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SENTINEL-1 AND SENTINEL-2 DATA FOR CHARACTERISING THE STATES OF CONTINENTAL SURFACE OVER A SEMI-ARID REGION EN TUNISIA

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ABSTRACT

Radar and optical data have shown great potential for monitoring soil and canopy parameters. In this context, Sentinel-1 (S-1) and Sentinel-2 (S-2) time series were used to retrieve different parameters using models and different algorithms. The main objective of this study is to analyze the potential a synergetic use of radar and optical data for the estimation of soil moisture, irrigation detection and soil texture over agricultural areas for sustainable management of water and soil resources.

First, the radar signal is simulated using a semi-empirical backscattering model over bare soil and vegetation cover. The Water Cloud Model parameterized with NDVI for vegetation contribution allows a good estimation of soil moisture by inversion techniques. Soil moisture time series were then developed for the spatialization of irrigation and soil texture. In this study, both products have shown good agreement with in situ measurements.

Index Terms— Sentinel-1, Sentinel-2, soil moisture, irrigation, soil texture, Water Cloud Model

1. INTRODUCTION

Semi-arid regions are characterized by limited water resources, affecting agricultural yield and thus food security. Soil surface and vegetation cover play a key role in various processes such as crop yield, water-use efficiency and climate change. In fact, soil moisture is a key parameter for evapotranspiration, runoff, infiltration, and particularly in water cycle. Soil moisture data at high spatial resolution is essential for agricultural management, such as monitoring of irrigation requirements of crop, as well as determining agricultural soil types [1,2]. At the agricultural field scale, the monitoring of spatio-temporal variations of soil and vegetation parameters could be estimated by several methods. These products are generally derived from remote sensing data, mostly from microwave data, highly related to soil parameters (soil moisture and soil roughness) and vegetation [3–5]. For instance, C-band radar data have shown their potential to retrieve soil moisture [6,7]. In addition, SAR observations are insensitive to atmospheric conditions, offering high spatial and temporal resolution products.

To understand the behavior of radar signal to soil and vegetation components, backscattering models have been developed in order to estimate soil and vegetation parameters [8]. For agricultural areas, algorithms are based on models integrating the signal attenuation effect due to covered surfaces and taking into account the vegetation contribution. The Water

Cloud Model (WCM) is one of the most used backscattering models for covered areas [9,10].

In the other hand, monitoring of soil moisture could provide information about the right amount of water to crops at the right time. However, few scientific investigations have been carried out on mapping irrigation, and there is little information about the topics. For instance, Gao et al. [11] have studied irrigation by mapping irrigated and rainfed areas, using radar data derived from Sentinel-1 images. Soil texture is also important for many agricultural and hydrological processes. Several techniques based on optical data have been used for the estimation of soil component. In the meanwhile, few researches proposed a mapping of soil texture, particularly at high spatial resolution.

The recent launch of Sentinel constellation has proved it potential to monitor agricultural areas by providing high spatial products. Data synergies offer the ability to merge different types of data for a continuous estimation on large scale.

In this context, the main objective of the present study is to analyze the potential of Sentinel-1 and Sentinel-2 data for the assessment of soil moisture. Section 2 describes the study site and the database with satellite data and ground measurements. Section 3 provides the methodology used to provide different products. Section 4 discusses the results obtained.

2. STUDY SITE AND DATABASE

2.1. Description of the study site

The study site is located in the Kairouan plain, centered in Tunisia. The area lies in a semi-arid climate zone with a mean annual rainfall of 300 mm. Agriculture is the main economic activity of the region where the dominant crops are mainly olive groves and cereal crops, which rely mostly on irrigation systems. The major issue of semi-arid regions focuses on the water deficit resulting from the combined effect of the high demand of water and the scarcity of resources (drought and climate change). Soil texture consist mainly of alluvial deposits, clay and coarse sand, and is characterized by a large spatial variability.

Several reference fields (bare soil, irrigated and rainfed cereal crop) were selected for ground measurements.

2.2. Database

2.2.1. Satellite data

2.2.1.1. Sentinel-1

Synthetic Aperture Radar (SAR) images in the C-band are acquired between two agricultural seasons (2015-2016 and 2016-2017). The IW S-1 GRD products are in dual-polarization (VV and VH) with a spatial resolution of 10 m. All the images were processed using the SNAP Toolbox developed by the European Spatial Agency (ESA).

2.2.1.1. Sentinel-2

S-2 optical images were selected, on dates close at the same period of S-1 image. The S-2 data were derived from cloud-free images with radiometric and atmospheric corrections, with a spatial resolution of 10 m. The Normalized Difference Vegetation Index (NDVI) was then computed in order to characterize the vegetation, using the red and infrared bands.

2.2.2. Ground measurements

Soil parameters include soil moisture measurements using Thetaprobe and roughness using pin profiler of 1

m. For vegetation parameters, LAI and vegetation height have also been measured to characterize cereal crops. Simultaneously to S-1 acquisitions, the ground measurements were made over the crop season (from December to March). Several sensitivity analysis of the radar signal to soil and vegetation parameters were established.

3. METHODOLOGIES

3.1. Soil moisture estimation

Various studies have shown the backscattering coefficient sensitivity to soil moisture according to a linear relationship. To predict the backscattering coefficient, the WCM is used in this study. The model links the vegetation and soil contribution to the radar signal [12]. It expressed as follow*:*

$$\sigma^0 = \sigma^0_{\text{vég}} + \tau^2 \sigma^0_{\text{sol}}$$

To describe the vegetation dynamics, the NDVI was used, derived from S-2 spectral bands.

In order to retrieve soil moisture, we proposed an inversion of the WCM based on Neural Networks (NN) techniques.

3.2. Irrigation mapping

The process for irrigation mapping is based on using different classification algorithms. The first algorithm is built on Support Vector Machine (SVM) classification to identify the boundaries between irrigated and rainfed cereal crops. The input parameters represent the mean and variance of soil moisture time series, computed from S-1 and S-2 data by inverting the WCM. After finding the optimal hyperplane to separate between both areas, a Decision Tree classifier has been applied to complete the classification by producing an annual irrigation map.

3.3. Soil texture retrieval

The aim of this section is to establish a spatialization of the clay content in the same study area, the Kairouan plain. On the other hand, soil texture is a function of clay, silt and sand fractions and can be strongly influenced by water retention and infiltration. Therefore, the texture is highly dependent on the dynamics of soil moisture [13].

The algorithms proposed in this study are based on classification method: Random Forest (RF). Soil moisture maps have been analyzed and used as input in the algorithms.

4. RESULTS AND DISCUSSIONS

4.1. Soil moisture mapping

Figure 1 illustrates an example of a soil moisture map derived from the inversion of the WCM using NN techniques. Validation is achieved by ground measurements, acquired by Thetaprobe over reference fields. The validation step showed good agreement between measured and estimated soil moisture with an RMSE of 6 Vol. % and a bias of approximately less than 1 Vol. %.

The following map provides soil moisture over the Kairouan plain on 24 December 2016. Most of the fields in this map present high value of soil moisture due to the precipitation 3 days ago.

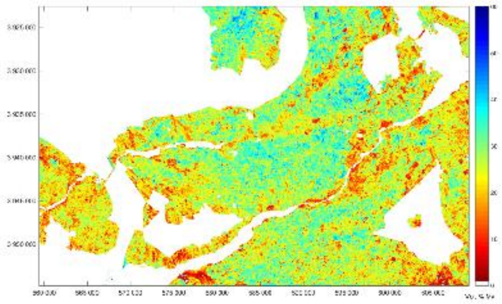

Figure 1. A soil moisture map derived from the inversion of the WCM

4.2. Irrigation mapping

The overall classification accuracy (OCA) achieved with the soil moisture parameter reveals good results with 77.2% and a Kappa coefficient (K) equal to 0.58.

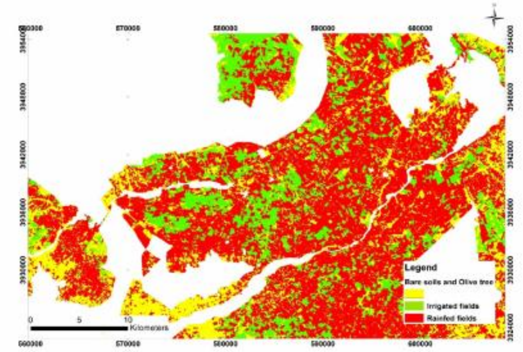

Figure 2. Irrigated and rainfed area mapped using soil moisture parameters

4.3. Soil texture mapping

Three main classes have been generated, ranged between 15 % and 60 % of clay content as shown in Figure 3. The third class with high value of clay content dominates the center of the Kairouan plain. Sandy soils are present mainly in the south-western portion of the site, where olive orchards are widely cultivated. Sandy soils are present mainly in the south-western portion of the site, where olive orchards are widely cultivated. With an OCA equal to 0.65, the results present good agreements, comparing to ground measurements.

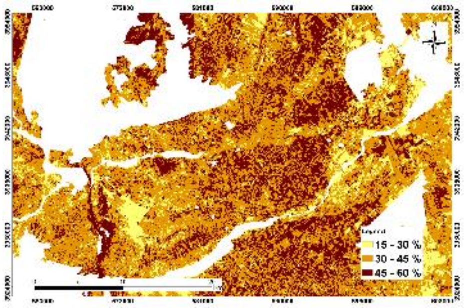

Figure 3. Clay map using Random Forest classifier and soil moisture parameter

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