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OBIA based hierarchical image classification for industrial lake water

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ABSTRACT

Water management is very important in water mining regions for the sustainability of the natural environment and for industrial activities. This study focused on Acigol Lake, which is an important wetland for sodium sulphate (Na_2SO_4) production, a significant natural protection area and habitat for local bird species and endemic species of this saline environment, and a stopover for migrating flamingos. By a hierarchical classification method, ponds representing the industrial part were classified according to in-situ measured Baumé values, and lake water representing the natural part was classified according to in-situ measurements of water depth. The latter is directly related to the water level, which should not exceed a critical level determined by the regulatory authorities. The resulting data, produced at an accuracy of around 80%, illustrates the status in two main regions for a single date. The output of the analysis may be meaningful for firms and environmental researchers, and authorizations can provide a good perspective for decision making for sustainable resource management in the region which has uncommon and specific ecological characteristics.

1. Introduction

For wetlands that have fragile environments or that are under pressure from industrial activities, resource management, ecological balance and water sustainability are very important. Common environmental concerns caused by industrial activities that are close to wetlands are pollution, reduction and destruction of wetland habitat and water resources, and drying up of water areas. Beyond being close to industrial operations, a wetland or a lake can be a field of activity itself. This kind of lakes can be defined as industrial lakes. They generally are saline lakes, since salinity is an important characteristic for being a potential industrial lake. The industrial operations in these kinds of regions can be named as water mining activities. In water mining areas, monitoring the water use, determining the actual water status and the multi-temporal changes, identifying the existing and potential future problems should be of great importance. Remote sensing (RS) is an efficient tool for monitoring and analyzing the lake properties such as water level and budget, coastline change, and content (chlorophyll, suspended particular matter, salinity etc.) distribution (Ritchie et al., 2003). The advantage of using RS in management is evident: it provides a synoptic view of whole water basins, including coastal areas (Kratzer et al., 2014).

In literature, there are many studies of using RS efficiently for analyzing water properties, and moreover integrating the results with hydrological models. For example Jordan et al. (2014) has performed a study to explore the implication of vegetation dynamics on soil erosion and total suspended sediment (TSS) loading to surface rivers. Their study showed spatial and temporal trajectories of land cover/land use change (LCLUC) derived from satellite data are combined with hydrological modeling. There are conceptual models developed to integrate RS data into coastal zone management such as done by Kratzer et al. (2014). There are also many studies of lake salinity. Wang and Zhao (2012) examined the salinity of the Gasikule Salt Lake in China using high resolution RS data. Using traditional salinity estimation methods that employ in-situ spectral measurements and Spot 5 satellite images, they proposed a multi-dimensional salinity index and they found that it allowed good assessment of the mineral resources of the lake. There are studies using comparatively newer methods. Bertani et al. (2010) discriminated between saline and non-saline lakes using object-based image processing (Bertani et al., 2010). By applying a process-based classification they concluded that the object-based method was suitable for their study. Yue et al. (2010) also performed object-based classification of Spot 5 satellite images and used Support Vector Machine (SVM) classification, which allowed them to make a comparison that showed that object-based classification was superior to pixel-based classification.

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It is an important fact that over the past century, mineral extraction have had great impacts on saline lakes globally (Tweed et al., 2011) and they are being investigated. To minimize these effects, industrial activities in such areas must be done with consideration of the lake environment as a whole. Overviewing the previous studies, it was recognized that there is a gap in combined analysis of the industrial and natural region statuses of industrial lakes.

In this study, Acigol Lake was examined, which is a natural protection area in Turkey. In addition to being a habitat for local birds and endemic species, and a stopover for migrating flamingos, it is also the major sodium sulphate (Na_2SO_4) production resource. The Na_2SO_4 and sodium chloride (NaCl) production in this lake is carried out using the artificial ponds placed inside the lake. Lake water is transferred to the ponds for evaporation stage depending on the Baumé values, which is the density of dissolved salt and used as the criteria for decision making. Within this context, Lake Acigol consists of two main parts: Lake-water area (considered to be the natural region) and pond area (considered to be the industrial region), where the natural region is the resource for the industrial region. In the study, considering these two main regions, satellite RS image was used to create water status map using the in-situ depth & Baumé measurements as reference and test data.

As the approach of satellite data processing, object-based image analysis (OBIA) was preferred. OBIA approach has a promising methodology because it is close to human perception, which starts with segmenting the image into homogeneous regions that approximately correspond to real-world objects (Baatz et al., 2004), and continue with classifying them according to the calculated object properties such as texture, shape, layer-based values and context of the object (Blaschke, 2008). The dissatisfaction with pixel-by-pixel image analysis was mentioned in the literature recently (Cracknell, 1998; Blaschke and Strobl, 2001) and OBIA, a comparatively new approach that has been built on older segmentation, edge-detection, feature extraction and classification concepts has begun to be preferred widely (Blaschke, 2010) instead. It has many advantages and it is becoming more popular compared to conventional pixel-based methods as claimed in the recent articles (Gamanya et al., 2009). The main reason to prefer this approach is having the possibility of detecting targets bigger than pixels and classifying them. Additionally this brings the availability of using intrinsic characteristics of the objects, such as texture, geometry and spectral properties and also using contextual or spatial behavior through neighborhood or topological relationships between objects (Benz et al., 2004).

For Acigol, a hierarchical classification (HC) method based on OBIA approach was applied. The HC can be defined as a classification procedure that comprises a rule-based decision system. Using OBIA based HC, the ponds were classified according to Baumé values, and the lake water was classified according to water depth, which is directly related to the water level. The water level is an important parameter because its value has to be kept within acceptable limits for the sustainability of the lake and the natural life of the wetland, and it is an indicator for the current and ongoing operationality of the industrial activity going on in the area. It has to be mentioned here that, water level is critical to maintain chemical balance as well as it is crucial to ecological balance, since water decrease also means the increase in ion concentration.

It is thought that water drawing, which today is done by just considering the pond status by the firms, has to be done with consideration of the lake water status as well. Regulatory authorities have to prepare legislation mandating that the decisions have to be taken with consideration that water consumption cannot exceed a critical level that is determined by the regulators.

This study aimed to offer an easy and practical method for obtaining knowledge about the whole water status at a time. The obtained results are acceptable, meaningful and promising for the public and private sectors as well as for the researchers seeking to provide a clear vision of how to achieve sustainable resource management of the wetlands, which are vitally important for all natural life in the region. As remarked in the literature, RS analysis, when applied to hydrology, is best embedded in Hydrologic Geographical Information Systems (HGIS) (Meijerink and Mannaerts, 2000), the results of this study can be integrated in HGIS and effectively used for illustration of scenarios such as how water levels can be affected by water drawing for ponds, and also for discussion of limits of the lake's potential.

2. Study area

In this study, a hyper-saline lake Acigol was chosen as the study site. The lake, which is located between 37°55′27.98″ and 37°45′7.41″ northern latitude and 30° 0′17.24″ and 29°41′11.72″ eastern longitude, is in the border region of Denizli and Afyon provinces (Figs. 1 and 2).

Acigol Lake is at the center of a 1609 km^2-wide lake-basin area (Akar et al., 2012) at an altitude of 836 m (EIEI, 2005). Acigol Lake is categorized as shallow water, which is defined as having an unstable and dynamic hydrologic structure that causes continuous and instant variations by Ali and Khairy (2012). Although this area features predominantly Mediterranean climate, it is influenced by continental climate in the winter; therefore the climate of the area is defined as semi-arid (Erinç, 1967; Sungur, 1974; Ozdemir and ve Bahadir, 2009). According to the Turkish State Meteorological Service (TSMS), maximum and minimum long-years' monthly average air temperature was recorded in July with 34.4 °C and in January with 2.1 °C, respectively. Maximum and minimum long-years' monthly average total precipitation was recorded in December to be 93 mm, and in August to be 8.4 mm, respectively. According to TSMS data, the regional wet season starts with the beginning of October and the regional dry season starts with the beginning of June.

The lake is primarily fed by the Kocacay Stream, but during the wet season the Akpinar and Gemis Springs also feed into it (Karaman et al., 2011b). The water output of the lake consists of evaporation and water drawing for industrial purposes (Karaman et al., 2011c). According to the ongoing project CAYDAG-110Y255 (CAYDAG-110Y255, n.d.), since 2010, the maximum and minimum depth of the lake was measured as 2.3 m (wet season in 2012) and 1.48 m (dry season in 2012), respectively. The lake area was measured as 68.12 km^2 in 2010, and the water volume was estimated to be 9,905,4305.16 m^3 according to Tasdelen et al. (2010).

Acigol is the primary sodium sulphate production lake in Turkey (Gundogan et al., 1995; Karaman et al., 2011a; Helvaci et al., 2013). In Fig. 2, both the natural and the industrial areas of the lake can be seen clearly. In addition to being an industrial lake, Acigol is also a very important natural protection area because it is a stopover for migrating flamingos (*Phoenicopterus ruber*) (Kahraman, 2007), and it is a substantial habitat for the local bird species, which feed and breed in this saline environment (Özesmi et al., 2008; Balkız et al., 2009). It has been categorized as one of the focus regions in the Important Bird Areas of Turkey project, which is conducted by the Investment and Management Directorate of the Ministry of Culture and Tourism (URL-1).

2.1. Chemical characteristics

Acigol is a hyper-saline lake with a brine composition of Na–Cl–SO_4 (Budakoğlu et al., 2014; Mutlu et al., 1999; Helvaci et al., 2013). It is alkaline (pH 8.0–8.6) and contains dissolved sulphate at around 258.68 meq/l (Tasdelen et al., 2010). In 2010, it was calculated that the lake contains 1,230,740 tons of dissolved sulphate (Tasdelen et al., 2010). The high sulphate content is based on the transportation of sulphate minerals to the lake from surrounding geological sites such as springs and also from groundwater (Karaman et al., 2011a). Another source is the chemical sulphate-reduction and oxidation process of bacterial activation that evolves on gypsums on the lake floor (Mutlu et al., 1999; Akarsubaşı et al., 2011; Helvaci et al., 2013). The ion concentration reaches its maximum during the summer because of evaporation, and it decreases during the precipitation seasons. Considering the size