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Sustainable strategies for smart cities: Analysis of the town development effect on surface urban heat island through remote sensing methodologies

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ABSTRACT

In recent years the use of satellite remote sensing techniques has proven to be a useful tool for monitoring urban surface parameters: data provided on the reflective and thermal state of the urban texture, both at local and global scale, give fundamental information on the surface urban heat island (SUHI) control of the urban planning.

In this work, the retrieval of the urban albedo and land surface temperature (LST) from Landsat 7 satellite data is performed over a selected area of a town in Central Italy (Terni), exhibiting a significant urban change during the last 10 years. Comparing two satellite images on 2005 and on 2015, the spatial pattern of albedo and LST shows an average albedo decrease of 0.03 during this period and a daytime SUHI increase of 2.3 °C.

As highlighted by a focused local scale analysis, built-up area modifications moved towards both a reduction and an increase of the surface albedo, comparing the previous situation of the area and the reflective properties of materials chosen for the new settlements or refurbishments.

The proposed analysis with remote sensing data may be considered an effective indicator able to point out if urban changes like interventions and new constructions move towards an urban sustainable development in terms of SUHI mitigation.

1. Introduction

Sustainability is one of those fundamental issues whereby modernity is challenged and affects different aspects: land consumption and environment (overloading), energy (gradually depleting), culture (on mass lines), landscape (scarred and overcrowded), urban settings and infrastructures (congested), local resources of a cognitive, aesthetic and motivational nature (devalued). Cities constitute the main driving force of economic development, but they also represent a problem from an environmental point of view: in fact, they are responsible for 60–80% of global energy consumption and around the same share of the global carbon emission (http://ec.europa.eu/clima/policies/international/paris_protocol/cities/index_en.htmhttp://ec.europa.eu/clima/policies/international/paris_protocol/cities/index_en.htm). Studying new strategies for reducing the environmental impact represents an ethical commitment well before a scientific one. The new paradigm "*smart city*" refers to an urban model sustainable, intelligent, competitive, inclusive, creative, hyper-connected, technological, efficient, e-governed, and open. In this paradigm shift, moving from the *city* to the *smart city*, the purpose is to favour the re-use of the existing avoiding the consumption of land, protecting and enhancing the urban green, promoting energy efficiency and reducing polluting emissions: in short, to improve the life of people who live in cities (Verducci & Desideri, 2012).

In the urban sustainable development issue, the mitigation of the urban heat island (UHI) is a key point.

UHI is a phenomenon caused by the increase of urbanization process, together with an increase of air pollution and anthropogenic heat sources. The city growth has changed the nature of surfaces reducing the presence of vegetation, with building structures and materials trapping solar radiation during the day, determining a significant temperature differences between urban and rural areas (Anniballe, Bonafoni, & Pichierri, 2014; Oke, 1982; Rizwan, Dennis, & Chunho, 2008; Stathopoulou et al., 2009). The UHI effect exacerbates during the summer, increasing energy consumption and producing dangerous effects for human health.

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Currently, this phenomenon affects not only large metropolitan areas, but also smaller cities.

There are several strategies to mitigate UHI phenomenon, based on wisely designing the urban residential environment to obtain significant long-term energy savings and health benefits (Gaitani et al., 2014; Mackey, Lee, & Smith, 2012; Smith & Levermore, 2008; Synnefa, Santamouris, & Livada, 2006; Takebayashi & Moriyama, 2007). Different urban cooling strategies have been proposed and developed and, among the most effective ones, the increasing of urban surface reflectivity (Akbari, Damon Matthews, & Seto, 2012; Bretz, Akbari, & Rosenfeld, 1998; Dimoudi et al., 2014; Suehrcke, Peterson, & Selby, 2008; Taha, Akbari, Rosenfeld, & Huang, 1988; Wang & Akbari, 2016) and the intensification of urban vegetation (green roofs, street trees, and green spaces) (Dimoudi et al., 2014; Wang & Akbari, 2016;; Givoni, 1991) play a fundamental role.

Generally, a built-up area exhibits a variable thermal pattern with high and low Land Surface Temperature (LST) zones, corresponding to low and high reflectivity impervious surfaces, respectively. A high reflective surface is typically light in colour and absorbs less solar radiation than a conventional dark-coloured one: less absorbed radiation brings to a lower LST, directly reducing building heat gain and air-conditioning demand. The albedo is a parameter that quantitatively describes the reflective behaviour of a surface: it represents the total hemispherical reflection of a surface integrated over the solar spectrum. It can be assumed that the average albedo of existing roofs does not exceed 0.30 but it can be increased to about 0.55 ÷ 0.60 with appropriate refurbishing and interventions (Akbari, Menon, & Rosenfeld, 2009). In particular, it is possible to apply coverings such as cool roof paintings to increase the albedo of residential and industrial building roofs and consequently mitigate the UHI.

Remote sensing techniques and data processing methodologies allow retrieving surface and air parameters, with the aim of monitoring Earth surface both at local and global spatial scale, and during different temporal intervals (Kikon, Singh, Singh, & Vyas, 2016; Raghavan, Mandla, & Franco, 2015).

In this work, the retrieval from Landsat 7 satellite data of the urban albedo and LST is carried out over a small area of a town in Central Italy (Terni), characterised by a clear urban change during the last 10 years. An analysis of the albedo variations and its impact on LST using satellite images on 29th of July 2005 and on 25th of July 2015 is provided, both at local and global scale. Spaceborne remote sensing techniques and methods allow monitoring the spatial pattern of surface reflective and thermal parameters and their temporal evolution that can be related to the urban texture change. Therefore, this analysis may constitute an effective indicator pointing out if urban changes like refurbishments, interventions and new constructions move towards an urban sustainable development.

2. Study area

The study area is the Maratta zone of the city of Terni, Central Italy (Fig. 1), covering a rectangular surface of 3.0 km x 1.5 km. The UTM WGS84 coordinates (33T zone) of the selected area (Fig. 1 b) and c)) are: longitude range [m E]: 302300–305300 and latitude range [m N]: 4714350–4715850.

The role of Terni, in the landscape of average Italian cities, is connected to its industrial history that saw, in the second half of the 19th century, a transformation of an average size historic town centre, still structured along the lines of the urban layout of the ancient Roman town, into the dynamic city of the 1930s, at the top of the national table in the manufacturing of iron and steel and production of electricity. The area of Maratta, the subject of study and analysis, developed as a settlement, is characterised by the presence of two major subsystems: the first one consists of an urban layout made up of large industrial structures (a warehouse with open area) placed among small local handicraft activities and parts of a residential fabric, and small service areas. The second one is represented by its particular environmental situation, rich in stretches of water and areas of agricultural vegetation. These two factors should tie in more closely, especially during urban changes like refurbishments, interventions and new constructions. In this case, an accurate analysis, both at local and global scale, on reflective behaviour of building coverings (or, more generally, of impervious surfaces), and on its impact on LST changes was carried out on July 2005 and ten years later, using satellite images. The assessment of urban changes and their effects over a 10 years span is the first step to set up an urban sustainable design strategy in terms of SUHI mitigation for the future.

3. Data description and processing

3.1. Satellite data: Landsat 7 ETM+

The Landsat 7 satellite, operational since 1999, carries the Enhanced Thematic Mapper Plus (ETM +) sensor. ETM+ is composed by six reflective bands in the visible (VIS), near infrared (NIR) and short-wavelength infrared (SWIR), a band in the thermal infrared (TIR) region, and includes a panchromatic band (Table 1). It has a spatial resolution of 30 m for the six reflective bands, 60 m for the thermal band, and 15 m for the panchromatic one.

TIR band data are also delivered at 30 m, after resampling with a cubic convolution, by the USGS (http://earthexplorer.usgs.gov).

In this work, the Landsat 7 passages over Terni reported in Table 2 were considered.

The two images, downloaded from USGS at 30 m resolution, were processed according to the calibration technique proposed by (Chander, Markham, & Helder, 2009), in order to convert digital number values to at-sensor spectral radiance values. The computation of the surface reflectance of the ETM+ reflective bands (Chander et al., 2009; Chavez, 1996) was carried out applying the atmospheric correction described in (Chavez, 1996), that is characterised by the advantage of requiring only data from the same satellite scenes, without needing contemporary in-situ measurements.

Table 1
Landsat 7 ETM + bands.

Band description (30 m native resolution unless otherwise denoted)	Spectral range (μm)
B1–VIS (blue)	0.45–0.51
B2 – VIS (green)	0.52–0.60
B3 – VIS (red)	0.63–0.69
B4 – NIR	0.77–0.90
B5 – SWIR	1.55–1.75
B6 – TIR (60 m)	10.31–12.36
B7 – SWIR	2.06–2.35
B8 – panchromatic (15 m)	0.52–0.90

Table 2
Data description of the two selected Landsat 7 scenes.

Date	Scene Center Time (CEST: Central European Summer Time)	Landsat scene ID	Path	Row
29 July 2005	11:42 CEST	LE71910302005210EDC00	191	30
25 July 2015	11:52 CEST	LE71910302015206NSG00	191	30

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