Capability of high resolution satellite images to characterize urban surfaces: spectra comparison and correlation with in field/lab measurements

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Abstract Environmental remote sensing is an increasingly useful tool for the study of large areas thanks to new sensors with high spatial resolution. These sensors could be able to identify and analyse several urban surfaces, like roofs and pavements. Thus they could be used to study urban areas for several applications, as the characterization of different surfaces related to the development of the UHI (Urban Heat Island) phenomenon. The main goal of this paper is to study the spectral correlation between this kind of satellite imagery (high spatial resolution and good spectral resolution) and ground measurements using instruments with high spectral resolution. For this purpose, an image from WorldView 3 sensor was acquired and several spectra of urban surfaces were measured with the ASD FieldSpec 4 field spectroradiometer. The study area is the ceramic district of Sassuolo, in the northern part of Italy. Statistic parameters were used to assess the differences between acquired spectra and satellite image spectra. The achieved results are encouraging: remote sensing could characterize the correlation between remote sensing data and ground measurement is high for homogenous surfaces.

Keywords: Remote sensing, environment, UHI, urban surfaces

1. Introduction

The urban heat island refers to a phenomenon in which urban areas are significantly hotter than the surrounding zones, such as the surrounding rural areas. This temperature increase is the result of various factors related to urbanization and land use in urban areas (Oke, 1995).

There are several factors that contribute to the urban heat island. One of the main factors is the "thermal absorption effect". Buildings, roads, and other urban infrastructure are made of materials that absorb and retain heat, such as concrete and asphalt. These materials have a higher thermal capacity compared to rural areas, which are often covered with vegetation and more permeable soils. As a result, during the day, these surfaces absorb a considerable amount of heat from the sun and gradually release it throughout the night, keeping the urban environment warmer (Mohajerani et al., 2017).

Another key factor is the reduced presence of vegetation and open spaces in urban areas. Trees and plants in rural areas provide shade and cooling through evapotranspiration, the process by which plants release water into the air. However, in urban areas, vegetation cover is often limited or replaced by impermeable surfaces. Consequently, the presence of shade is reduced, and the cooling effect of evapotranspiration is limited, contributing to the temperature increase(Oke,1995).

Human activities in urban areas, such as vehicular traffic and the use of appliances, generate additional heat. Cars, for example, emit heat from their engines and exhaust systems. The accumulation of heat from these anthropogenic sources further contributes to the urban heat island (Rathnayake et al., 2020: Piracha and Chaudhary, 2022).

The urban heat island can have various negative effects on the environment and human health. Higher temperatures can increase energy consumption for building cooling, raise the risk of heat strokes, and affect air quality. Furthermore, the temperature increase can negatively impact local biodiversity and alter ecosystems (Heaviside et al., 2017).

To mitigate the effect of the urban heat island, several strategies are employed. These include increasing vegetation coverage in urban areas through the creation of parks and gardens, using low-emissivity building materials, and urban planning that promotes natural ventilation and shading (Leal Filho et al., 2017).

It is therefore important to characterize urban surfaces in order to study appropriate mitigation and adaptation measures for this phenomenon.

Remote sensing, in this sense, is an important tool for the analysis and characterization of large urban areas (Zhu et al., 2019). In particular, satellite sensors with high spatial resolution and good spectral resolution allow for the extraction of important surface characteristics such as albedo, which is the fraction of solar radiation reflected back into the atmosphere (Gueymard et al., 2019).

In this study, a Worldview3 (WV3) satellite image was used to compare surface reflectance and albedo measurements derived from satellites with point measurements taken in the field. This approach will allow us to understand the reliability of using satellite imagery as a basis for urban planning.

2. Materials and methods

The study area is the municipality of Sassuolo, located in northern Italy and characterized by the presence of a large industrial area. The image acquired for the area is from the WV3 satellite with 16 multispectral bands in the VNIR (Visible-Near Infrared) and SWIR (Short Wave Infrared) spectral regions and a spatial resolution of 1.20m in the VNIR region and 7.50m in the SWIR region. For ground measurements, the spectroradiometer ASD Fieldspec 4 was used. It measures solar reflectance in the range of 350-2500 nm, thus VNIR-SWIR spectral regions.

The spectra of several typical urban surfaces were acquired both through satellite images and with a spectroradiometer through ground-based measurements.

The surfaces chosen were:

- Polyolefin roof
- Aged tiles roof
- New tiles roof
- Asphalt parking
- Bituminous membrane
- Parking with cobblestones

The ground-based measured spectra were processed to simulate the spectra measured by satellites in order to perform a comparison. The Worldview3 image was pre-processed, and radiometric and atmospheric corrections were applied.

The surface reflectance of the different bands was also used to calculate the albedo following the method of Kuester (2016) with the coefficients of Thuillier et al. (2003).

3. Results and discussion

The qualitative and quantitative comparison of the surface reflectance spectra for the chosen ROIs was conducted, employing statistical parameters like the Root Mean Square Error (RMSE).

To estimate deviations between the two spectra (the simulated one and the satellite one), the RMSE was utilized, following the guidelines of Wald (2002).

A crucial aspect of the comparison lies in the time gap between the satellite image acquisition (2018) and the ground measurement campaign (2023). Materials undergo an aging process that can significantly alter their characteristics.

The most accurate comparison was performed for the bituminous membranes, as measurements were obtained from both satellite and field instruments, including the spectroradiometer and spectrophotometer. Figure 1 presents the spectral signature of the urban surfaces acquired from satellite data, juxtaposed with the ground instrument readings. For bituminous membrane the deviation is minimal, confirmed by the RMSE values below 0.4. Also for the cobblestones park the deviation is minimal while for tiles roofs the difference is more evident especially in the SWIR region. .

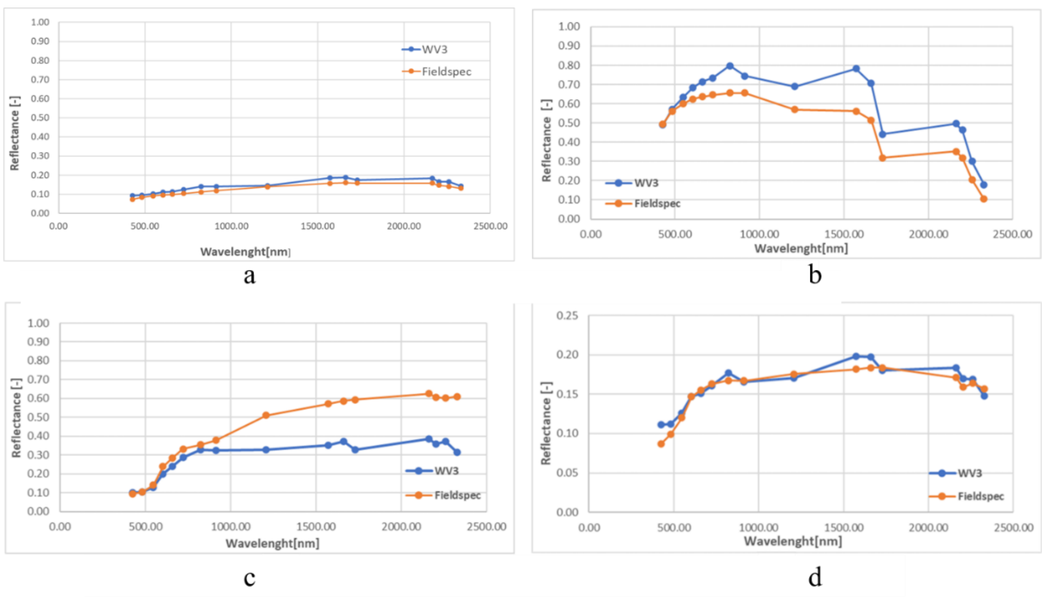

Figure 1. Comparative spectral signature of a) Bituminous membrane, b) Polyolefin roof, c) New tiles roof, d) Parking with cobblestones

4. Conclusions

In conclusion, the findings demonstrate that WV3 satellite images can be effectively utilized for the study and characterization of urban surfaces. The ground-based measurements have confirmed that homogeneous surfaces exhibit highly similar spectra both on the ground and from satellite observations. These studies provide a valuable foundation for territorial planning and inform mitigation and adaptation actions for the urban heat island (UHI) phenomenon.

References

Gueymard, C. A., Lara-Fanego, V., Sengupta, M., & Xie, Y. (2019). Surface albedo and reflectance: Review of definitions, angular and spectral effects, and intercomparison of major data sources in support of advanced solar irradiance modeling over the Americas. Solar Energy, 182, 194-212.

Heaviside, C., Macintyre, H., & Vardoulakis, S. (2017). The urban heat island: implications for health in a changing environment. Current environmental health reports, 4, 296-305.

Kuester, M. (2016). Radiometric use of Worldview-3 imagery. DigitalGlobe

Leal Filho, W., Echevarria Icaza, L., Emanche, V. O., & Quasem Al-Amin, A. (2017). An evidence-based review of impacts, strategies and tools to mitigate urban heat islands. International journal of environmental research and public health, 14(12), 1600.

Mohajerani, A., Bakaric, J., & Jeffrey-Bailey, T. (2017). The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete. Journal of environmental management, 197, 522-538.

Oke, T. R. (1995). The heat island of the urban boundary layer: characteristics, causes and effects. Wind climate in cities, 81-107.

Piracha, A., & Chaudhary, M. T. (2022). Urban air pollution, urban heat island and human health: a review of the literature. Sustainability, 14(15), 9234.

Rathnayake, N. U., Perera, N. G. R., & Emmanuel, M. P. R. (2020, March). Anthropogenic heat implications of Colombo core area development plan. In IOP Conference Series: Earth and Environmental Science (Vol. 471, No. 1, p. 012002). IOP Publishing.

Thuillier, G., Hersé, M., Labs, D., Foujols, T., Peetermans, W., Gillotay, D., ... & Mandel, H. (2003). The solar spectral irradiance from 200 to 2400 nm as measured by the SOLSPEC spectrometer from the ATLAS and EURECA missions. Solar Physics, 214, 1-22..

Wald, L. (2002). Data fusion: definitions and architectures: fusion of images of different spatial resolutions. Presses des MINES.

Zhu, Z., Zhou, Y., Seto, K. C., Stokes, E. C., Deng, C., Pickett, S. T., & Taubenböck, H. (2019). Understanding an urbanizing planet: Strategic directions for remote sensing. Remote Sensing of Environment, 228, 164-182.