Remote sensing based tools to assess risk in rice agriculture

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Abstract

In rice growing, production risk is strongly dependent on the availability of fresh water. The contribution of remote sensing observations in identifying the conditions under which rice is cultivated, particularly throughout the growing season, can be instrumental in water and crop management. This work discusses the usefulness of different remote sensing products, of different spatial resolutions, to describe the local rice growing conditions in the Lower Mondego region, aiming to enhance the use of these tools as a support element in irrigation management.

Keywords: Satellite Sentinel-2, drone, NDVI, environmental monitoring, precision agriculture.

Resumo

Deteção remota na avaliação de risco em orizicultura. Em orizicultura, o risco associado à produção é fortemente dependente da disponibilidade de água doce. A contribuição da deteção remota na identificação das condições observadas ao longo da estação de cultivo do arroz pode ser fundamental para a gestão da água e agronómica. Este trabalho discute a utilidade de diferentes produtos de deteção remota, com diferentes resoluções espaciais, para descrever as condições locais na região orizícola do Baixo Mondego, visando potenciar o uso dessas ferramentas no apoio à gestão da rega.

Palavras-chave: Satélite Sentinel-2, drone, NDVI, monitorização ambiental, agricultura de precisão.

Introduction

Risk is inherent to rice farming, which is strategic for food security in many countries. In particular, production risk, which derives from the uncertain natural growth processes of the rice crop as affected by weather, irrigation water availability, disease, pests, and other factors, affect both the quantity and quality of the commodities produced. In recent years, remote sensing products are increasingly being used as a complementary source of information to *in situ* environmental monitoring networks (e.g. Sheffield *et al.*, 2018). Images obtained from satellites and Unmanned Aerial Systems (UAS), are offering attractive routes to acquire field data of important temporal and spatial resolutions in a fast and easy way that could routinely assist to support better informed agronomic management decisions. Remote sensing products have been widely used in environmental surveying and scientific research.

This study discusses the usefulness of such products to better characterize rice farming conditions in the Lower Mondego region and, therefore, to contribute to estimate crop water requirements and to better inform irrigation water management. The intent is to support local practices by better understanding the local territorial conditions.

Remote sensing and environmental monitoring

Environmental monitoring has become increasingly important to better understand the Earth System, envisaging environmental protection and sustainability. At present, a broad range of remote sensing systems allow to acquire information of varying resolutions and products that have manifold applications in different sectors and areas of research. Essential information is provided by a suite of space borne sensors in the optical, thermal and microwave spectrum, and systems measuring atmospheric composition and gravity fields (e.g. Belward & Skøien, 2015; Denis *et al.*, 2017).

Global, regional and local studies require data of, correspondingly, increasing resolution. Some datasets are freely available. In general, global scale studies rely on low spatial resolution Earth observations using sensors (e.g. Moderate Resolution Imaging Spectroradiometer – MODIS; Advanced Very High Resolution Radiometer – AVHRR); regional studies are rather interested in historic archives of moderate resolution images (e.g. National Aeronautics and Space Administration - Landsat, available since 1984) and European Space Agency - Sentinel data (available since

2015) through optical and microwave images; and, finally, local studies search for high-resolution images (e.g. Zhu & Scott Mackay, 2001; Zhu, 2017). Because satellite data resolutions are still too coarse to address plot scale conditions, UAS constitute a useful solution to obtain higher resolution data. These aerial systems, developed in recent decades, have the potential to fill the scale gap between space borne observations and detailed field observations, and are contributing to increase our knowledge about e.g. surface processes and land cover dynamics (e.g. González-Jorge *et al.*, 2017; Tatum & Liu, 2017; Manfreda *et al.*, 2018; Tmušić *et al.*, 2020; de Jong *et al.*, 2020).

Studies using remote sensing include, for example, crop biomass development, precision agriculture, food and water security, vegetation mapping (forest, grassland, wetlands, riparian), coastal systems, topographic survey, geomorphology, archaeology, health-related services, snow and ice dynamics, and landslide monitoring. Applications related to rice agro-systems (e.g. Oguro *et al.*, 2003; Chosa *et al.*, 2010; Kuenzer & Knauer, 2013; Dong et al., 2015; Duan *et al.*, 2019; Wan *et al.*, 2020) are also found; rice cultivation is one of the largest users of the world's freshwater resources. Whilst, there are seldom any studies dedicated to rice cropping in the Mediterranean region and the Iberian Peninsula. This study focuses on rice cultivation in Portugal, which is found mostly in dedicated downstream areas of the Tagus, Sado and Mondego River basins. It aims at using remote sensing tools to estimating rice water consumption, thus, saving water by improving rice irrigation, and assessing rice production risk, both of great importance to local economies.

Application of remote sensing to better characterize rice farming in the Lower Mondego region

Presentation of the case study

Rice cultivation has long been a tradition in the Lower Mondego Valley, which is found mostly in the lowlands where soil drainage is poor and salinity is high. It generates significant local rural employment and direct and indirect economic activity (rice industry, machinery, agrochemicals, transport). There is also a cultural value associated with the tradition of rice production in this region, which influences other activities of a social and gastronomic nature.

The selected study area (fig. 1), of approximately 335 ha, is an irrigation unit (Bloco 1 – Quinta do Canal, coordinates: 40° 7' 0.16" N, 8° 47' 47.34" W) that is predominantly dedicated to rice cultivation (about 332 ha). Quinta do Canal is located in the left bank of the Mondego River, in the downstream part of the Lower Mondego Valley. The area is bounded to the north by the Mondego River, to the south by the Pranto River and to the west by the Mondego River estuary. Quinta do Canal is amongst the most downstream irrigated lands of the Lower Mondego Irrigation District.

Fig. 1 - Location the study area "Quinta do Canal", on the left bank of the Mondego river, and of the two selected rice fields (adapted from Google Maps, 2021).

Quinta do Canal integrates 71 rice fields. The rice produced has long grain, of the variety Ariete, sub-species *Oryza sativa* L. ssp. *japonica*; commercially, it is known as "Carolino" rice. Traditional irrigation is by continuous flooding.

Portugal shares concerns with the main European rice producer countries, Italy and Spain, in relation to rice cultivation (global) sustainability. It is anticipated that the current situation, that faces a number of problems, is aggravated by the consequences of the expected climate change and the increasing pressure on water resources. Research in progress explores alternative irrigation and agronomic practices adapted to the local conditions that might lead to less irrigation water application, keeping crop productivity high and environmental impacts low. For this purpose, it is important to increase the knowledge about the water dynamics of rice growing.

Available remote sensing products

This study explored satellite Sentinel-2 imagery and data obtained through dedicated UAS flights undertaken in 2020, during the rice crop cultivation season.

The available satellite Sentinel-2 images obtained from March 1 to October 31, 2020, were downloaded from the Copernicus open-access website (https://scihub.copernicus.eu). Level-2A images at 10 m full spatial resolution, already atmospheric corrected, were selected. Only images showing a cloud cover lower than 8% were retained. The Sentinel-2A optical instrument allows to obtain data in 13 spectral bands.

The UAS data used were collected during a flight made between 2:30 pm and 4:00 pm on July 9, 2020, under conditions of no wind and clear sky. A DJI Matrice 600 drone equipped with a camera X5 for RGB and a Micasense RED Edge –M multi-spectral sensor was used (photo 1), that collected images having a spatial resolution of 0.074×0.074 m^2. The UAS was autonomous and was operated respecting a pre-set flight plan.

Photo 1 - View of the rice fields in the study area of Quinta do Canal (left panel) and of the UAS (DJI Matrice 600 drone) used for the field survey (right panel) (photographs by R. Jorge, on 9^{th} July 2020).

Methodology outline

All selected Sentinel-2A images of the study area were classified using the Normalized Difference Vegetation Index (NDVI). NDVI values were calculated using the formula: NDVI=(NIR-RED)/(NIR+RED), where RED and NIR stand for the spectral reflectance measurements acquired in the red (visible) and near-infrared band regions, respectively. RED and NIR are represented by spectral bands 4 and 8. The NDVI varies between -1.0

and +1.0; it is directly related to the photosynthetic capacity and hence energy absorption of plant canopies. Thus, this index is useful to detect live green plant canopies based on multispectral remote sensing data.

Based on satellite data, NDVI maps were obtained for each rice plot using Quantum GIS (QGIS) software. For the UAS flight images' data, including orthorectification and elaboration of NDVI maps, the Pix4D software (Pix4D S.A., Prilly, Switzerland) was used.

Basic statistics were obtained for the collected data, extracted using the zonal statistics plugin in QGIS. The temporal variation of the rice plots' NDVI estimated from Sentinel-2A data was analysed. The Sentinel-2A and UAS based NDVI estimates were compared.

Results and Discussion

Data from two of the Quinta do Canal's rice fields, identified as plot 1 (3.15 ha) and plot 2 (1.6 ha) (see fig. 1), are used to illustrate some of the results obtained for the 2020 rice cropping season. This season lasted 151 days: sowing date was May 10 and harvest date was October 10.

The temporal variation of the NDVI average values was estimated from Sentinel-2A data (fig. 2). This type of NDVI profile has been reported for rice by previous studies in the Mediterranean region (e.g. Corvino *et al.*, 2018; Rolim *et al.*, 2019; Sarvia *et al.*, 2021), but results for the conditions in the Lower Mondego region are lacking.

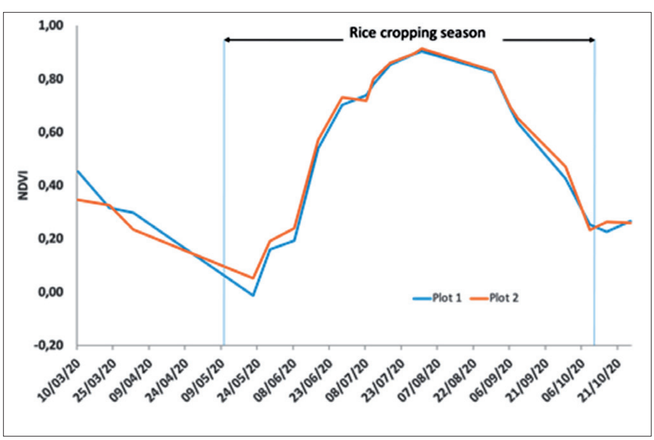

Fig. 2 - NDVI average values calculated for irrigated agricultural plots 1 and 2 (Quinta do Canal, fig. 1) using satellite Sentinel-2A imagery obtained in 2020. The period plotted include the rice cropping season, that lasted 151 days in 2020: sowing date was May 10 and harvest date was October 10.

As expected, the NDVI profiles reflect the different conditions of the field plots, over time, and the different rice cropping phases: initial growth, crop development, reproduction and maturity phases. The observed differences between the two field plots are explained by differences in field conditions and crop responses to the applied water and agronomic practices. The lowest NDVI values, around zero, are observed in the initial phase; they are related to the flooding of the fields close to the rice crop sowing time. The highest NDVI values, of approximately 0.90, are observed in August, and reflect the peak greenness of rice that corresponds to the heading stage. Towards the end of the cultivation period, the NDVI values decrease until the plant reaches full maturation and is harvested, in the beginning of October. For the Lower Mondego region's conditions, the specific local signature depicted by NDVI is a useful tool to better characterize rice crop responses and, thus, water requirements, and to support water management and agronomic decisions.

Comparison of the NDVI values obtained during the rice reproductive phase for plots 1 and 2, from satellite Sentinel-2A (July 8) and UAS data (July 9), show that the NDVI average values estimated from UAS data (0.87±0.05 and 0.88±0.03, respectively, for $n_1 \approx 6.26\times10^6$ and $n_2 \approx 3.17\times10^6$, being n_i the number of pixels in the plot 1 and plot 2 UAS images) are higher than the values estimated based on the Sentinel-2A data (0.74±0.07 and 0.72±0.04, respectively, for $n_1=321$ and $n_2=160$, being n_i the number of pixels in the plot 1 and plot 2 Sentinel images). Between the two platforms, the differences in the NDVI estimates could be explained by using reflectance measurements that were not recorded simultaneously and the fact that different instruments acquire different spectral channels through different cameras or focal planes, since each sensor has its own characteristics and performance. It is also to be expected that the NDVI estimates obtained at other times from data of different origins and other conditions (e.g. weather) could be different between the platforms. In short, using the NDVI for quantitative assessments as opposed to qualitative surveys demand that a number of issues are properly addressed for interpretation of results to be meaningful. However, such discussion is outside the scope of this text.

NDVI maps derived from both Sentinel-2 and UAS images were obtained using QGIS software (fig. 3 is for plot 2). The two maps show that the quality of the mapping is, as expected, affected by the different resolution of the two remote sensing products; for plot 2, the number of analysed pixels is 160 for the Sentinel-2 images and approximately 3.17×10^6 for the UAS images. Indeed, the NDVI map obtained from the UAS data is closer to the original conditions in the field; ditches, roads and tracks are easily identified in these maps. However, Sentinel-2A data imagery provides already much detail in comparison to other satellites and can be useful for improving the local knowledge on land surface processes.

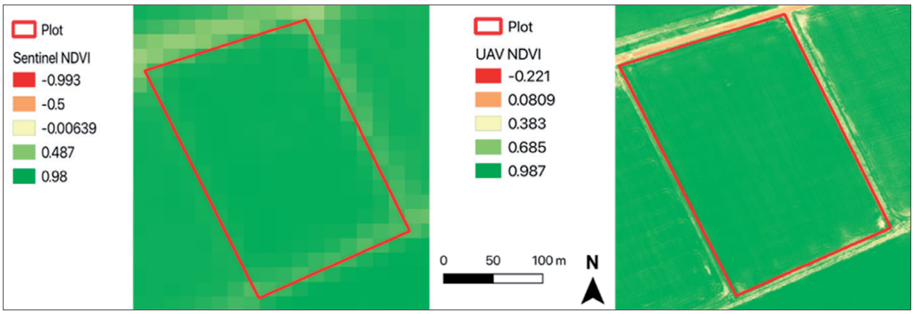

Fig. 3 - NDVI maps calculated for rice plot 2 (Quinta do Canal), using data from Sentinel-2A (left) and UAS (right) imagery. The data were obtained in 2020, during the rice reproductive phase. Please note that the colour classification is different between the two maps.

Conclusion

Analyses of different vegetation indices calculated using remote sensing data from different reflectance bands help to obtaining a picture of the territory at the regional and local scales, which is particularly useful for agriculture. Their variation over time allows to monitor progresses in crop development, and the need and effect of irrigation and agronomic practices. Particular features of different crops and growing conditions justify that some indices are more adequate than others on a case-to-case basis, according to the different vegetation's spectral signatures.

Fine-scale information is necessary to allow detailed analysis within agricultural rice production areas and to give specific indications regarding different adopted water and crop management practices. This study, for rice, illustrates that remote sensing data can play an important role towards producing, managing and making use of spatial information. The approach is flexible enough to be applied in different contexts and constitutes a practical basis to monitor and understand our living environment, which helps to preserve and manage our resources. The territorial coverage of the data and the frequency of the observations are favourable attributes of remote sensing based study approaches.

Public administrations (or other institutions) should promote advances in increasing the quantity and quality of geographical data and systematically collect, organize and update information, which would improve the reliability of vulnerability and risk assessments. The development of adaptation strategies (for example, in relation to climate change) is also tied to political, social and economic factors that play an important role in decision-making; such factors need to be also considered.

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