Advances in Geosciences Konstantinos Perakis & Athanasios Moysiadis, Editors
EARSeL, 2012

Integrated Use of Satellite Remote Sensing and GIS for the Development of a Sophisticated Sustainability Index for Urban Areas: A Case Study of Paphos City (Cyprus)

Chrysostomos Italos, Diofantos G. Hadjimitsis, Dimitrios D. Alexakis, Kyriacos Themistocleous, Athos Agapiou, Argyro Nisantzi, Christiana Papoutsa and Giorgos Papadavid
Cyprus University of Technology, Department of Civil Engineering and Geomatics, Limassol, Cyprus; italos@cytanet.com.cy, d.hadjimitsis@cut.ac.cy

Abstract. Sustainable development is focused on developing a mutually beneficial relationship between the economic development and the environment. In practice, sustainable development focuses on finding methods to promote growth that do not destroy the environment, or compromise future generations' access to natural resources. This study aims at developing a novel methodology based on an integrated database for the extraction of sustainability indicators concerning the urban environment. The pilot area is the city of Paphos - Cyprus where during the last decades the phenomenon of urban sprawl has been recorded. A set of indicators are developed to support sustainable development strategy in Cyprus. Sustainability indicators are assessed according to coefficients which are determined on the basis of the nature of each indicator (urban/environmental, economic and social). A significant component of the current proposal is the application of sophisticated satellite remote sensing techniques for studying in detail the multi-temporal evolution of urban sprawl phenomenon in the broader study area. The land cover regime is thoroughly searched through the use of satellite imagery and aerial photos and digital maps are developed covering a period from 1963 until today. In addition, spectroradiometric measurements from different heights and for different targets are acquired in order to search the mixed pixel phenomenon and improve the land use/land cover classification products. For that purpose, a thermo-camera is also used. The preliminary results are considered to be promising enough for the construction of efficient thematic maps and the development of final sophisticated sustainability indicators.

Keywords. Sustainability indicators, remote sensing, land use, spectroradiometer, Cyprus.

1. Introduction

During the last years tremendous building development has been recorded in Cyprus and especially in Paphos district so a strategic development plan is necessary. This Cyprus University of Technology (CUT) aims to develop a novel methodology based on an integrated database for the extraction of sustainability indicators concerning urban environment. Multi-temporal monitoring of land use and land cover changes will be recorded with the use of satellite remote sensing and spectroradiometric measurements. A set of available satellite imagery of multiple spatial and spectral resolutions (i.e. Landsat, ASTER, Quickbird etc.) and aerial photos will be processed for the production of a time series of land use/cover maps since 1963, for the broader area of the city of Paphos. Sophisticated classification algorithms and image analysis techniques will be used for the assessment of urban sprawl and how this affects the sustainable development of Paphos area. At the final stage of the model, a GIS based spatial analysis tool will be developed where all the indicators will be incorporated for planning of sustainable urban development. This tool will import, evaluate and process the indicator data and extract the final results in form of maps, tables and texts and a

final sustainability index. Analytic Hierarchical Process (AHP) and Multivariate Analysis (MA) will be used in GIS environment to calculate indicators weighting.

2. Study area and data

The pilot area is the city of Paphos at western Cyprus where during the last decades the phenomenon of urban sprawl has been recorded (Figure 1).

Figure 1: Study area (Paphos district).

For the purposes of the overall project and the insitu campaigns (Figure 2), the above tools and data were incorporated:

- Spectro-radiometers (GER1500+ SVC 1024) Concerning GER 1500 instrument it has the capability to record the reflectance from 400 nm up to 1050 nm (blue/green/red and NIR band) while the spatial resolution of each measurement was estimated up to 0.02 m^2. A calibrated spectralon panel was used in order to minimize illumination errors during the data collection
- Image Processing Software (ERDAS IMAGINE) for the application of pre & post processing techniques. Specifically, all the images will be transformed to the same format and to the same Geodetic System of Reference (WGS 84) so that all data can be fused to the same projection system. Regarding the geometric registration of satellite images, uniformly allocated ground control points were selected. In addition, the DN (Digital Number) values of the images were firstly converted to radiance values and then to reflectance values. The atmospheric correction procedures were completed through the "darkest pixel" application **Error! Reference source not found.**, **Error! Reference source not found.**.
- Aerial photos of the study area (Year of acquisition : 1963)
- Sun-photometers in order to measure atmospheric conditions during field campaign. The Microtops II sun photometer measures aerosol optical thickness and direct solar irradiance at 5 wavelengths: 440, 500, 675, 870, 936 and columnar water vapor (CWV) at three wavelengths. The sun-photometer provides optical depths by knowing the respective radiation intensities at top ofatmosphere (TOA), using its internal calibration **Error! Reference source not found.**.

- GPS for Positional Measurements
- Distometer for height calculation
- Thermo-camera (Flir B535) for the acquisition of thermographic images
- Thermometer for temperature measurements
- Solar Irradiance Meter
- Mobile Crane

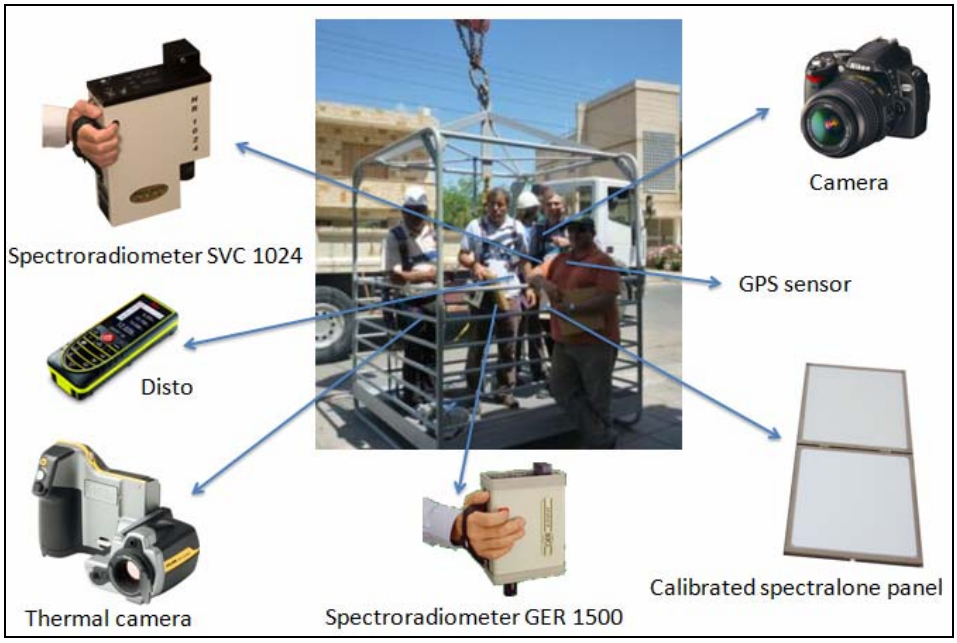

Figure 2: In situ campaign equipment.

3. Methodology

The objective of the proposed project is to establish a GIS-based decision support system for assessing whether a city (e.g. Paphos) in Cyprus is moving towards sustainable development. The project expects to develop an integrated database incorporating environmental, economical, social and aesthetic data concerning sustainability management. The fully updated database will be the main source for the development and evaluation of approximately 50 indicators.

Some of the indicators incorporated in the final model were:

- Economic (Gross domestic product, employment, life expectancy, pollution abatement expenditure)
- Transport use (car use and total passenger travel, short journeys, real changes in the cost of transport)
- Energy (fuel prices in real terms, residential energy use)
- Land use and Land cover (rural land cover, green spaces in urban areas, agricultural productivity, designated and protected areas, house hold numbers)
- Water resources, climate change (emissions of greenhouse gases)
- Marine and coastal areas (pollution, bathing water quality)
- Soil quality (heavy metal concentration in top soils)
- Air quality (AOD and particle matters measurements)
- Waste indicators (household waste, energy from waste)

One of the most important indicators is the multi-temporal evolution of land use and land cover regime of the study area. For this purpose, different kind of satellite images such as Landsat, ASTER, Modis, Quickbird were used to assist the evaluation of land use and land cover changes in Paphos. All these images are of medium to high spectral and spatial resolution. At the next step, additionally to the Corine Land cover data, satellite remote sensing classification algorithms were applied to satellite images in order to evaluate the evolution of land use regime during the last 30 years. Thus, initially spectroradiometric measurements from different heights and for different targets were acquired in order to search the mixed pixel phenomenon and improve the land use/land cover classification products. For the same purpose a thermo-camera was also used and the final preliminary results were evaluated for their efficiency.

The incorporation of all the indicators to an integrated GIS tool will conclude to the development of a final sustainability index concerning Paphos area in Cyprus. A web based GIS system will provide information about sustainability development to the policy makers and to the public in daily base (Figure 3).

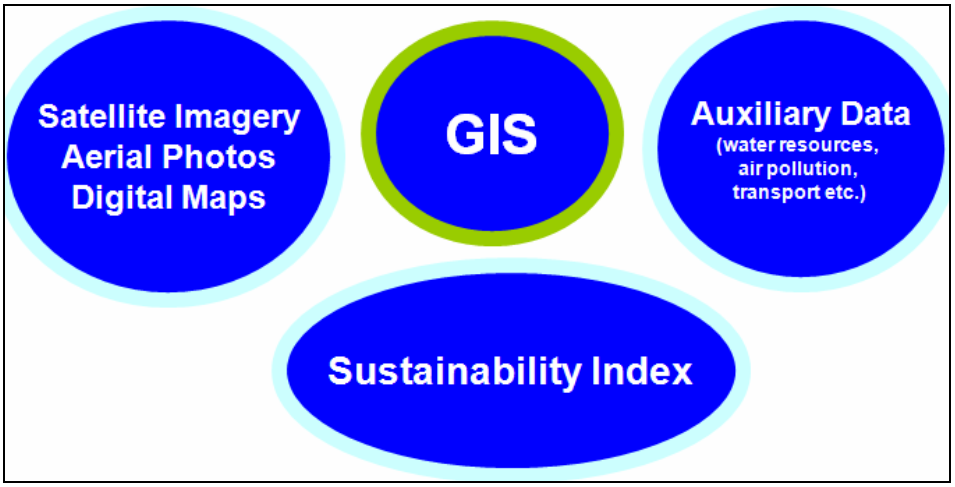

Figure 3: Flow diagram of the overall methodology.

4. Results

The preliminary results of the project concern the creation of thematic maps through the use of supervised classification algorithms. The initial results are shown in Figure 4 (a,b,c,d) where the urban sprawl phenomenon of the last 50 years is clearly denoted. Specifically in Figure 4 (a, b) aerial photos acquired at 1963 and Landsat ETM+ images were overlaid in GIS environment and compared for their urban land cover regime. Moreover, for the construction the thematic map classification products (Figure 4 c, d) the Maximum Likelihood (ML) classification algorithm was applied to Landsat ETM + image acquired at 2009 and the image was separated to 4 main land use classes. The urban sprawl phenomenon of Paphos broader area is clearly denoted.

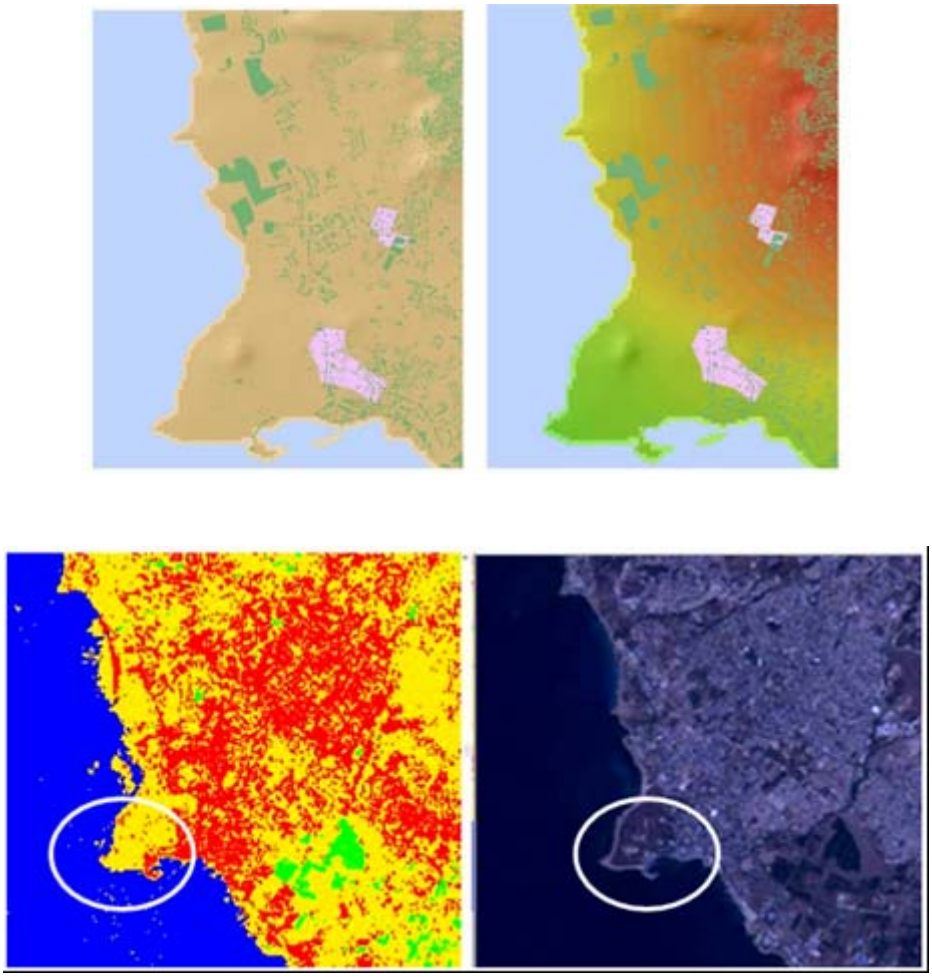

Figure 4: a) Overlay of the two different layers in GIS environment (green = 2008, purple = 1963). b) Density maps of urbanization for 2008 overlay with buildings of 2008 (green polygons) and buildings of 1963 (purple). c) Supervised Classification results at the "Nea Paphos" site using Landsat ETM+ image taken in 2009.With red colors the urban areas are indicated ; yellow=land; blue = water; green=irrigated/vegetated areas. d) Landsat ETM+ image taken in 2009.

Moreover, the research team proceeded to the development of a spectral signature database with the use of spectroradiometer measurements. For this purpose, two different kinds of spectroradiometers were used: the GER 1500 with 4◦ (field of view) and SVC 1024 with 14◦. The different fields of views were selected in order to simulate the different pixel size and spatial resolution of different satellite images. For this purpose, the researchers went up on a mobile crane and took spectroradiometric measurements in different heights above the ground (20m, 40m, 60m) (Figure 5 a, b). The targets were chosen to be either spectral clear (one class per pixel) or mixed ("mixed pixel" phenomenon) in order to search, evaluate and compare mixed pixel measurements and use them in the near future for the improvement of our land use / land cover classification accuracy.

Figure 5: a) Study area and mobile crane b) Spectroradiometric measurements from the height of 40 m above the ground.

The first preliminary results indicated different spectral responses of materials such as asphalt in measurements taken from different heights above the ground (Figure 6a). Concerning vegetation soil measurements (Figure 6b), the first results indicated a light different spectral response between "clear" and "mixed" pixels in the area of 550nm and red edge area as well.

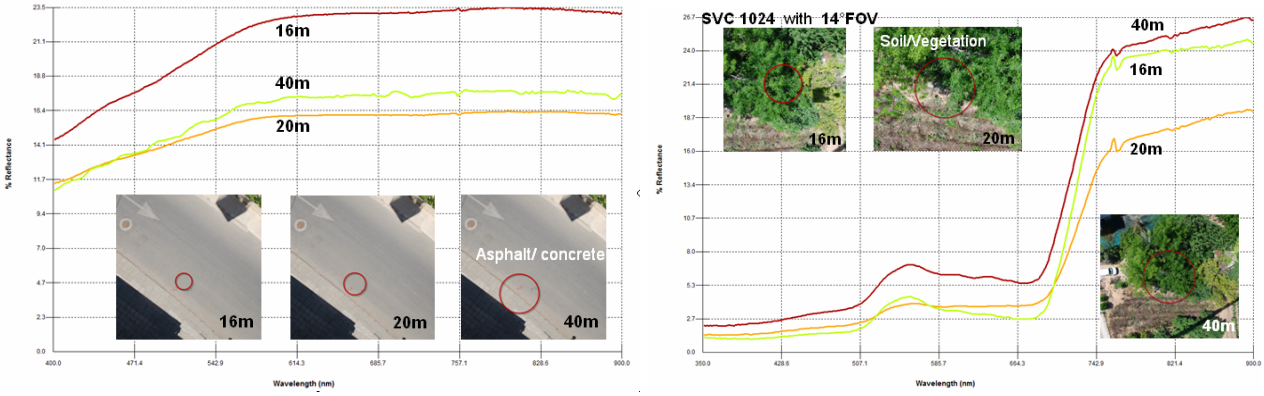

Figure 6: a) Spectroradiometric measurements of asphalt with the use of GER1500 spectroradiometer b) Spectroradiometric measurements of "vegetation" and "vegetation" mixed pixels with the use of SVC 1024 spectroradiometer.

The research team also used a thermo camera and the thermal infrared band of spectrum in order to detect any considerable thermal differences between urban construction materials. Figure 7 (a, b) shows the thermal differences between vegetation and soil materials as well as between roof and asphalt materials. The higher values of cement made materials are clearly denoted. All these measurements will be incorporated in the final GIS model in order to enrich the sustainability indicators results.

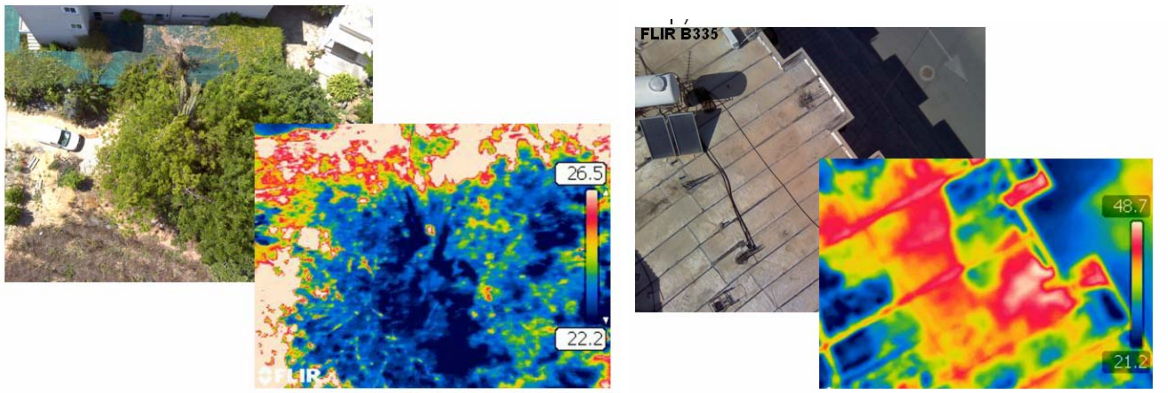

Figure 7: a) Thermocamera measurements concerning areas of vegetation-soil b) Thermocamera measurements concerning roof and asphalt areas.

5. Conclusions

It is well known that there is a lack of a systematic monitoring tool for retrieving land use and land-cover changes to assist the local authorities for decision making. This fact is enhanced by the fact of the dramatic urban development that has been occurred in the last 20 years in the Paphos District area. Remote sensing can be used as an effective tool for monitoring land use and land cover changes.

The first preliminary results of the study denoted the contribution of spectroradiometric measurements in the optimization of land use/land cover classification products. The novel methodology of data acquisition from different heights proved to be really efficient in order to simulate satellite imagery measurements. In addition, measurements in the thermal infrared part of spectrum highlighted the potential of thermo-camera to detect urban heat island phenomenon.

At the near future, the research team will proceed to further critical evaluation of the 'mixed' pixels response with the use of more targets. After the collection of all required data, a complete and fully updated spectral database will be developed. The spectral signatures derived from the database will be incorporated in GIS environment and be used with other environmental and socioeconomic factors in order to develop a final innovative sustainability index.

Acknowledgements

The authors would like to acknowledge the Cyprus University of Technology/Department of Civil Engineering and Geomatics (Remote Sensing Laboratory) for supporting this study.

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