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# Quantitative mapping of the soil rubification process on sand dunes using an airborne hyperspectral sensor

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**Abstract**

Soil rubification is defined as a pedogenesis stage in which iron is released from primary minerals to form free iron oxides that coat quartz particles in soils with a thin reddish film. This study used an airborne hyperspectral sensor to spatially map soil rubification on the surface of coastal sand dunes in Israel. The area selected for this study is located south of the city of Ashdod, Israel, and is one of the last remaining coastal sand dune areas in the country. The study area occupied about 60 $km^2$, and was covered by two flight lines of the CASI 48-channel sensor from an altitude of 2650 m, providing a pixel size of about 3 m. A traditional way to estimate rubification is to chemically measure the iron oxide concentration in the sand. The Dithionite Citrate Bicarbonate (DCB) method, which is a laboratory "wet"-based procedure, was used to precisely measure the free iron oxide status of selected locations along the area. The soil reflectance properties of these samples were measured in the laboratory across the Visible and Near InfrarRed (VIS–NIR) region and was used with the DCB-Fe data to evaluate a spectral-based model for assessing the rubification extent solely from spectroscopy. After the CASI data were atmospherically, BRDF and geometrically corrected, they were run against the spectral model on a pixel-by-pixel basis, generating a rubification map from a far distance. Spectral validation of independent samples and field measurements of dune movement over 17 months showed that the map is reliable and significantly correlated with known stabilization processes throughout the area (the overall accuracy estimated as 78%). It was concluded that soil spectroscopy, either from field or air, enables the detection of small changes in the Fe absorption feature across the VIS region that provides information regarding the iron oxide minerals and content. This supports the utilization of a sensitive airborne hyperspectral sensor to rapidly and quantitatively evaluate spatial information concerning important pedogenic processes.


*Keywords:* Remote sensing; Reflectance spectroscopy; Rubification; Sand dune; Free iron oxide; Soil mapping

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## 1. Introduction

Remote sensing of soils plays a major role in both soil survey and soil mapping applications. Air photos and satellite imagery are the major database from which final products, such as soil maps, are produced. The combination of remote sensing and traditional soil survey methods provides a spatial overview of large areas and effectively sheds light on regional temporal processes. Air photos and satellite images are based on the spectral reflectance information of soils, which relates to the soil chemical and physical characteristics. Unfortunately, both air photos and satellite imagery suffer from low spectral resolution and, thus, provide only limited spectral information about the targets explored. The high spectral resolution capability of remote sensing from airborne sensors means, significantly broadens the utility of this tool for further mapping of the soil surface from a more precise chemical and physical point of view (Ben-Dor, 2002). During the past few years it has been shown that soil spectra across the Visible–Near InfraRed–Short Wave InfraRed (VIS–NIR–SWIR) spectra region are characterized by significant chromophores (e.g. OH, Fe3+, CO3 and COOH) enabling quantitative analysis of soil properties (Ben-Dor, 2002). Accordingly, remote sensing of soils by high spectral resolution sensors is receiving more and more attention to rapidly and quantitatively map soils from far distances (Ben-Dor et al., 1999, 2002, 2004; Malley et al., 2004; Baptista and Netto, 2001). Imaging Spectrometry (IS) or hyperspectral technology is an advanced tool that provides high spectral resolution data (near-laboratory-quality reflectance and emittance data) for each single picture element (pixel) from a far distance (Goetz et al., 1985). This information allows the identification of objects based on the spectral absorption features of the chromophores and has been found to be very useful in many terrestrial and aquatic applications (Clark and Roush, 1984; Goetz et al., 1985).

One of the most important phenomena in the soil formation process over a sand dune environment is the *rubification* process. *Rubification* is defined as a pedogenesis stage in which iron is released from primary minerals to form free iron oxides that coat quartz particles in soils with a thin reddish film (Buol et al., 1973). The free iron oxides coat the quartz particles and provide a reddish chroma to the matrix as well as stability (Ben-Dor and Singer, 1987). There is abundant evidence that many dune sands become reddened with time. That process is promoted by warm temperatures, oxidizing conditions and periodic presence of moisture (Norris, 1969). Williams and Yaalon (1977) have demonstrated reddening in sand dunes under laboratory weathering conditions. Their research showed that organic matter is not necessary to initiate the process. On the coastline of Israel sand has been accumulated to form the coastal dune strip. The sand in this strip is brought from the Nile delta via a counter clockwise long-shore current along the eastern shore of the Mediterranean Sea (Nir, 1989), as presented in Fig. 1.

Along the beaches of Israel, the color of the sand changes progressively from the Gaza Strip in the south to Athlit, ca. 130 km, to the north, ranging from 7YR7/4 (reddish light yellow) to 10YR7/10 (yellowish gray). According to Emery and Neev (1960), the change in color reflects a reduction in iron oxides within the sand transported by the long-shore currents. As the sand is transported inland by the south westerly winds of the winter storms (Tsoar, 1990), the sand grains gain stronger red colors via the soil rubification process. During the rubification process, sand reddening occurs as a result of an interaction between electromagnetic radiation and free Fe oxides. Fe in the free iron oxides is spectrally active across the VIS–NIR region via the electron transition (of 6A1→T1g between 750–950 nm and 6A1→T2g between 550–650 nm) and is responsible for the Fe absorption of radiation that gives the soil its red color. Based on the free iron oxides that redden the sand, and using spectral color indices or linear mixing models, Madeira et al. (1997) and White et al. (1997, 2001) showed that it is possible to account for iron oxide status using the Landsat Thematic Mapper data (only six bands in the VIS–NIR–SWIR region) over lateritic soils in Brazil, and sand dunes at the Namib, and at the Northern Rub' Al Khali (United Arab Emirates), respectively. Field spectroscopy was used by Bullard and White (2002) to quantify iron oxide coatings on dune sand in the Simpson-Strzelecki Desert, Australia. However, the iron content detected by all of the studies above was relatively higher than what may be found in the initial stages of the rubification process as presented