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Crop type mapping in a highly fragmented and heterogeneous agricultural landscape: A case of central Iran using multi-temporal Landsat 8 imagery

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ABSTRACT

Crop type mapping and studying the dynamics of agricultural fields in arid and semi-arid environments are of high importance since these ecosystems have witnessed an unprecedented rate of area decline during the last decades. Crop type mapping using medium spatial resolution imagery data has been considered as one of the most important management tools. Remotely sensed data provide reliable, cost and time effective information for monitoring, analyzing and mapping of agricultural land areas. This research was conducted to explore the utility of Landsat 8 imagery data for crop type mapping in a highly fragmented and heterogeneous agricultural landscape in Najaf-Abad Hydrological Unit, Iran. Based on the phenological information from long-term field surveys, five Landsat 8 image scenes (from March to October) were processed to classify the main crop types. In this regard, wheat, barley, alfalfa, and fruit trees have been classified applying inventive decision tree algorithms and Support Vector Machine was used to categorize rice, potato, vegetables, and greenhouse vegetable crops. Accuracy assessment was then undertaken based on spring and summer crop maps (two confusion matrices) that resulted in Kappa coefficients of 0.89. The employed images and classification methods could form a basis for better crop type mapping in central Iran that is undergoing severe drought condition.

1. Introduction

The availability of air-space born infrared imagery in the aftermath of the World War II (Aronoff, 2005) as well as by the launch of Landsat 1 (formerly ERTS-1) in 1972 (Gupta, 2003), which was originally designed for the earth's green cover monitoring, marked the dawn of a new era in the study of agriculture. According to the reflective behavior of green cover to the electromagnetic spectrum, infrared images consider as the most important tools for detecting and analyzing the integrity and resilience of vegetation cover (Aronoff, 2005; Jensen, 2009). To date, various satellite platforms and sensors have been launched to study the current land surface conditions, resulting an expanded pool of knowledge on the potential of remote sensing for investigating agro-environmental systems (Foerster et al., 2012), food security and land resource management (Khan et al., 2010).

Remote sensing studies of agricultural landscapes can be categorized into three main groups from the standpoint of spatial resolution (pixel size). The first category includes studies that monitor the dynamics of agricultural lands at a regional scale and cover an enormous extent employing imagery data with coarse spatial resolution (>250 m, e.g., VGT sensor and MODIS) (Khan et al., 2010). The second group includes studies on the identification and classification of different crop types (Aronoff, 2005). Nowadays, this line of study has attracted considerable attention in which the researches employ imagery data with medium spatial resolution between approximately 10 m such as Spot imagery (Doraiswamy et al., 2004) and 30 m such Landsat data (Akbari et al., 2006). Based on the last category, fine spatial resolution imagery are dominant data type that are used to detect and monitor various forms of field in situ conditions including soil moisture, crop freshness, disease and grass weeds (Wu et al., 2007; López-Granados et al., 2006). In this case, imagery data should be selected at spatial resolution of less than five meters (e.g., QuickBird, IKONOS, and OrbView) through imagery data at centimeter spatial resolution which are - taken by aircraft sensors. The collected information through 3S technologies (RS, GIS and GPS) (Seelan et al., 2003) can assist the

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researchers to generate precise and spatially explicit data for agricultural land use management and planning, which is known as Precision Farming or Site Specific Crop Management (Aronoff, 2005).

The studies within the second group play a central role in agricultural land use management. They could realistically answer the question of where "what" is being cultivated? (detection of crop types and in their corresponding locations) (Khan et al., 2010). However, agricultural landscapes has been characterized as the most complex and dynamic land cover pattern to be classified using medium spatial resolution imagery data. This is mainly due to the variation in geometry and size of agricultural fields and different combination of crop types, which lead to a high proportion of mixed pixels (Wu and Li, 2012), as well as high variability of phenological stages of crop types such as early or delay sprouting, establishment and maturation related to farming practices and environmental factors.

Low efficiency of common classification algorithms (parametric and non-parametric classifiers) in categorizing crop types from single-date images (Foerster et al., 2012) has raised the idea of developing methods which are based on linking the spectral behavior and satellite-derived reflectance values of crop types over a growing season (Odenweller and Johnson, 1984). This approach requires field-based identification of overall pattern of growth stages and spectral behavior of crop types throughout a growing season, which is known as spectral-temporal profiles, and afterwards acquiring multi-temporal imagery data which are in coincidence to where a certain crop type represents a distinctive spectral characteristic and/ or follow a unique spectral-temporal profile.

Landsat, amongst the growing number of satellites in this class, provides the most popular and applicable imagery, and in many cases, its ability in the study of agricultural landscapes has been successfully proven. For example, Foerster et al. (2012) used multi-temporal Landsat TM and ETM+ data to precisely classify 12 common crop types in a great region in Northeast Germany for several consecutive years. Crop type's spectral–temporal profiles and agro-meteorological information were the key elements in developing a useful hierarchical classification approach. Liu et al. (2005) applied the same data for the time period between 1990 and 2000 to estimate spatiotemporal patterns of dry farming and paddy land across the entire China. They clearly revealed a huge agricultural land use change especially within the suitable locations that might be a great challenge for future China.

Furthermore, Akbari et al. (2006) successfully classified common crop types by processing Landsat ETM+ images of the years 2000 and 2001 in the Zayandeh-rood River Basin in central Iran, where the study area of this research covers a large part of this basin. Nowadays, this area has been witnessing a wide range of challenges including rapid expansion of abandoned farmlands (in response to persistent multi-year drought condition), very small field size farming as a result of traditional heritage system, uncontrolled and unplanned urban growth, and the lack of scientific system and general consensus for crop type selection by local farmers.

In this case, Landsat 8 has been remarkably improved in contrast to previous Landsat TM and ETM+ systems, especially in radiometric and spectral resolution and targeted to achieve more information from the earth's surface (Roy et al., 2014). Detailed information on Landsat 8 abilities are given in Roy et al. (2014) that conducted a comprehensive review on the characteristics of Landsat 8 imagery. Therefore, the primary objective of this study is to provide a new basis for detecting and classifying the main crop types in Najaf-Abad Hydrological Unit, a highly fragmented and heterogonous landscape using enhanced Landsat 8 imagery, a series of inventive classification algorithms along with experts' knowledge on the temporal-spectral behavior of crop types.

2. Material and methods

2.1. The study area

The research was conducted in Najaf-Abad Hydrological Unit (NAHU) which is the smallest subunit of Zayandeh-rood River Basin in Isfahan province, Iran. It is located between 32°18′–32°5 0′N longitude and 50°52′–51°42′E latitude and covers an area of 1716 km^2 (Fig. 1). The topography of the study area is predominantly plain, accounting for approximately 1017 Km^2 (60%) of the entire area. The average slope in NAHU is less than five percent. The study area is characterized in its periphery by a disconnected series of mountains that form the boundary of the NAHU. The major water resource is Zayandeh-rood Seasonal River. This river originates from Zard-kooh Mountain in the southwest of the basin. It traverses 35 km inside the NAHU and finally reaches to the Gavkhooni wetland in the northeast. According to Domarton method, climate of the study area is characterized as semiarid. The multi-year mean annual temperature is 15.2 °C (59.4 °F) having hot summer and cold winter. With records dating back to 1961, July is the hottest month with an average temperature of 42.5 °C (108.5 °F) and December is the coldest month with an average temperature of 18.5 °C (65.3 °F). All precipitation in the study area occurs during the winter months and early spring, with annual average of 150.9 mm (5.9 in.) (IMO, 2015).

Historically, agricultural activities have been the major use of land. In the early 17th century, which is in coincidence with Safavieh dynasty, an effective agricultural water management system was first developed by great Sheikh-Bahaei. He properly modified the pattern use of the only water resource, Zayandeh-rood seasonal river, through the entire basin. His agricultural water management system was maintained until the construction of a dam on the river in 1970. Nowadays, agricultural land areas are rapidly decreasing. Insufficient water supply to the dam, allocated a limited portion of water quota to agricultural activities. During the last decades, agricultural lands became smaller in their spatial extent and formed a highly fragmented and heterogeneous farming spatial pattern.

2.2. Phenological cycles of crop types and image selection

Selecting imagery data with appropriate characteristics (temporal, spectral and spatial resolutions) is the first important step to the success of an accurate image analyzing and processing. In this research, along with the spectral and radiometric capabilities of Landsat 8 in vegetation studies such as crop type mapping, the spatial characteristics of agricultural fields (geometry and size) has been taken into account in order to realize whether or not Landsat 8 will meet the objective of this study. To date, approaches such as variance-based methods (Woodcock and Strahler, 1987) have been suggested for determining optimal spatial resolution which also need extensive field data collection. However, the only available information of agricultural fields in the study area is the non-spatial data from the Organization of Agriculture Jahad-Isfahan (OAJI, 2014) which indicates the mean of 0.32 ha with standard deviation of 0.12. Accordingly, due to the higher size of agricultural fields compared to spatial resolution of Landsat 8. This imagery system was applied in this research (Woodcock and Strahler, 1987).

In the semi-arid regions of central Iran, the growth of all crop types occurs during March through late October. Within this period, regardless of establishing and harvesting process (phenological cycle), all crop types reach to their maximum growth and remote sensing data collected over this time can be used for crop type classification. In this case, several field investigations were performed in the entire study area between March and October