Evaluation of RapidEye-3 Satellite Data for Assessing Water Turbidity of Lake Borabey

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Abstract: In water resources management, remote sensing data and techniques are essential in watershed characterization and monitoring, especially when no data are available. Water quality is usually assessed through in-situ measurements which require high cost and time. Water quality parameters help in decision making regarding the further use of water-based on its quality. Turbidity is an important water quality parameter and an indicator of water pollution. In the past few decades, remote sensing has been widely used in water quality research. In this study, we compare turbidity parameters retrieved from a high-resolution image with in-situ measurements collected from Borabey Lake, Turkey. Here the use of RapidEye-3 images (5 m-resolution) allows for detailed assessment of spatio-temporal evaluation of turbidity, through the Normalized Difference Turbidity Index (NDTI). The turbidity results were then compared with data from twenty-one in-situ measurements collected in the same period. The actual water turbidity measurements showed high correlation with the estimated NDTI mean values with an R^2 of 0.84. The research findings support the use of remote sensing data of RadipEye-3 to estimate water quality parameters in small water areas. For future studies, we recommend investigating different water quality parameters using high-resolution remote sensing data.

Keywords: remote sensing; water quality; turbidity; turbidity index

1. Introduction

In the past few decades, remote sensing techniques and capabilities have been studied for monitoring several water quality parameters. It has been concluded that remote sensing is an effective tool for synoptic soil moisture assessment, water extends and level monitoring, water demand modeling, groundwater management, flood mapping, and water quality monitoring [1]. Thus, Sentinel-1 has been used for water resource management applications [2], Landsat-8 [3,4], and Sentinel-2 [5] have been used for water bodies extraction, MODIS (Moderate Resolution Imaging Spectroradiometer) has been used for water quality assessment [6]. Alos, Unmanned Aerial Vehicle (UAV) data have been used for water quality measurements. Landsat data have also been used for assessing detailed water quality parameters, such as suspended sediments, Secchi depth, chlorophyll-a, and turbidity [7]. Water quality parameters help in decision making regarding the further use of water-based on its quality. Turbidity, as one of the most important water quality parameters, is often measured, and it quantifies water clarity. Monitoring turbidity through remote sensing data is relevant as an indicator of the optical environment for water qulity monitoring purposes [8]. Several remote sensing studies have quantified the relationship between actual and estimated turbidity from satellite remote sensing data [9]. However, the use of middle or low spatial resolution data is not useful in monitoring small lakes, dams or rivers. Thus, in this study, we use high spatial resolution satellite data for estimating the correlation between the in situ turbidity, and turbidity estimated from RapidEye sensor. Specific objectives were: a) to retrieve turbidity from RapidEye-3, and b) to correlate satellite retrived turbidity with in-situ turbidity measurements.

2. Materials and Methods

2.1. Study Area

Borabey Lake which is located in Emirce Village on Bozdag slopes north of the Eskisehir city center was chosen as the study area in this paper. The lake covers an area of approximately 166.559 m^2 at an altitude of approximately 924 m. Borabey Dam was built between 1991–1992 by the Provincial Directorate of Rural Services at the time in order to support the local agriculture. The lake, which was allocated to be used as the Water Sports Center of Anadolu University in 1999, later was planned to be used in order to contribute to the drinking and utility water network of Eskisehir. However, in 2011 this purpose was canceled. Details about the Borabey Lake are given in Table 1 [10].

Table 1. Borabey Dam Technical Information.

Barrage Crest Length	411 m
Dam Height	23 m
Fill Volume	368.000 m^3
Irrigation Area	248 ha
Storage Volume	1600.000 m^3

2.2. Data and Methods

Water sample collections were initiated during the summer season, on August 12, 2014. Following random sampling technique, a total of 21 water samples were collected and transferred to the laboratory to perform the turbidity test (Figure 1). The remote sensing data was acquired just a few days apart, on 17 August 2014. The RapidEye instrument acquires data in five different spectral bands with a 5 m spatial resolution. Details about the RapidEye satellite image are given in Table 2.

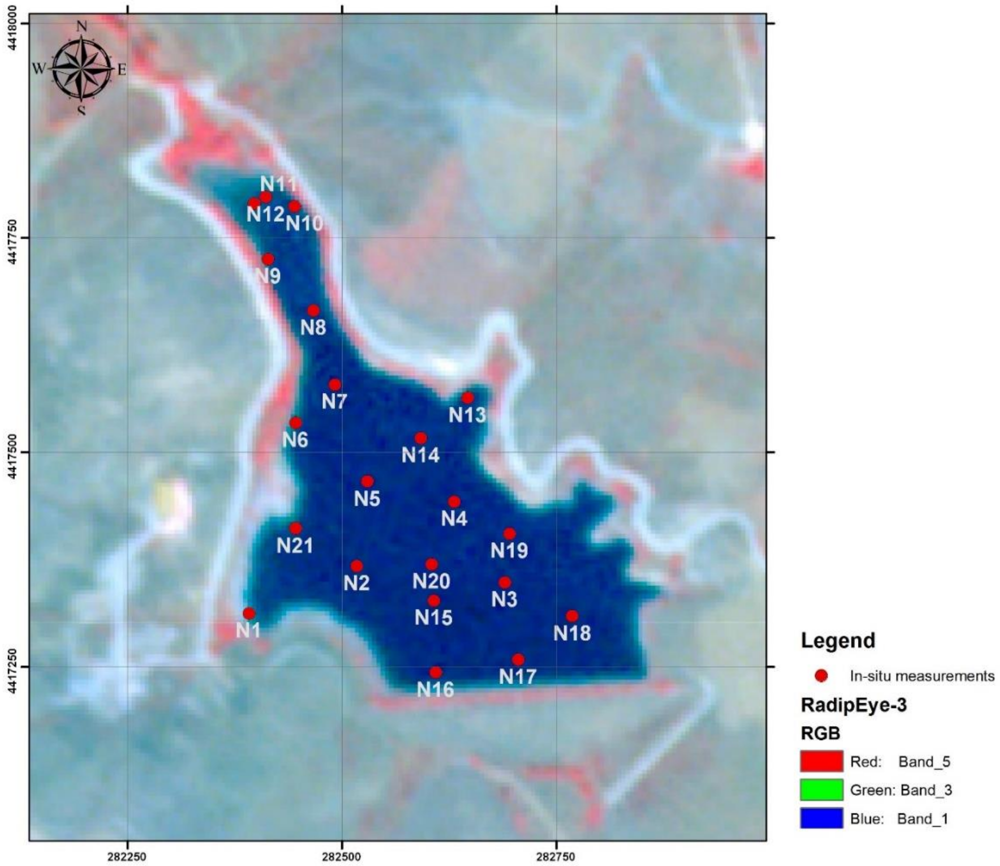

Figure 1. RapidEye-3 image of Borabey Lake, and the in-situ measurements.

Table 2. Spectral bands for the RapidEye Satellite Constellation.

Band No	Band Name	Spectral Range [μm]
1	Blue	440–510
2	Green	520–590
3	Red	630–685
4	Red-Edge	690–730
5	Near Infra-red	760–850

In order to retrieve the turbidity from the satellite image, a normalized difference turbidity index (NDTI) [11] was used in this study. The index was developed to estimate the water turbidity using remote sensing data specifically for ponds and inland waters. It can be estimated as follows:

$$\mathrm{NDTI} = \frac{Red - Green}{Red + Green} \quad (1)$$

3. Results

Statistical analyses were made in order to evaluate the relationships between the actual water turbidity collected in situ and the corresponded turbidity in reflectance values estimated from remote sensing data with the NDTI.

The in-situ water quality parameters were a few days before the in-situ measurements, but it was concluded there was no significant time difference between the in-situ sampling and remote sensing data acquisition.

Statistical analyses that included calculations of the linear regression between the two variables and normalization of the data were performed. The results of the study show that the NDTI provided strong positive correlation with turbidity in Borabey Lake ($R^2 = 0.84$). Pearson correlation analysis was used to investigate the strength of the association between the two variables with a correlation coefficient (r). Significance levels were reported to be significant ($p < 0.05$) or not significant ($p > 0.05$) with a t-test, which provides evidence of an association between the two variables. Figure 2 demonstrated the linear regression analysis of NDTI and in-situ measurements.

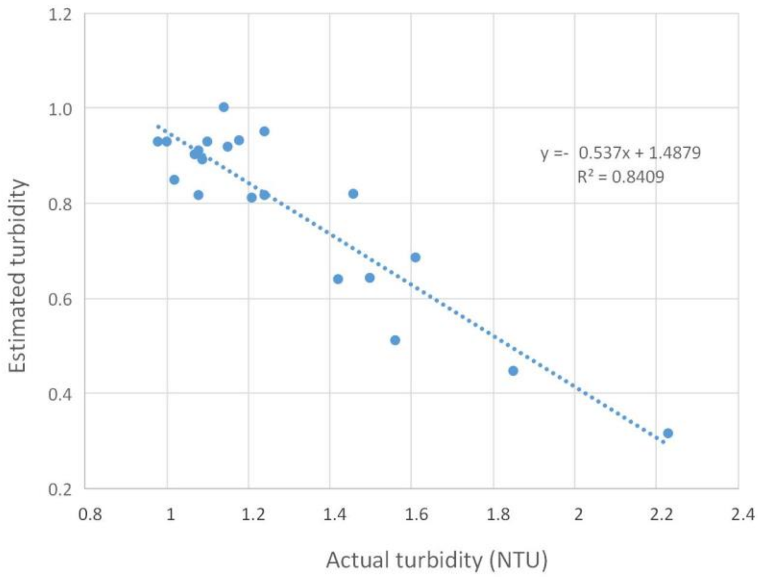

Figure 1. Correlation between estimated (NDTI) and actual turbidity.

Pearson correlation analysis showed that the correlation coefitient (r) is 0.92, with high level of significance ($p < 0.05$).

4. Discussion

The main objective of the represented study was to investigate the ability of high spatial resolution satellite data for estimating the turbidity in small water areas. For that purpose, NDTI was used for retrieving turbidity from RapidEye-3, and the results were compared with in-situ measurements collected in the same time period. The results of the study show that the NDTI provided strong positive correlation with turbidity in Borabey Lake ($R^2 = 0.84$). The results are similar to other investigations where, Masocha et al. [4], found that blue/red ratio provided strong positive relation between measured and retrieved turbidity in two different lakes ($R^2 = 0.81$; $R^2 = 0.65$). Different turbidity retrieval approach showed a good correlation for two different study areas ($R^2 = 0.87$; $R^2 = 0.66$) [12]. However, the use of NDTI showed higher correlation with the actual turbidity.

This study represents another study case that confirms the use of satellite remote sensing in water quality mapping and monitoring. The essence of the paper is the use of high-resolution satellite imagery for monitoring water turbidity in small water areas.

For future studies, we recommend investigating different water quality parameters with high-resolution satellite imagery, as well as different approaches for estimating water turbidity.

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Author Contributions: All authors contrubited equaly.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

MODIS: Moderate Resolution Imaging Spectroradiometer
UAV: Unmanned Aerial Vehicle
NDTI: Normalized Difference Turbidity Index

References

1. Andres, L.; Boateng, K.; Borja-Vega, C.; Thomas, E. A review of in-situ and remote sensing technologies to monitor water and sanitation interventions. *Water* **2018**, *10*, p. 756.
2. Amitrano, D.; Martino, G.; Iodice, A.; Mitidieri, F.; Papa, M.; Riccio, D.; Ruello, G. Sentinel-1 for monitoring reservoirs: A performance analysis. *Remote Sens.* **2014**, *6*, p. 10676–10693.
3. Kaplan, G.; Avdan U. Water extraction technique in mountainous areas from satellite images. *J. Appl. Remote Sens.* **2017**, *11*, p. 046002.
4. Masocha, M.; Dube, T.; Nhiwatiwa, T.; Choruma, D. Testing utility of Landsat 8 for remote assessment of water quality in two subtropical African reservoirs with contrasting trophic states. *Geocarto international* **2018**, *33*, p. 667–680.
5. Kaplan, G.; Avdan U. Object-based water body extraction model using Sentinel-2 satellite imagery. *Eur. J. Remote Sens.* **2017**, *50*, p. 137–143.
6. Politi, E.; Prairie, Y.T. The potential of Earth Observation in modelling nutrient loading and water quality in lakes of southern Québec, Canada. *Aquat. Sci.* **2018**, *80*, p. 8.
7. DOGAN, H.M.; POLAT, F.; BUHAN, E.; KILIÇ, O.M.; YILMAZ, D.; Buhan, S.D. Modeling and Mapping Temperature, Secchi Depth, and Chlorophyll-a Distributions of Zinav Lake by Using GIS and Landsat-7 ETM+ Imagery. *J. AgriculturalFaculty of GaziosmanpasaUniversity*, **2016**, *33*, p. 55–60.
8. Dogliotti, A.I.; Ruddick, K.G.; Nechad, B.; Doxaran, D.; Knaeps, E. A single algorithm to retrieve turbidity from remotely-sensed data in all coastal and estuarine waters. *Remote Sens. Environ.* **2015**, *156*, 157–168.
9. Ehmann, K.; C. Kelleher; Condon, L.E. Monitoring turbidity from above: Deploying small unoccupied aerial vehicles to image in-stream turbidity. *Hydrol. Processes* **2019**, *33*, 1013–1021.
10. Kaya, M. Interaction of water quality with basin components in small water bodies. *Anadolu University* **2012**, p.109.
11. Lacaux, J.P.; Tourre, Y.M.; Vignolles, C.; Ndione, J.A.; Lafaye, M. Classification of ponds from high-spatial resolution remote sensing: Application to Rift Valley Fever epidemics in Senegal. *Remote Sens. Environ.* **2007**, *106*, p. 66–74.

12. Güttler, F.N.; S. Niculescu; Gohin F. Turbidity retrieval and monitoring of Danube Delta waters using multi-sensor optical remote sensing data: An integrated view from the delta plain lakes to the western–northwestern Black Sea coastal zone. *Remote Sens. Environ.* **2013**, *132*, p. 86–101.