THE USE OF REMOTE SENSING AND GEOSPATIAL TECHNIQUES FOR URBAN CLIMATE ANALYSIS: A CASE STUDY OF ABU DHABI CITY AREA

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Abstract

This study demonstrated the potentiality of the use of remote sensing and geospatial techniques for urban climate analysis with a case study of Abu Dhabi city area. A first analysis assessed the variation of Land Surface Temperature (LST) at different spatial scales its relationship with land cover, Normalized Difference Vegetation Index (NDVI), and percentage of Impervious Surface Area (ISA) has also been investigated for the period between 2000 and 2010 using data from multiple satellites and ground measurements. In the second analysis, the data were assimilated in a Surface Energy Balance (SEB) model to assess urban energy fluxes in Abu Dhabi metropolitan area during the winter and the summer seasons. The maps produced from LST and SEB projects will be disseminated through the WebGIS Portal of the Research Center for Renewable Energy Mapping and Assessment.

Keywords: Earth Observation, Land Surface Temperature, Surface Energy Balance, urban area, WebGIS.

1 INTRODUCTION

Cities are dynamic environments, where local climate change variations are generally due to human activities and artificial land surface modification: urban sprawl is re-shaping landscapes and affecting quality of life in human environments. Therefore, urban areas need to be monitored with high accuracy and at regular time intervals. Reliable data in populated areas are essential for urban planning where urban climate models, remote sensing and geospatial techniques are valuable tools to accomplish these objectives [1].

One of the key parameters for studying global or regional land surface processes and interactions with the atmosphere in urban environments is Land Surface Temperature (LST). It was used in several applications in various areas like urban heat island (UHI) monitoring [2], Surface Energy Balance (SEB) estimation [3] and climate change studies [4]. UHI is a urban phenomenon whereby highly dense built-up areas trap the heat making the city warmer than the surrounding suburban areas. This local variation of temperature is due to several factors such as, surface morphology (i.e., urban form), presence of impervious building materials, sparse vegetation, anthropogenic heat, and presence of water surface and air pollutants [5]. Thus, effects of the urban surface on the fluxes of heat, moisture, and momentum need to be accounted for land-surface schemes used in numerical models. The result of these energy processes defines the Surface Energy Balance (SEB), which estimates the contribution of land surface and land cover modification as well as the effect of anthropogenic activities. The derived map could then be stored and analyzed with geospatial techniques in order to provide end users with valuable information to support decision making processes.

The transposition of these concepts to desert city areas faces particular challenges. Even if previous studies on climate interactions in arid urban environments are fairly limited, a recognised characteristic of cities located in desert areas is the relatively high vegetation cover in urban areas compared to suburban areas where sand is more abundant. It was observed that this discrepancy in vegetation cover makes the suburban areas warmer than urban areas [6]. Regarding the energy balance, extreme temperatures coupled with the continuous irrigation of landscaped areas throughout the year increase the evapotranspiration, which directly contribute to the rise of the net radiation values from the surface [7]. Therefore, this work aims to provide an overview of the possible applications that could be derived from the interaction between temperature and land cover, as LST and SEB retrieval, with the prospective dissemination of the obtained products through webGIS portal.

2 STUDY AREA

Abu Dhabi lies on a T-shaped island (Lat. 24°28′N, Long. 54°22′ E) jutting into the Arabian Gulf from the central western coast. The city of Abu Dhabi is witnessing a fast and continuous urban expansion over the recent decades. In 1985 the government started the conversion of the desert area (located outside the main island) to residential and industrial use and the creation of new man made islands for residential and recreational activities in the areas surroundings of the main city. Mussafah is an industrial area located in the proximity of the access to downtown area. It is characterized by dense low rise buildings and very rare vegetation. Khalifa City A is a recent residential suburb, with a lower building density compared to Mussafah and downtown area, with focus on villas and dedicated green areas.

Abu Dhabi has a predominantly hot and arid climate, and precipitations are scarce and occur only during colder months. Natural vegetation is represented by rare bushes and a significant mangroves forest, while planted trees and irrigated grass characterize the vegetation cover in urban areas. Fig. 1 shows the selected testing sites used for LST and SEB calculation. In addition to the two suburbs sites, in downtown region several sites with different characteristics have been analyzed considering the percentage of vegetation with middle resolution images: a high density built-up area with no vegetation, a medium density built up area with presence of vegetation, a low density built up area with green areas and the mangroves (natural coastal vegetation). Another site representing sand surfaces with no human activities was also added to this analysis.

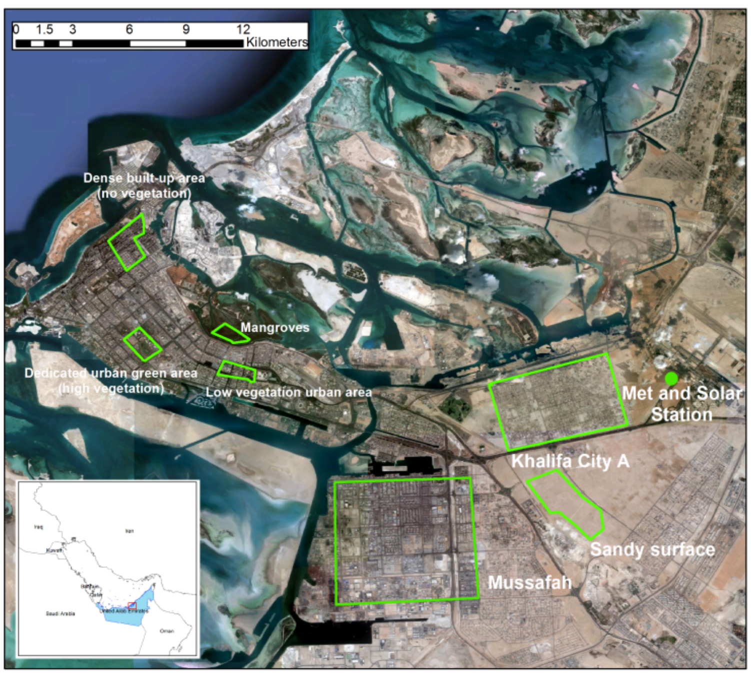

Fig. 1: study area and testing sites

3 DATA SETS AND METHODOLOGY

Several satellite and ground based datasets related to LST, NDVI, land cover and SEB have been collected and analyzed in this study for further implementation in a webGIS system.

3.1 Land Surface Temperature analysis

For the analysis of the correlation between temperature, vegetation and land cover, the approach used in this study was to combine the available information retrieved from three categories of sensors: (1) low spatial resolution sensors with 15-min revisiting time like SEVIRI (on board on Meteosat) were used for monitoring the hourly variation of LST, (2) moderate spatial resolution sensors like MODIS/Terra and Aqua data were used essentially for observing the temporal trend of LST and NDVI variation during the period 2000-2010 for day and night acquisitions and (3) medium spatial resolution ASTER and LANDSAT 7 images were used to investigate the LST relationship with land cover, NDVI and Impervious Surface Areas (ISAs) at a higher scale on specific dates.

3.2 Surface Energy Balance analysis

Eight ASTER data, collected over the period of 2000-2010, have been used to identify the main testing site to study the fluxes of the different urban energy balance components. In addition to satellite measurements, in situ data of water vapour, wind speed and air temperature have also been provided by the UAE National Center of Meteorology & Seismology. The SEB has been estimated with the following general equation [8]:

$$R_n = G + LE + H \qquad (1)$$

where the absorbed net radiation (R_n) should balance outgoing fluxes of ground heat (G), sensible heat (H) and latent heat (LE).

Energy fluxes have been analyzed considering a bi-seasonal pattern, based essentially on historical temperature data: a *winter* season which includes months from November to February and a *summer* season, from March to October. For each flux, an invariant area of 1 km² has been selected for different sites displayed in figure 1.

3.3 WEBGIS Implementation

The main goal of the WebGIS implementation is to disseminate the produced information to potential users. It is based on open software and open standards in order to be technology independent and avoid interoperability issues. It is constituted, beyond the data presented in this paper, by a map server and a WegGIS Portal. For the map server, the GeoServer software, a server that allows users to share and edit geospatial data remotely using open standards, was used and configured to provide the map through the Web Map Service (WMS) standard. The Web Map Service (WMS) is, among many others, one of the most important specifications developed by OGC. This specification defines the interface to remotely share and access Geographic Information (GI) where the “requested map” is sent to the end user as a static image [9]. The WebGIS Portal was developed to provide users with a tool where they can access both LST and SEB maps with a simple internet browser avoiding the installation of any additional software packages, along with some tools to offer additional functionalities to analyse the data.

4 RESULTS

4.1 Land Surface Temperature at different resolutions

Day measurements from the MODIS Aqua and Terra satellites were consistent, where the downtown area displayed lower values compared to other testing sites during the day, indicating the inversion of UHI phenomenon in Abu Dhabi. The opposite has been verified during the night, where suburbs become cooler compared to downtown area, showing the standard UHI. With middle resolution satellites, it was possible to observe the local variation of temperature at district level and its correlation with land cover classes over the studied period of 2000-2010 (Fig. 2). Classification maps were produced using a Support Vector Machine (SVM) classifier, where five ground-truth classes were identified: buildings, roads, soil, vegetation and water. After the classification, the buildings and roads classes were merged into one class representing the impervious regions (built-up class), defining the impervious areas on a scale ranging from 0 (non built-up area) to 100 % (fully built-up area). The temperature drop seemed to be inversely related to the presence of vegetation: the higher the percentage of vegetated pixels, the lower the temperatures of the observed area. In the dedicated green area, temperature was generally five Kelvin lower than in the suburbs and around two Kelvin lower than in the bare area.

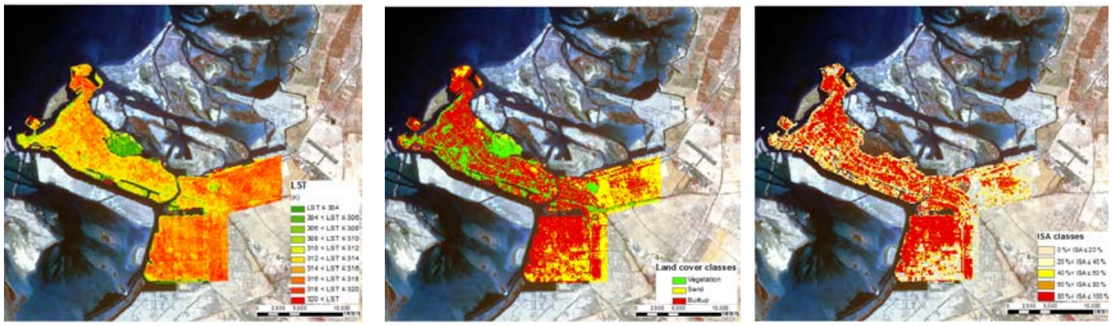

Fig. 2: example of obtained ASTER maps of LST (a, above), land cover (b, middle) and ISA percentage (c, bottom) for 10th June 2008 image

4.2 Surface Energy Balance at district scale

The analysis of each heat flux exhibited a similar trend during the 8 tested images, with higher fluxes values during the summer as expected. In vegetated surfaces, vegetation keeps the temperature low by evapotranspiration (urban vegetation is constantly irrigated) and absorbs more solar radiation than other surfaces, so that the latent heat flux is high over vegetation and consequently, the net radiation as well. Built-up areas have a pattern similar to desert areas due to their capacity of heat storage but the presence of human activities increases the values of H. The presence of vegetation in downtown areas has shown to have an effect on the overall balance by increasing the contribution of LE values and reducing H values. Key parameters on SEB as surface albedo and emissivity should have large variability in urban areas because of the large material. The future availability of high spatial resolution images (higher than the current 90 m provided by ASTER) could help to better discriminate these land cover materials.

4.3 WEBGIS

The output maps of the previous analysis were projected in a common reference system and implemented in the WebGIS portal of the Research Center for Renewable Energy Mapping and Assessment at Masdar Institute. The portal allows displaying the ingested layers at different spatial details and query's can be submitted, in order to display temporal trend for different products (Fig. 3) in a selected point. This temporal trend is shown in a graph where the values are from all the layers that are turned on at that moment. It is also possible to access the legend of each layer individually, beyond all the usual functionalities like zoom in, zoom out or pan.

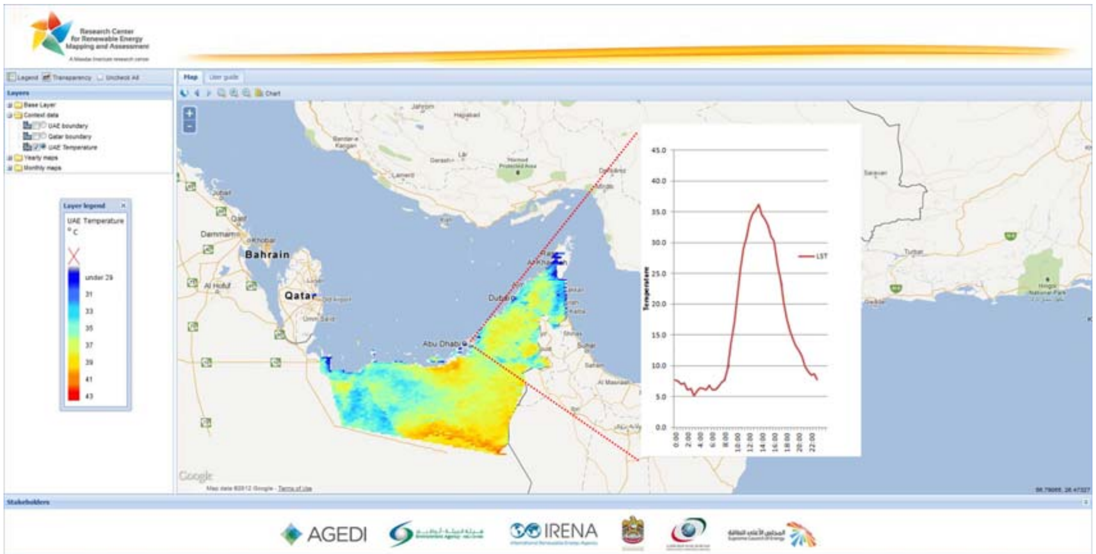

Fig. 3: In the WebGIS portal, users are able to activate a set of layers and analyse the corresponding values in a specific point. In this example, a daily dataset of LST images from SEVIRI have been activated and the daily variation of temperature over a specific point is displayed.

5 CONCLUSIONS

The study of temperature and land cover interactions provides valuable insights for the analysis of urban environment as well as assistance in various decision making processes for the city planning and development. Remote sensing and geospatial techniques are valuable data source to accomplish this objective. A multi-sensor approach meets the temporal and spatial requirements of frequent and highly detailed observations from visible to thermal infrared part of the spectrum, which is generally not possible with the use of a single satellite. Finally, the implementation of these products in a web portal allows benefiting all potential users of these maps through a user-friendly interface and possibility to visualize and query the ingested maps.

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