxic conditions and it exhibits eutrophic characters.

Keywords: GIS, modeling, clorophyll-a, temperature, secchi depth, remote sensing.

Zinav Gölünün Sıcaklık, Seki Derinliği ve Klorofil-a Dağılımının Landsat-7 ETM+ Görüntüsü Kullanılarak Modellenmesi ve Haritalanması

Öz: Türkiye'deki Zinav Gölünün sıcaklık, seki derinliği ve klorofil-a içerikleri Coğrafi Bilgi Sistemleri (CBS) ve Uzaktan Algılama (UA) ile modellenmiş ve haritalanmıştır. Sıcaklık (^oC), seki derinliği (m) ve klorofil-1 (mg/l) alan verileri Eylül 2011 ve Ekim 2012 tarihleri arasında göl üzerinden koordinatlı bir şekilde 5 istasyondan toplanmıştır. Seki derinliği 25 cm çapındaki Hidrobios marka seki diski ile ölçülmüştür. Sıcaklık belirlemesinde çoklu ölçüm cihazı (YSI-556MPS) kullanılmıştır. Helios- α model UV-Vis spektrofotometresi ve monokromatik metodla klorofil-a içerikleri hesaplanmıştır. Koordinatlı alan verileri ve Landsat- 7 ETM+ görüntüsünün (Tarih: 27 Nisan 2012, Satır/Sıra: 175/32) termal bandının (6.1) sayısal numaraları kullanılarak Zinav Gölünün sıcaklık raster haritaları oluşturulmuştur. Seki derinliği ve Landsat 7 ETM+ görüntüsünün band1/band3 değerleri arasındaki ve seki derinliği ile klorofil-a değerleri arasındaki ilişki uygun eğri analiz metodu ile modellenmiştir. Üretilen modelin CBS' de çalıştırılması ile Zinav Gölünün seki derinliği, sıcaklık ve klorofil-a içeriklerini ortaya koyan raster haritalar üretilmiştir. Sonuçlar gölün anoksik durumda olduğunu ve ötrofik karakter sergilediğini göstermiştir.

Anahtar Kelimeler: CBS, modelleme, klorofil-a, sıcaklık, seki derinliği, uzaktan algılama.

1. Introduction

Water is fundamental to human life and the health of the environment. Good water quality can support a rich and varied community of organisms and protects public health. For these reasons, water quality measurements and interpretations have a high priority for monitoring and protection of the water ecosystems (Gleick, 1998).

Besides, studies related to water quality can be more effectively conducted by using modern satellite technologies. Remote sensing is one of the developed technologies that supplies great advantage for water quality studies. Nowadays, the usage of satellite imagery plays an important role in the wetland and lake studies related to water quality (Abdullah et. al., 2002; Allee and Johnson, 1999; Baban, 1993; Dekker and Peters, 1993; Ekstrand, 1992; Ritchie et. al., 1990; Doxaran, 2002).

Monitoring of lakes with satellites is a useful tool that has a good potential to monitor some water quality parameters such as chlorophyll, total suspended solids, minerals, and dissolved organic matters (Mayo et. al., 1995; Zhang et. al., 2002). Secchi disk is one of the most important water quality measurements and has a direct relationship with spectral-radiometric monitoring of lakes. In the lakes where water clarity suppressed by an excess of phytoplankton, chlorophyll and satellite observations also show high correlation (Olmanson et. al., 2001). Landsat-7 Enhanced Thematic Mapper Plus (ETM+) sensors have been providing near-continuous multispectral coverage with 16 day temporal resolution since 1982. This remarkable temporal coverage supplies the perfect data set for studies of natural resources for improved management, and contains thermal infrared (band 6.1) data that can be transformed to temperature (Moran et. al., 2001). Zinav Lake located in Kelkit Basin in Tokat Province, Turkey. It has regional and national importance because of its natural structure, biological diversity, and unique landscape. Zinav Lake is the biggest natural lake of Kelkit Basin. Monitoring the lake`s water quality is extremely important for sustainable management. For this reason, this study aimed to model and map the temperature (°C), secchi depth (m), and chlorophyll-a (mg/l) variables of Zinav Lake by using field data, geographic information systems (GIS) and Landsat-7 ETM+ image.

2. Material and Methods

This study was conducted in Zinav Lake which is located in the Central Black Sea Region of Turkey. The Zinav Lake is situated in the northwest district of Reşadiye county of Tokat province in Turkey, and covers 0.34 km^2 surface area. The average depth of the lake is 10-15 meters. The precise position of study area can be described as between the 37o16’5”-37o16’35” East longitudes and 40o26’35”-40o27’10” North latitudes (Figure 1) Because of the smallsurface area (0,34 km2), total 5 sampling stations were determined as enough to represent the upper, middle and lower sections of the Zinav Lake. These stations can be summarized as (1) Zinav Creek entrance (littoral zone in north), (2) middle of the lake, (3) near the west shore of the lake, (4) near the east shore of the lake, and (5) Zinav Creek exit (littoral zone in south) (Figure 1).

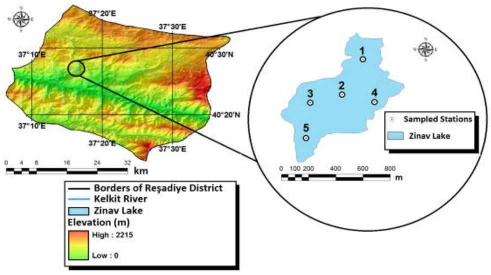

Figure 1. Borders and topography of Reşadiye county of Tokat province, location of Zinav Lake, and sampled stations on Zinav Lake.

Şekil 1. *Tokat ili Reşadiye ilçesinin sınırları ve topografyası, Zinav Gölü`nün lokasyonu ve Zinav Gölü`nde örneklenen istasyonlar*

Field sampling studies were conducted in monthly basis between September- 2011 and October-2012. Samples were taken in the first available day (between 15th-25th days) of each month. Secchi depth (m) was measured by Hidrobios brand secchi disc with 25 cm diameter. A multi-measuring device (YSI-556MPS) was utilized to determine temperature (°C) values. Chlorophyll-a (mg/l) was measured by using Helios-α model UV-Vis spectrophotometer and monochromatic method.

Although field data are available for each month, finding cloud free Landsat-7 ETM+ images that were taken close to our sampling dates is not so easy. We found only one available cloud free Landsat-7 ETM+ image taken on 27 April 2012 (path/row: 175/32) in the image archive of U.S. Geological Survey Earth Resources Observation and Science (EROS) Data

Center. The date of this image was found very close to our sampling conducted on 23 April 2012. Therefore, we downloaded the image with its ortho-geocover attributes, and evaluated our field data with this image.

Because of a technical problem in the scan line corrector (SLC) of Landsat-7 ETM+ satellite, images acquired after 31 May 2003 have gaps that need to be filled. For this reason, the gaps of the downloaded Landsat-7 ETM+ image were corrected by using a gap fill method developed by Bustillos (2012) before analyzing. Basically this method based on a software script that can be run in ERDAS Imagine software (ERDAS, 2003). After this correction, the thermal band (band 6.1) of the Landsat-7 ETM+ image was subset to obtain the area of interest (AOI) by using a vector AOI that was created from the map of Zinav Lake (Figure 1). Consequently, a subset image of the thermal band was created.

Subset image of the thermal band was transformed to point data in ArcGIS (version: 9.3.1) software (ESRI, 2005) by using conversion tools (from raster to point). Geographic references (X and Y values) were assigned to the generated point data by using data management tools/features of ArcGIS. Points having zero values were erased to avert calculating errors. The final point data were exported to Microsoft Excel software, and the cell values as radiance were calculated by using Spectral Radiance Scaling Method (Coll et. al., 2010) that was explained below.

$CV_{R1} = ((LMAX_\lambda - LMIN_\lambda) / (QCALMAX - QCALMIN)) * (QCAL - QCALMIN) + LMIN_\lambda$

In Spectral Radiance Scaling Method: CV_{R1} is the cell value as radiance; QCAL is band-6 pixel (DN) value, $LMIN_\lambda$ is spectral radiance scales to QCALMIN ($LMIN_\lambda$ = 1.2378), $LMAX_\lambda$ is spectral radiance scales to QCALMAX ($LMAX_\lambda$ = 15.303), QCALMIN is the minimum quantized calibrated pixel value (typically = 1); QCALMAX is the maximum quantized calibrated pixel value (typically = 255). The calculated cell values as radiance were converted to temperature as Kelvin (^oK) in the Excel software. The formula used to convert radiance to temperature (^oK) without atmospheric correction is:

$T= K_2/\ln((K_1*\varepsilon/CV_{R1})+1)$

where: T is temperature as Kelvin (^oK); CV_{R1} is cell value as radiance; ε is emissivity (typically = 0.95), K_1 is the fixed value (666.09 for Landsat-7 ETM+), K_2 is the fixed value (1282.71 for Landsat-7 ETM+) (Coll et. al., 2010).

Using the following formula, Kelvin (^oK) values were converted to Celsius (^oC) in Excel software. After calculating temperature values as Celsius (^oC), point data were converted to temperature raster maps by using conversion tools (from point to raster) in ArcGIS.

$^oC = {}^oK - 273.15$

We utilized the methodology explained in Image Processing Protocol for Regional Assessments of Water Quality (Olmanson et. al., 2001) to calculate secchi depth (m) of Zinav Lake. For this aim, all downloaded Landsat -7 ETM+ image bands (bands 1-8) in TIFF format were stacked and converted to an image (img) file in ERDAS Imagine software (ERDAS, 2003). Then, outside of the lake surface area was excluded from the image by masking. Using masked image and the map calculation functions of ArcGIS, band-1 values were divided by band-3 values. We used the point shape file of sampled stations to extract the digital number (DN) values of band1/band3. We did this extraction in ArcGIS by overlaying the point shape file of stations on the band1/band3 raster map. Consequently, we created a spatial analysis data file including measured secchi depth (m) and detected (DN) values of band1/band3, and exported these data in a Microsoft Excel file. Using the exported data, relationship between secchi depth and band1/band3 values of Landsat-7 ETM+ image was modeled by curve fit analysis in SPSS software (SPSS, 2007). Before curve fit analysis, natural logarithm was applied to secchi depth (April) measurements at sampling stations in order to develop a robust model. Relationship between secchi depth and chlorophyll-a was also modeled by curve fit analysis in SPSS software (SPSS, 2007). Running the produced models in GIS, secchi depth (m) and chlorophyll-a (mg/l) raster maps of the Zinav Lake were created for April.

3. Results

Temperature raster map, created from Landsat-7 ETM+ thermal band (6.1), was shown in Figure 2. According to temperature raster map, temperatures were varied between 29.9 and 14.7 oC on 27 April 2012. In spatial point of view, temperature values were found highest in the south of the Zinav Lake. Moreover, temperature values were found relatively high in near-shore areas.

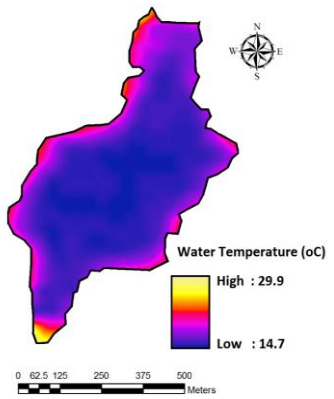

Figure 2. Temperature raster map of Zinav Lake on 27 April 2012

Şekil 2. *Zinav Gölü`nün 27 Nisan 2012`deki sıcaklık raster haritası*

The created regression models were given in Figure 3a and Figure 3b. The result of curve fit analysis with the second order showed that there was a strong relationship (R2=0.8995) between DN values of band1/band3 variables and natural logarithm of secchi depth (Figure 2a). Secchi depth and chlorophyll-a were also showed an exact relationship (R2=1.00) that means 100% (Figure 2b). These results implied that secchi depth can be safely calculated and mapped by using DN values of band1/band3 of Landsat-7 ETM+ imagery, and chlorophyll-a can be estimated and mapped by utilizing calculated secchi depth values. Secchi Depth (Figure 4a) and Chlorophyll-a (Figure 4b) raster maps, derived from the models, produced the parallel results to each other due to the strong (R2=1.00) relationship between those variables.

Secchi depth values were changed between 0.00-1.17 m (Figure 4a), while Chlorophyll-a varied between 98.54 and 8.64 ml/l (Figure 4b).

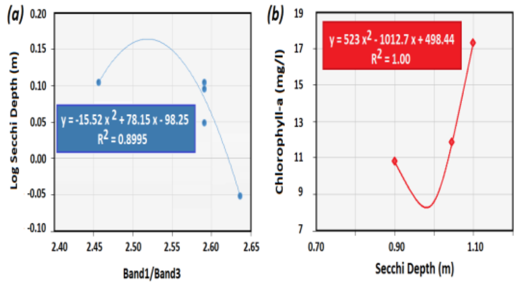

Figure 3. Developed models, scattergrams and polynomial trend lines of Log Secchi Depth (a) and Chlorophyll-a (b) in the second order (NOTE: Log Secchi Depth (m) and Chlorophyll-a (ml/l) were accepted as y (dependent variables) in the developed models).

Şekil 3. *Log Seki derinliğinin (a) ve Klorofil-a`nın (b) ikinci derecede geliştirilen modeleri, saçılım diyagramları ve çok terimli eğilim çizgileri (NOT: geliştirilen modellerde Log Seki derinliği (m) ve Klorofil-a (ml/l) y (bağımlı değişkenler) olarak kabul edilmiştir.*

From shore to interior, Secchi Depth values were increased, and the highest (1.17) secchi depth values were reached in the middle part of Zinav Lake. However, chlorophyll-a values decreased from shore to interior.

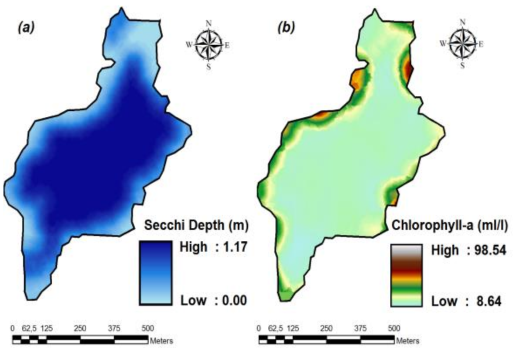

Figure 4. Secchi depth (a) and Chlorophyll-a (b) model raster maps of Zinav Lake.

Şekil 4. *Zinav Gölü`nün seki derinliği (a) ve Klorofil-a (b) model raster haritaları*

4. Discussion

Temperature, secchi depth, and chlorophyll-a are the key factors in aquatic ecosystems

(Dennison, 1993). An increase in water temperature causes a decrease in dissolved oxygen that is the main reason of high physiological demands and stress (Poff and Allan, 1995; Dukes and Mooney, 1999; Simberloff, 2000; Jackson and Olden, 2001). Secchi depth is a measure of water clarity (Preisendorfer, 1986). Higher values of secchi depth indicate clear water that lets light penetrate more deeply into the lake. This light allows photosynthesis to occur and oxygen to be produced (Harrington and Schiebe, 1992; Burns et. al., 2005). Chlorophyll-a is a specific form of chlorophyll used in oxygenic photosynthesis. It absorbs most energy from wavelengths of violet-blue and orange-red light. This photosynthetic pigment is essential for photosynthesis in eukaryotes, cyanobacteria and prochlorophytes because of its role as primary electron donor in the electron transport chain (Ever and Eichhorn, 2005).

GIS and RS tools gained great importance for the modeling and mapping processes of temperature, secchi depth, and chlorophyll-a (Giardino et al., 2001). Robust temperature data that belong to different dates can be obtained from the thermal (6.1) band of Landsat-7 ETM+ image, and it is possible to convert these reliable data to temperature raster maps by following Spectral Radiance Scaling Method (Coll et. al., 2010). Therefore, we easily produced temperature map of Zinav Lake by these available data and method. Moreover, Image Processing Protocol for Regional Assessments of Water Quality (Olmanson et. al., 2001) has also a potential to calculate secchi depth, and reported a strong relationship between secchi depth and band1/band3 values of Landsat-7 ETM+ image. Accordingly, our study produced similar results that enabled us to produce a robust model for secchi depth. Moreover strong relationship between secchi depth and chlorophyll-a also gave a chance for modeling and mapping secchi depth.

5. Conclusions

This study proved that continuous spatial data obtained from Landsat-7 ETM+ imagery constituted a good basis to model and map temperature, secchi depth, and chlorophyll-a variables in the Zinav Lake. Considering strong relationships (high R2 values), models were found to be robust. These models might be valid for the lakes of similar locations. On the other hand, higher resolution hyperspectral images obtained from Rapid Eye (5 bands), WorldView-2 (8 bands), Terra–ASTER (14 bands), Project for Onboard Autonomy (PROBA)–CHRIS (18 bands), and Earth Observing-1 (EO-1)–Hyperion (220 bands), could have helped to identify the spatial relationships among the different spectra in the study area. With the usage of high-resolution hyperspectral images and more detailed field observations, important water quality properties can be more accurately modeled and mapped in the near future.

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