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## RESEARCH PAPER

# Monitoring olive mills waste disposal areas in Crete using very high resolution satellite data

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### KEYWORDS

Olive mill disposal areas;  
 Remote sensing;  
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**Abstract** This paper evaluates the efficiency of different image analysis techniques applied to high resolution multispectral satellite data so as to identify olive oil waste disposal areas in the island of Crete where huge quantities of wastes are produced. For this purpose very high spatial resolution images including Pleiades, SPOT 6, QuickBird, WorldView-2 and GeoEye 1 have been exploited. The research included the application of the Normalised Difference Vegetation Index, Olive Oil Mill Waste Index as well as Principal Component Analysis. Moreover Intensity–Hue–Saturation transformation was carried out. Furthermore, unsupervised classification was performed for a variety of classes (5; 10 and 15) over the same area for two different periods. In addition, supervised linear constrained spectral un-mixing technique has been applied for the WorldView-2 image, to evaluate the potential use of sub-pixel analysis. Indeed, as it is demonstrated NDVI and OOMW indices may be used to enhance the exposure of disposal areas in high resolution satellite datasets, while the application of the PCA and HIS transformations seems to be able to further improve the results. Unsupervised classification techniques, with no ground truth data, can sufficiently work; however temporal changes of the disposal areas can affect the performance of the classifier. The use of spectral library was able to detect OOMW areas with a relatively high rate of success improving the results from the unsupervised classification. Finally, a COSMO-SkyMed radar image has been examined and fused with a hyperspectral EO-ALI image, indicating that such kind of datasets might be also explored for this purpose.

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## 1. Introduction

Olive oil industry is very important in Mediterranean countries, both in terms of wealth and tradition and it is considered to be as one of the driving sectors of the agricultural economy of the Mediterranean basin. The annual production in the Mediterranean region is estimated up to  $2600 \times 10^3$  tones (International Olive Council), whilst Greece to third world after Spain and Italy (Asfi et al., 2012; Roig et al., 2006).

However, the production process of olive oil may cause significant environmental problems since olive processing produces large amounts of solid waste and wastewater with high organic load and rich inorganic constituents (Dermeche et al., 2013; Doula et al., 2014; Alexakis et al., 2016; Peikert et al., 2015; Pavlidou et al., 2014). For instance, uncontrolled land disposal of olive oil mill waste water (OOMW) can potentially result in soil pollution as a consequence of its high chemical and biochemical oxygen demand in addition to high concentration of phytotoxic phenolic compounds (Peikert et al., 2015). In addition, several studies have shown the negative impact of oil wastes on soil microbial populations (Paredes et al., 1987) or on aquatic ecosystems (Dellagreca et al., 2001). Inappropriate disposal of olive husk and olive mill wastewater creates environmental problems such as odour and ammonia released into the atmosphere and leaching of inorganic and organic substances to the soil as well as leaching of these pollutants into the ground water (Rodis et al., 2002).

Therefore, as Bailey et al. (2002) argue safe disposal of wastes is very important with our culture, since we can no longer simply throw things away in random locations. Remote sensing technologies have been widely used as a systematic tool for mapping land use and land cover changes (Hegazy and Kaloop, 2015; Rawat and Kumar, 2015). Information on land use/cover and possibilities for their optimal use is essential for the selection, planning and implementation of land use

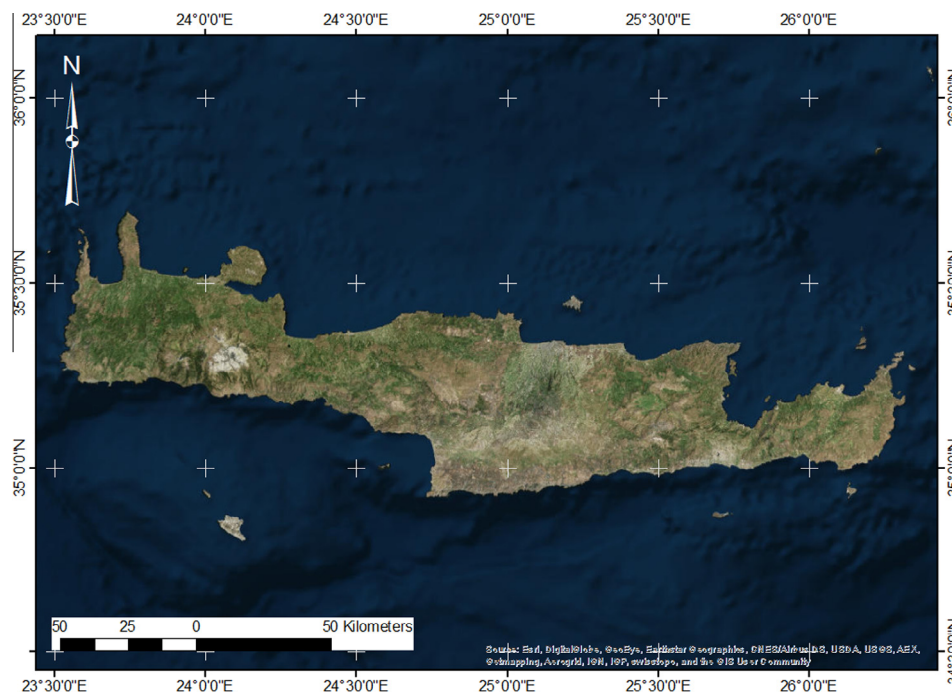
schemes to meet the increasing demands for basic human needs and welfare (Rawat and Kumar, 2015). Remote sensing images have been exploited in the last years for environmental application (Hegazy and Effat, 2010; El-Asmar et al., 2013) as an effort to detect and map olive oil waste disposal areas (Alexakis et al., 2016; Agapiou et al., in press, 2015). The results of these studies suggest that multispectral satellite data as well as spectral libraries can be used sufficiently as a systematic tool for monitoring olive oil disposal areas.

In the island of Crete, the management of olive oil waste disposal areas remains a critical and unsolved problem, especially in regions where huge quantities of wastes are produced. The aim of this study is to evaluate a variety of remote sensed data that could be used to monitor the olive mills waste water disposal areas using known image techniques. For this task the paper aims to investigate further the potential use of very high resolution satellite images for their capability to detect such areas. A variety of post-processing techniques have been applied including vegetation indices; PCA and IHS transformations, as well as classification analysis.

## 2. Methodology and resources

### 2.1. Study area

For the aims of this paper the island of Crete was selected as a case study. During the last quarter of the century, olive groves have expanded constantly in many semi-mountainous and coastal areas mainly in Crete and Peloponnese (Camarsa et al., 2010). Crete, located in the southern part of the Aegean Sea, is the fifth largest island of the Mediterranean Sea, and the largest island of Greece (Fig. 1). Crete spans 260 km from east to west while its widest point is around 60 km. Crete covers an area of approximately 8336 square kilometres while the climate



**Figure 1** The island of Crete used as a case study. In this island more than 1000 OOWM disposal areas have been recorded.

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