TEMPORAL STABILITY OF MINERAL INDICES IN A SEMI-ARID AREA

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ABSTRACT

The majority of geological remote sensing studies have been done in arid and semi-arid areas, leading to seamless compositional maps and a cross-continental geoscience product of Australia. A challenge remains when such products are to be made for continents with temperate and cultivated regions. For that, sensors with a continuous multi-temporal operation such as Landsat 8 OLI and Sentinel-2 MSI may have to be used to reach an optimal seasonal acquisition. This paper tests the robustness of Sentinel-2 MSI spectral indices over a semi-arid area in southern Spain. Spectral indices (band ratios) for mapping green vegetation and iron oxide mineralogy were acquired over a 1-year period, which had alternating dry and wet periods. Results show that changing soil moisture and weather conditions over a period of 1 year affect the stability of spectral mineral indices.

***Index Terms*—** Sentinel-2 MSI, geology, minerals, multi-temporal, weather

1. INTRODUCTION

Lithological mapping, a major component of geological remote sensing, is possible in areas with "good exposure" [1], which typically refers to arid and semi-arid areas. Mosaicking scenes with spectral indices such as band ratios has been used to create seamless compositional maps [2] and, more recently, a cross-continental geoscience product of Australia [3]. A challenge remains when such products are to be made for continents that cover temperate and cultivated regions, using sensors with a continuous multi-temporal operation (e.g. Landsat 8 OLI and Sentinel-2 MSI) [4, 5] that enable an optimal seasonal acquisition [6].

The two Sentinel-2 MSI instruments have 13 super-spectral bands of 10–60 m spatial resolution, covering the Visible and Near InfraRed (VNIR) and ShortWave InfraRed (SWIR) wavelengths with a 290 km swath width [7]. With two systems operational, the revisit time at the equator is ± 5 days [8]. Sentinel-2 MSI lacks relatively narrow spectral resolution SWIR bands [9] for mapping of surface mineralogy, but it can be used for mineral spectral indices originally developed for Landsat [10]. Also the relatively narrow VNIR bands aid the mapping of iron oxide mineralogy [11].

This paper tests the temporal robustness of Sentinel-2 MSI spectral indices over a semi-arid area in southern Spain. Spectral indices (band ratios) for mapping green vegetation and iron oxide mineralogy were acquired over a 1-year period, which had alternating dry and wet period.

2. METHODS AND DATA

The Google Earth Engine (GEE) [12] was used to collect Sentinel-2 MSI surface reflectance data acquired between June 2018 and June 2020. Data selection criteria were *sensor 2A*, *orbit 51* and $<$ *20% clouds*. Clouds and cloud shadows were masked with the "land/water/cloud mask (QA60)" and "scene classification layer (SCL)" bands that come with Sentinel-2 MSI data [13], and by masking pixels with a reflectance $< 1\%$ in the blue band.

(a) Bare soil (b) Natural vegetation (c) Former quarry

Fig. 1. The locations where the behavior of spectral indices over time is monitored: (a) bare soil, (b) natural vegetation, and (c) an abandoned quarry. Each color composite image covers 100×100m.

Table 1 shows the indices calculated in GEE: The "soil-adjusted vegetation index" (SAVI) [14] for observing green vegetation change, and two mineral indices for mapping proxies of ferric (Fe^{3+}) and ferrous (Fe^{2+}) iron oxide mineral groups, originally defined for ASTER [15].

The daily aggregate of precipitation was taken from ERA 5 climate data from ECMWF [16], while the daily aggregate of soil moisture was taken from NASA's GLDAS 2.1 "global land data assimilation system" [17]. The cloud cover was taken from Sentinel-2 MSI metadata. All three parameters were available within GEE.

The study was performed in the area of Rodalquilar in the Cabo de Gata National Park, Southern Spain, a semi-arid area known for hydrothermal alteration mineralogy and associated mining [18]. With prior knowledge of the area, three locations were selected for monitoring spectral indices: a bare soil, natural vegetation, and a rock surface in an abandoned quarry (Fig. 1).

Table 1. Sentinel-2 MSI bands used for mapping green vegetation & two iron oxide mineral groups.

Index	**ASTER**	**Sentinel-2 MSI**
SAVI*	$L * (3-2)/(3+2)$	$L * (8-4)/(8+4)$
$Iron^{2+}$	$(5/3) + (1/2)$	$(12/8) + (3/4)$
$Iron^{3+}$	$2/1$	$4/3$

* Soil-adjusted vegetation index, with $L = 1.5$.

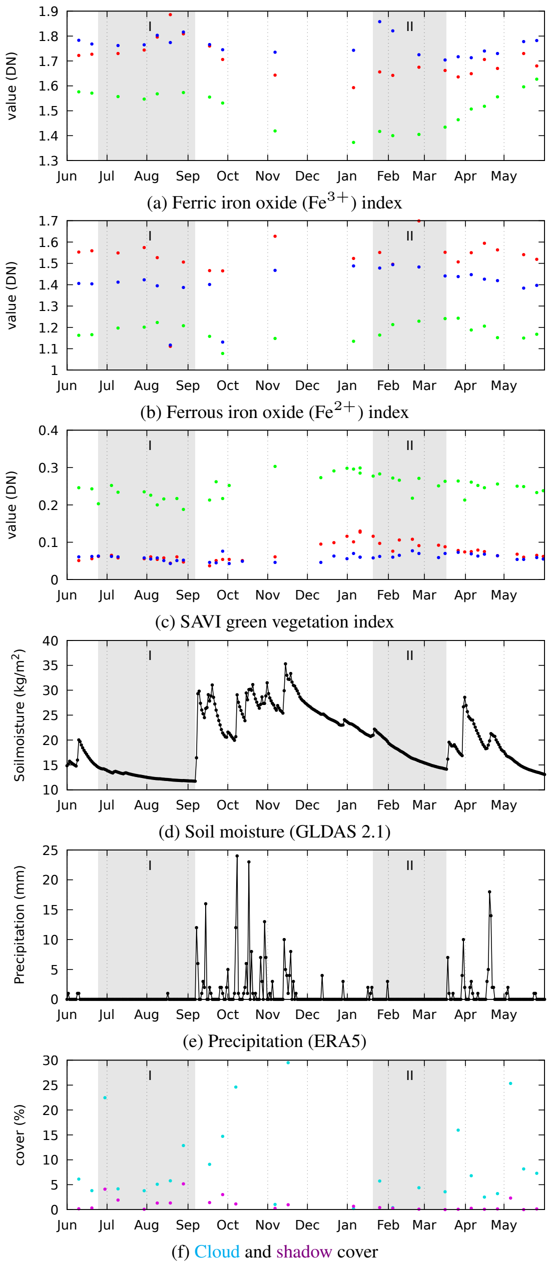
3. RESULTS

Fig. 2 contains all results of this study. The iron oxide indices acquired from bare soil and rock show variation over time (Fig. 2a & 2b), as does the vegetation index (Fig. 2c). The soil moisture taken from GLDAS 2.1 data (Fig. 2d) shows periods of drying and wetting of the soil and match rain events in the ERA5 data (Fig. 2e). Two dry periods can be observed in this timespan, 25 July to 7 September 2018 and 21 January to 18 March 2019 (grey bands I and II in Fig. 2). The cloud cover data obtained from Sentinel-2 MSI image metadata (Fig. 2d) shows overall lower values in dry periods and higher values within rainy periods, but there are exceptions.

The green vegetation index varies on natural vegetation and bare soil, but seems invariant on rock (Fig. 2c). Both mineral indices vary over time, also when measured on bare soil and rock in dry periods (Fig. 2a & 2b).

4. DISCUSSION AND CONCLUSIONS

It is to be expected that spectral indices change over a period of a year, especially in temperate regions where there is a yearly seasonality and vegetation cover. Typically, remote sensing geologists would select an image in dry periods I or II (Fig. 2). Yet, our results show that spectral indices are also affected within a few days, even when measured on



(a) Ferric iron oxide (Fe^{3+}) index

(b) Ferrous iron oxide (Fe^{2+}) index

(c) SAVI green vegetation index

(d) Soil moisture (GLDAS 2.1)

(e) Precipitation (ERA5)

(f) Cloud and shadow cover

Fig. 2. Indices for (a & b) iron oxide minerals and (c) green vegetation that cover bare soil, natural vegetation and in a quarry. The shaded periods are regarded "dry" based on the parameters in (d & e).

bare soil and rock surfaces within dry periods of the year.

The creation of seamless cross-continental geoscience products in non-arid areas requires data from operational missions such as Landsat and Sentinel to reach an optimal moment of acquisition. Selecting this moment is important even when only a single remote sensing image would be needed, and should be based on a multi-temporal analysis: The classic approach of selecting an image by visual inspection and cloud cover statistics does not necessarily result in the best choice of data; ideally, it should result in a product that is repeatable at other moments, as well as applicable to an area covered with multiple scenes. Lastly, the relation between soil moisture and index values in the two dry periods indicates that a the effect of precipitation does not disappear in a few days.

A continuation of this work would be to include more environmental parameters in the search for causes of found spectral variation over time. Apart from the precision of atmospheric correction that comes with the Sentinel-2 MSI surface reflectance product, the role of solar illumination (azimuth and elevation) has not been explored yet. Also more spectral indices would have to be analyzed, as the effect of the atmosphere differs per wavelength region, as does the role of green & dry vegetation cover.

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