Mapping Water Quality by Using Satellite Imagery

Berk USTUN, Turkey

Keywords: hydrography, in situ, multiple regression, coastal zone management

SUMMARY

The main purpose of this study is to present water quality conditions at the Lake Buyukcekmece, southwest Istanbul and investigate the feasibility of IKONOS multispectral imagery for water quality mapping in this fresh water reservoir for water quality parameters (WQPs) which are NO3-N and suspended sediment (SS) concentration. Field work including water sampling and ground truth is simultaneously performed with the IKONOS satellite overpass of the March 2004. High resolution IKONOS multispectral imagery collected on March 25, 2004 is selected as remotely sensed data source for water quality mapping. Water quality models are developed by using multiple regression (MR) technique that is mostly used in many water quality studies. In the image processing step, radiometric correction procedure including conversion from DN (digital number) to spectral radiance is applied to already geometrically corrected IKONOS data. The results show that the measured and estimated values for WQPs are in good agreement with R2 values of higher than 0.95. Additionally, the resulting water quality maps show spatial distribution of WQPs for the surface water of Lake Buyukcekmece for year 2004. As a result of this study, it is suggested that future water quality measurements should be supported by current satellite images.

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1. INTRODUCTION

The importance of fresh water reservoirs which are supporting huge metropolitan areas like Istanbul will be increasing day by day. And the Lake Buyukcekmece which is a very good example for such a fresh water reservoir is therefore well worth to investigate. Although Istanbul has enough fresh water reservoirs by means of number they are not adequate nowadays due to shortage of precipitation related to the climate change. This perceivable change multiplied the inquiries about the quantity and of course quality of water amount reserved in the basins close to the settlement and industrial areas of Istanbul. These inquiries lead us to write this paper which contains the research activities during this study.

The main goal of this paper is to emphasize that the water quality mapping at the Lake Buyukcekmece is very important not only for research staff but also for inhabitants of Istanbul. It is also worth to highlight that the mapping style, usage of multi-spectral high resolution satellite image data, is very efficient if you compare with other mapping and measurement techniques. This study is the first one involving the use of IKONOS multi-spectral data and real-time in situ measurements for water quality mapping in this region and gives valuable information to interpret water quality variations over the mentioned large water area with the help of high resolution satellite image data.


628000
633500
4551000
4543500
(meter, UTM Zone 35)
BLACK SEA
I S T A N B U L
MARMARA SEA
N
LAKE BUYUKCEKMECE
IKONOS-2 MS, 3/2/1
25/03/2004
0 0,5 1 2 3 km

2. METHODOLOGY

2.1 Study area

The Buyukcekmece Lake is a freshwater lake and located in the European part of Istanbul where the Karasu stream reaches the Marmara Sea. The stream was dammed to create a drinking water reservoir; during dry years less than 25% of the lake area remains flooded. Mudflats, sandbanks and reedbeds (Phragmites) have formed where silt deposition occurs. South of the dam is a brackish lake with reed fringes and islands. The lake is largely surrounded by arable land and, increasingly, industrial and residential development. Motorways cut across both ends of the lake (BirdLife International, 2006).
The surface area of the lake is 28.50 km2. The studied area captured by IKONOS-2 satellite is located between 28°31′13″-28°31′36″E and 41°06′20″- 41°06′37″N and covers a huge part of the Buyukcekmece Lake with an area of 24.37 km2 (Figure 1).

2.2 Image Processing

The remotely sensed data used for this study was a high resolution IKONOS-2 multispectral image acquired on March 25, 2004 (09:16 GMT). This georeferenced image was ordered from the Space Imaging Eurasia (INTA Space Systems, Inc.) with the ID number of 2004032509165560000011118122. After the preparation of data set by merging spectral bands, the image was radiometrically corrected to convert DNs to spectral radiance and to minimize atmospheric effects (Chavez, 1996; Lillesand et al. 2004; Ormeci and Ekercin, 2006). We used the following equation for this process (Space Imaging Eurasia, 2006):

$$L_\lambda = \frac{10^4 * DN_\lambda}{CalCoef_\lambda * Bandwidth_\lambda} \tag{1}$$

where;

Lλ : Radiance for spectral band λ at the sensor's aperture (W/m2/µm/sr),
DNλ : Digital value for spectral band λ,
CalCoefλ : Radiometric calibration coefficient [DN/(mW/cm2-sr)],
Bandwidthλ : Bandwidth of spectral band λ (nm).

CalCoefλ and Bandwidthλ for the IKONOS bands are reported by Space Imaging Eurasia (2006). The details of radiometric correction process are given in Table 1.

Table 1. *Results of radiometric correction process aiming conversion from DNs to spectral radiance for high resolution IKONOS-2 multispectral data*

Station Name		**DN** - Digital Number (Average of 5 by 5 array)					**L** - Spectral Radiance			
		Spectral Band					Spectral Band			
		B1	B2	B3	B4		B1	B2	B3	B4
	Calibration Coefficients	728	727	949	843	Band Width (nm)	71,3	88,6	65,8	95,4
1		278	282	138	80		53,56	43,78	22,10	9,95
2		320	375	232	118		61,65	58,22	37,15	14,67
3		268	281	128	94		51,63	43,63	20,50	11,69
4		279	292	139	105		53,75	45,33	22,26	13,06
5		318	374	229	119		61,26	58,06	36,67	14,80
6		255	226	120	75		49,13	35,09	19,22	9,33
7		405	547	464	288		78,03	84,92	74,31	35,81
8		278	282	138	80		53,56	43,78	22,10	9,95
9		253	242	129	74		48,74	37,57	20,66	9,20
10		321	377	219	109		61,84	58,53	35,07	13,55
11		327	409	316	210		63,00	63,50	50,61	26,11
12		347	432	310	198		66,85	67,07	49,64	24,62

** B1, B2, B3, B4 respectively indicates the Blue, Green, Red and Near infrared bands of IKONOS*

2.3 Correlating Remotely Sensed Data and Water Quality Parameters (WQPS)

In the study, multiple regression algorithm was used to explore the relationships between water quality parameters and real time IKONOS data in the study area. This algorithm can be expressed as;

$$WQP_s = A_0 + \sum_{i=1}^{k} A_i * (\mathrm{IKONOS}_i) \qquad (2)$$

where; IKONOSi is the spectral radiances of four IKONOS bands; k is the IKONOS band number from 1 to 4; A0 and Ai are the empirical regression coefficients derived using the observations from the ground truth points (Zhang et al., 2003).
The independent variables used in the multiple regression are spectral bands of IKONOS multispectral imagery; blue (B1): 0.45-0.53µm, green (B2): 0.52-0.61µm, red (B3): 0.64-0.72µm and near infrared (B4): 0.77-0.88µm. In order to remove (probable) errors result from GPS (Global Positioning System) measurements in the field work, the average digital number of pixels (5x5 array) surrounding the sample pixel was used to correlate water quality parameters with the real time IKONOS multispectral imagery having 4m spatial resolution. The level of significance, p=0.05, was used to denote statistical significances of statistical data analysis in the study.

2.4 In-Situ Data

The Buyukcekmece Lake, Istanbul which has already been confronted with the problems of industrialization and urbanization receives wastewaters from many industrial and municipalities and is influenced by a host of irrigation, agriculture and other natural variations. These waste discharges and landslides occurred around the lake (Hacıyakupoğlu, 2003; Demirci, 2001) loads high concentrations of suspended particles through the rivers connected to the lake. Therefore, Suspended Sediment (SS) was selected as physical water quality parameter for mapping water quality in the lake. NO3-N is a nutrient element in the waters and it indirectly affects water transparency. The Buyukcekmece Lake reservoir has a very high level of nitrogen. Even if NO3-N is not optically active, NO3-N data was used as a chemical water quality parameter, along with the physical water quality parameter (SS), for this case study (Bilge et al., 2003). Due to limitations on performing laboratory analysis, two parameters were tested and used in the study.
The field work involving water sampling and ground truth was carried out on March 25 of 2004. It was simultaneously performed with the overpass of the IKONOS satellite (25/03/2004 - 09:16 GMT). Taking into account the number of sampling point (and density for per km2) in the previous studies related to remote sensing (Table 2), it was decided to collect water samples at twelve points for this case study (24.37 km2) covering the huge part of the Buyukcekmece Lake (28.50 km2). These samples were used for water quality modelling (nine points) and accuracy assessment (three points). 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 attached to a laptop computer showing the situated position on the high resolution IKONOS (pan) image using ERDAS Imagine© software.

Table 2. Water sampling statistics used in some applications related to water quality modelling with remote sensing data.

Researcher	Region	Surface Area (km^2)	Number of Sample Point
Bilge et al., 2003	Porsuk Dam, Turkey	179,40	13
Gan et al., 2004	Ariake Sea, Japan	1700,00	33
Pozdnyakov et al., 2005	The Baltic Sea	~15000,00	13
Sváb et al., 2005	Lake Balaton, Hungary.	596,00	10
Wang et al., 2006	Reelfoot Lake, Tennessee	296,40	19
Zhang et al., 2003	Gulf of Finland	29600,00	53
For this case study	*Lake Buyukcekmece, Turkey*	*24,37*	*12*

3. RESULTS AND DISCUSSION

Simple regression analysis for suspended sediment (SS) and nitrogen (NO3-N), in relation to IKONOS bands are presented in Table 3. Examination of the correlations between estimated and observed values at different IKONOS bands ranged from 0.1111 to 0.9948. These results clearly show that the use of all IKONOS bands is the best selection for the development of model aiming the estimation of water quality parameters for lake water surface. Therefore, all bands of IKONOS image data were selected as the independent variable to relate water quality parameters and spectral radiance. The multiple regression algorithms which have been developed from four bands of IKONOS were applied to show patterns of water quality by applying the function to each pixel and contouring these values into classes (Ekercin, 2007).

The results indicate that the accuracy of suspended sediment (SS) and nitrogen (NO3-N) estimation by applying multiple regression algorithm is very high (R2= 0.9948 and 0.9234 respectively). Retrieved results for suspended sediment (SS) and nitrogen (NO3-N) are presented in Figure 2 and Figure 3. The developed algorithms, which are derived by using multiple regression, were verified by using in-situ measurements collected at three individual sample points for validation of the developed model (Figure 4).

Water quality maps are produced by using the derived multiple regression models and in-situ measurements collected at the stations belonging to water quality parameters which are suspended sediment (SS) and nitrogen (NO3-N). These maps present apparent spatial variations of selected parameters and inform the decision makers of water quality variations over the study area in the Lake Buyukcekmece, Istanbul.

The Lake Buyukcekmece receives wastewater directly from the municipal sewage treatment and agricultural sources. These discharges have load nutrients to the lake. The interpretations of resultant water quality maps verify this circumstance. Especially, (relatively) high suspended sediment (SS) and nitrogen (NO3-N) concentrations along the east coast of the lake indicate the discharges coming from the agricultural areas located along the east coasts of the Lake Buyukcekmece.

Table 3. Correlation (R^2) between suspended sediment (SS), Nitrogen (NO3-N) and spectral bands of IKONOS multispectral data (B1, B2, B3, B4 respectively indicates the blue, green, red and near infrared (NIR) bands of IKONOS image data).

WQPs	**B1**	**B2**	**B3**	**B4**	**B1, B2**	**B2, B3**
Suspended Sediment (SS)	0,6718	0,6531	0,7705	0,9056	0,6836	0,8161
Nitrogen (NO_3-N)	0,1111	0,0850	0,1331	0,0334	0,3644	0,2162
WQPs	**B1, B3**	**B1, B4**	**B2, B4**	**B3, B4**	**B1, B2, B3**	**B1, B2, B3, B4**
Suspended Sediment (SS)	0,8105	0,9385	0,9473	0,9412	0,8161	0,9948
Nitrogen (NO_3-N)	0,1475	0,2327	0,1412	0,6338	0,6857	0,9234

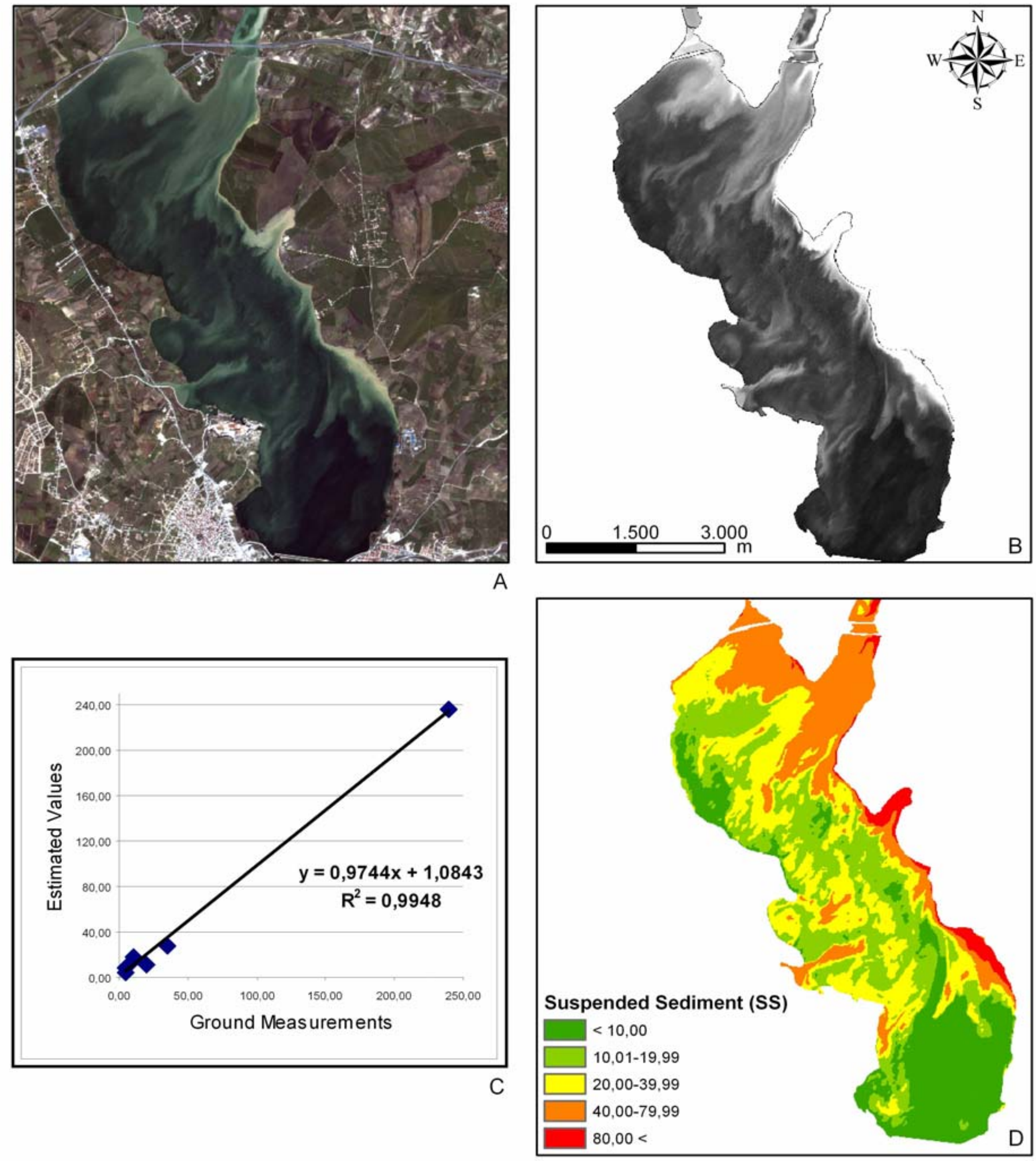

Figure 2. The details of multiple regression and water quality mapping processes for suspended sediment.

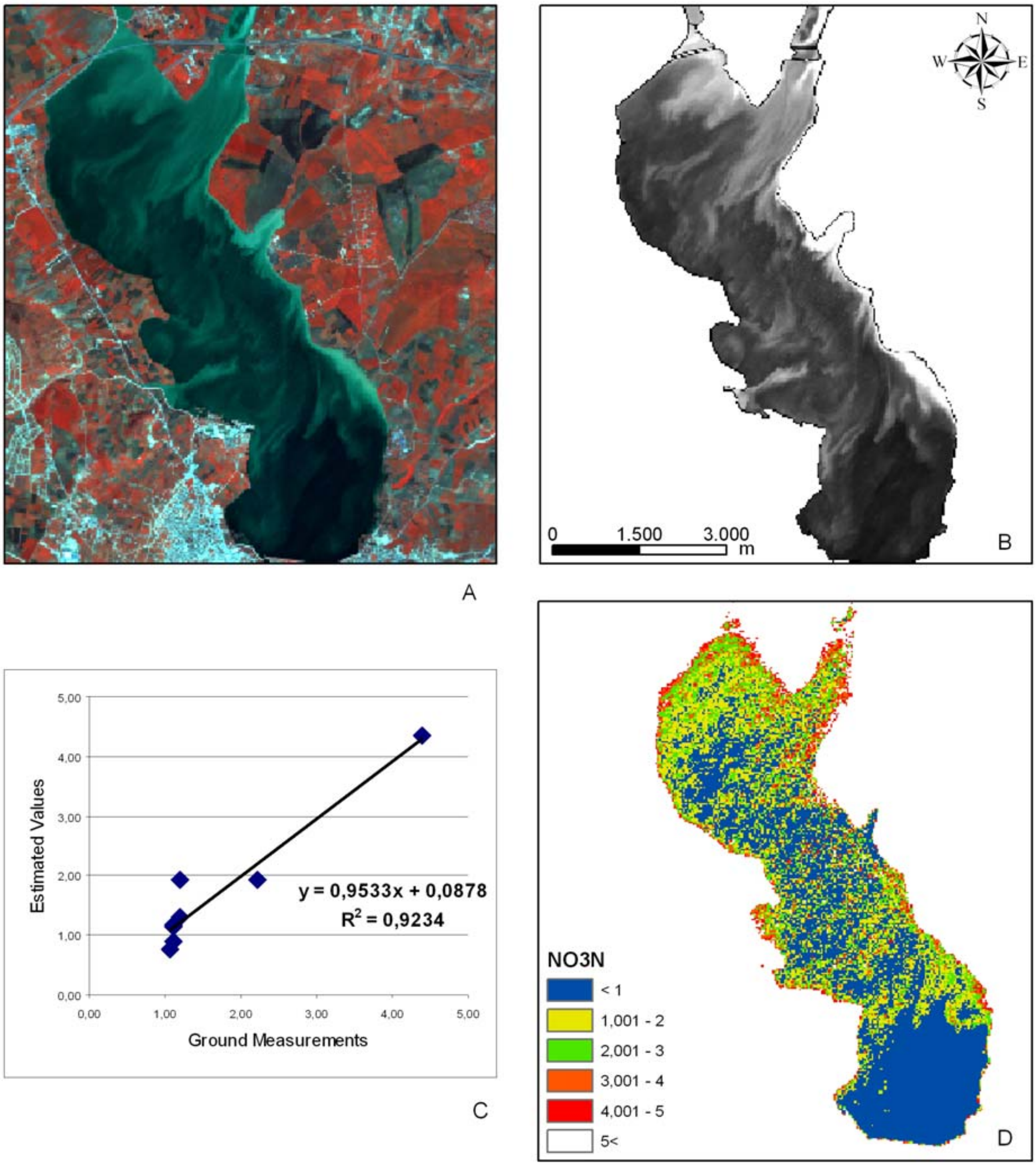

Figure 3. The details of multiple regression and water quality mapping processes for NO_3-N parameter.

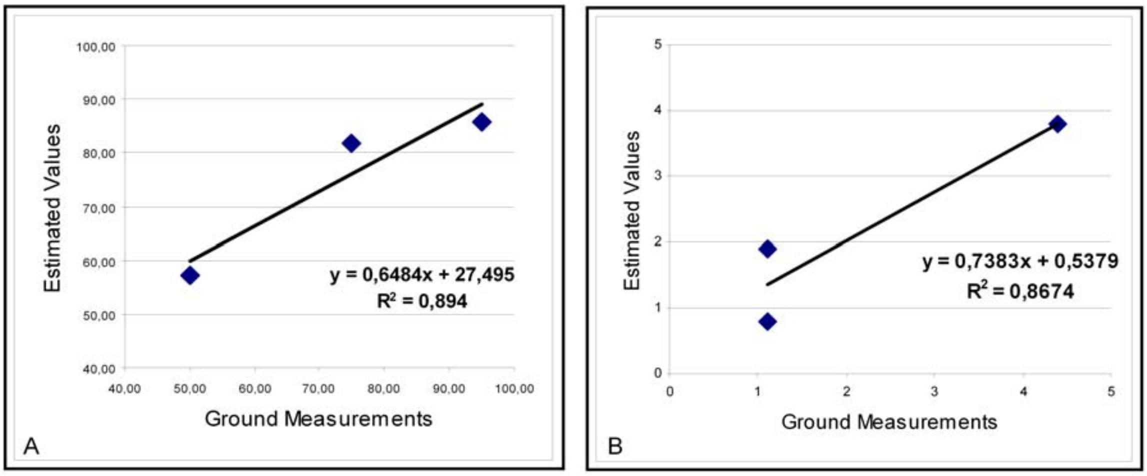

Figure 4. Verification of the developed algorithms (a) Suspended sediment (b) NO_3-N.

4. CONCLUSIONS

In this study, we examined the present water quality conditions at the Lake Buyukcekmece, southwest Istanbul and investigated the feasibility of IKONOS multispectral imagery for water quality mapping in this fresh water reservoir for water quality parameters (WQPs) which suspended sediment (SS) and nitrogen (NO3-N) concentration. Multiple regression results give significantly consistent information with very high determination coefficients.

Water quality maps which are produced in the study present apparent spatial variations of selected parameters and inform the decision makers of water quality variations over the study area in the Lake Buyukcekmece, Istanbul.

The results also addresses that the use of real time in-situ and remotely sensed data increases the reliability and accuracy of the study aiming water quality mapping.

In this study, only twelve sample points were used, so further work using more data from more sample points may be useful to strengthen these conclusions.

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