THE POTENTIALS OF LARGE-SCALE OPEN ACCESS REMOTELY SENSED READY PRODUCTS: USE AND RECOMMENDATIONS WHEN MONITORING URBAN SPRAWL NEAR CULTURAL HERITAGE SITES

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ABSTRACT

Recent studies show how remote sensing data elaboration practices have been shifted from (pre and post) processing of a few number of satellite images, to the use of an extensive dataset. Ready calibrated and validated satellite products, have been populated lately in the literature, driven by the open access policy of space agencies such as those of the European Space Agency (ESA), advance image processing (e.g., deep learning and machine learning) and availability of big data cloud infrastructures.
Nevertheless, this shift has not yet well-fitted with research questions and needs of a range of disciplines considered to be "application fields" from a geomatic and geospatial science perspective. In this paper we aim to showcase the challenges when using sophisticated collections such as Global Human Settlement Layer (GHSL) data for heritage applications. Cultural heritage domain relies on remote sensing information for purposes of mapping, monitoring and management and often requires tailored made considerations on the changing context that surrounds the single sites is presented. The paper gives some indications on use and recommendations when using this kind of data for monitoring urban sprawl near some cultural heritage sites in Cyprus.

Index Terms **—** Earth Observation, Cultural heritage, Global Human Settlement Layer, Copernicus, Sentinel-2, SDG

1. INTRODUCTION TO THE TOPIC

When adopted in 2015, the 2030 Agenda for Sustainable Development has stressed the importance of Geospatial Information and Earth Observations (EO), including satellite observations, to provide information for Sustainable Development (SDG) Targets and Indicators. In 2017, Andreson et al. [1] argue that one of the objectives was to "improve national statistics for greater accuracy, by ensuring that the data are "spatially-explicit" and directly contribute to calculate the agreed SDG Targets and Indicators support the fostering of synergy between the SDGs and multilateral environmental agreements".

Copernicus, the European Union's flagship Earth Observation and Monitoring programme, has been identified as a powerful instrument to help monitor these indicators and support the implementation of the SDGs. The unprecedented amount of data and information generated by Copernicus should hence support decision-makers in developing adequate policies to achieve the goals, and it should facilitate the monitoring of the SDGs.

Specifically related to the topic of Cultural heritage, the Target 11.4 of SDG 11 "Sustainable cities and communities" requires to *"Strengthen efforts to protect and safeguard the world's cultural and natural heritage"*. With this paper the authors explore the contribution of EO to this target, based on two ideas: (i) to observe the dimensions of the urban development in proximity of the cultural heritage sites of great importance (both in terms of urban extension as well as urban density); (ii) to use, for this purpose, the open (geospatial) information based primarily on the products of EO technologies such as Global Human Settlement Layer (GHSL).

2. RESEARCH QUESTIONS

Previous studies have showcased the importance of remote sensing and satellite sensors for capturing the dynamics of urban sprawl and especially the changes in the vicinity of cultural heritage sites [2-4].
In fact, although it seemed that the scientific literature does not fully explore the effects of "urban development", in [5] the authors argue that, on the bases of the reports examined (Grey literature), there is a very concrete perception of threat excreted by this phenomena, especially in those areas where there is a lack of systematic planning or a mature attention towards safeguarding the cultural heritage sites.

Relevant research shows how practice has been shifted from pre- and post- processing of limited number of satellite images [6], to the use of big data cloud infrastructures and sophisticated image processing [7]. Recently, ready big data products, previously calibrated and validated, have been populated in the literature, driven by the open access policy of space agencies and public programmes such as Landsat in the United States and Copernicus in European Union, , advance image processing (e.g., deep learning and machine learning) and availability of big data cloud infrastructures.

In this paper we aim to showcase this shift using the Global Human Settlement Layer (GHSL) data, over the span of several decades, specifically from 1975 to 2020. A series of scenarios were examined at specific periods and analysis of diachronic maps have been used to illustrate and discuss the changes occurring around two important cultural heritage sites in Cyprus.

3. HOW CAN EO-BASED INFORMATION BE USEFUL TO STUDY A NON-SUSTANABLE URBAN DEVELOPMENT AS A THREAT TO CULTURAL HERITAGE?

Before diving into practical aspects on data used and tests conducted on specific case studies, authors retain necessary to better explain the choice of satellite remote sensing technologies and its specific derivatives for monitoring of threats such as urban planning, usually monitored by more traditional instruments and mapping products.

Contemporary urban growth is highly characterised by suburbanisation. Urban sprawl is generally defined as the *“rapid and uncoordinated growth of urban settlements and their fringes, associated with modest population growth and sustainable economic growth”*. Local connotation of urban sprawl is highly dependent on the cultural, geographic and political context where sprawl is taking place. For example, there are substantial differences in the definition of this phenomena in Europe and in United States.

In 2010, Besussi [8] labels the three main elements that define how cities develop and grow are: i) the infrastructure; ii) the people and iii) the economic activities. The interactions between these domains are directly related to the development of the global economy, and they manifest in building and transportation technology, underlining the importance of both economic and technological development.

From a satellite remote sensing perspective, the extent of urban area regards the definition of urban artificial structures occurring irreversibly on the surface of the Earth. Remote sensing methodology uses the classification process of surface reflectance characteristics, and it is usually based on comparable measures of contrast between natural and artificial land cover. Such methodology further proposes indicators able to measure the extent and magnitude of size and changes in urban fabric and hence its natural surroundings.

Considering the three city “ingredients” mentioned, it can be argued that, since it is able to provide direct indication of the physical form and morphology of urban land cover in cities, remote sensing data can represent a powerful complementary source to traditional socio-economic surveys. In developing countries, for example, where socio-economic framework data might not be available, it is seldom regularly updated or even freely accessed and validated, remote sensing data can be of great very use for urban changes (and urban sprawl) monitoring.

Experts remind that, to fully study urban structure and growth these three components should be integrated: remote sensing data, detailed socio-economic data on urban distribution (census) and data from national mapping agencies. Besussi et al. [8] further argue that the ways in which urban remote sensing might be able to provide data that can be complemented by traditional socio-economic data was at its “infancy stage”. One of the reasons for this is that although increasingly at a high level of detail and spatial precision, VHR remote sensing images of urban areas still say, “rather little about urban lifestyles, unless supplemented by socio-economic data”. It is crucial, from urban studies point of view, to fuse socio-economic data which is much more scale dependent in terms of the way it is structured and delivered, that remote sensing data.

From earth observation studies perspective, it can be added that such discrepancies occur also due to a basic difference in these two macro-datasets. The socio-economic information on a given territory is usually is refers to statistical units – in Europe for example they refer to Nomenclature of territorial units for statistics (NUTS) – and these are represented as boundaries or areas (hence using vector formats). It is very important to note that these are “a-priory” decided boundaries i.e. even if varying in time, there is a strict (vectorial) definition of their size and form. Remote sensing imagery, on the other hand, is delivered as a continuum of matrixes of pixels and over different wavelengths (in raster format over multiple spectral bands) that, to be matched to a distinct parameter must be classified. A classification can be based on physical patterns, such is the case of urban development or urban sprawl analysis. Such classification, however, will be highly dependent on the class definition and hence ability to define a series of “appropriate samples” of urban sprawl that should be as extensive as possible to truly define (or improve a definition) of the areas subject to urban sprawl on a given satellite (or airborne) imagery.

This brings us back to the initial statement of the importance of the ground truth data for validation and potential calibration of assumptions based on earth observation data only. Authors perfectly acknowledge and support this kind of procedures and it is in this perspective that we would like to illustrate the use of earth observation - based information that has been proceed in this logic framework that is to say the GHSL layer that *“relies on the design and implementation of spatial data processing technologies that allow automatic data analytics and information extraction from large amounts of heterogeneous geospatial data including global, fine-scale satellite image data streams, census data, and crowd sourced or volunteered geographic information sources”* [9].

4. DATA SET AND METHOD ADOPTED

4.1 Global Human Settlement layer dataset

The GHSL – Global Human Settlement Layer, is a freely distributed dataset developed and provided by the Joint Research Centre (JRC) for the European Commission [9]. Based on the GHS Report [10] *"The Global Human Settlement Layer (GHSL) project produces new global spatial information, evidence-based analytics and knowledge describing the human presence on Earth. It operates in a fully open and free data and methods access policy"*.

The GHSL Data Package, released in 2023, contains the following products:

- GHS-BUILT-S: GHS built-up surface spatial raster dataset
- GHS-BUILT-H: GHS building height dataset
- GHS-BUILT-V: GHS built-up volume spatial raster datasets
- GHS-BUILT-C: GHS Settlement Characteristics
- GHS-POP: GHS population spatial raster dataset
- GHS-SMOD: GHS settlement layers, application of the Degree of Urbanisation method
- GHS-DUC: GHS Degree of Urbanisation Classification, application of the Degree of Urbanisation methodology
- GHS-SDATA: GHS release supporting data
- GHS-BUILT-LAUSTAT: GHS built-up surface statistics in European Local Administrative Units

For the purposes of this paper, authors have used the GHS built-up surface spatial raster dataset (GHS-BUILT-S).

4.2 Processing method applied on GHSL selected data

As explained by the Report, GHS-BUILT-S spatial raster dataset illustrates the distribution of the built-up surfaces estimates between 1975 and 2030 in 5-year intervals and two functional use components a) the total build-up surface and b) the non-residential build-up surface. The GHS layer is derived from the analysis of the Copernicus based Sentinel-2 composite (since 2018) as well as the Landsat sensors since 1975. Values of each raster dataset are expressed as 16bit integers (unit) with a range between 0 - 10,000 and represent the number of square meters of built-up surface (also known as a "building footprint") in the cell. More information related to the analysis of these products can be found in the relevant report [10].

The GHS-BUILT-S products for the years 1975, 1980, 1985, 1990, 1995, 2000, 2005, 2010, 2015 and 2020 have been downloaded over the area of Cyprus and Greece (Tile ID: R5_C21). The spatial resolution of these raster datasets was 100 meters. These raster datasets were downloaded at a local computer and further processed in the ArcGIS Pro environment (v. 3.0.2). The analysis included: (a) cartographic maps per product; (b) investigation of pseudo-color composites by combining all the information of the raster tiles; and (c) Principal Component Analysis (PCA).

The latest was used so as identify significant changes during the whole period of this study, as the first principal component (PC1) can enhance the variance of the dataset, which can be linked to the (land-use) changes and specifically the changes in the values for the built-up surface. In addition, difference maps between pairs of products for the years 2022 (latest available data) and 1975 (earliest available data) have been applied to showcase the changes in the bult-up surface, in specific areas of interest.

5. FIRST RESULTS

Figure 1 depicts the built-up areas between 1975 (top) and 2020 (bottom) products. Areas with the highest percentage of built-up surface is shown with yellow color while lower percentage of built-up surface within each pixel is shown with blue color.

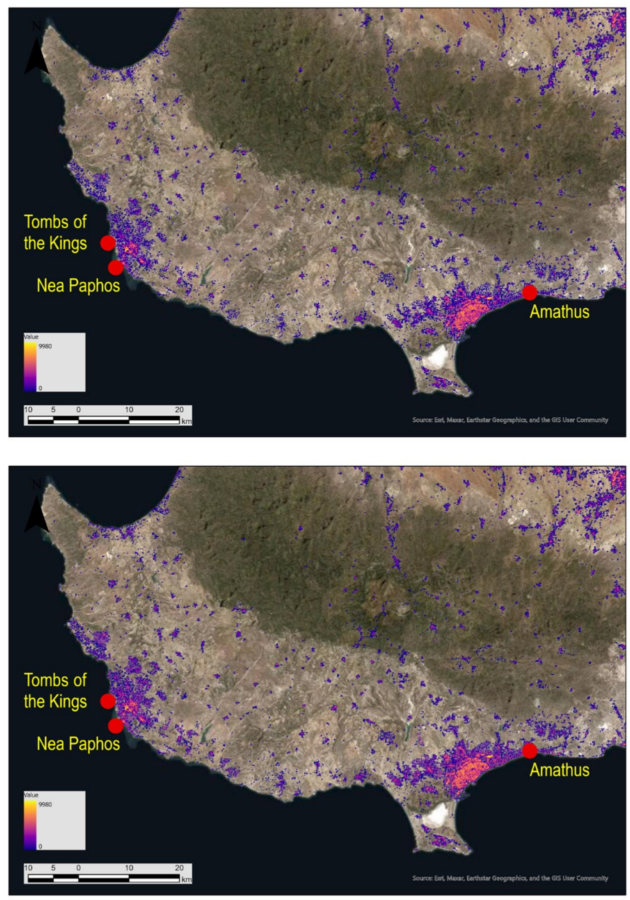

Figure 1 Built-up areas between 1975 (top) and 2020 (bottom) products near three important archaeological sites of Cyprus: UNESCO World Heritage sites of Tombs of the Kings and Nea Paphos and the archaeological site of Amathus near Limassol.

A closer look into specific areas of interest in Cyprus can showcase the significant changes occurred in the built-up surface during the period 1975 to 2020.

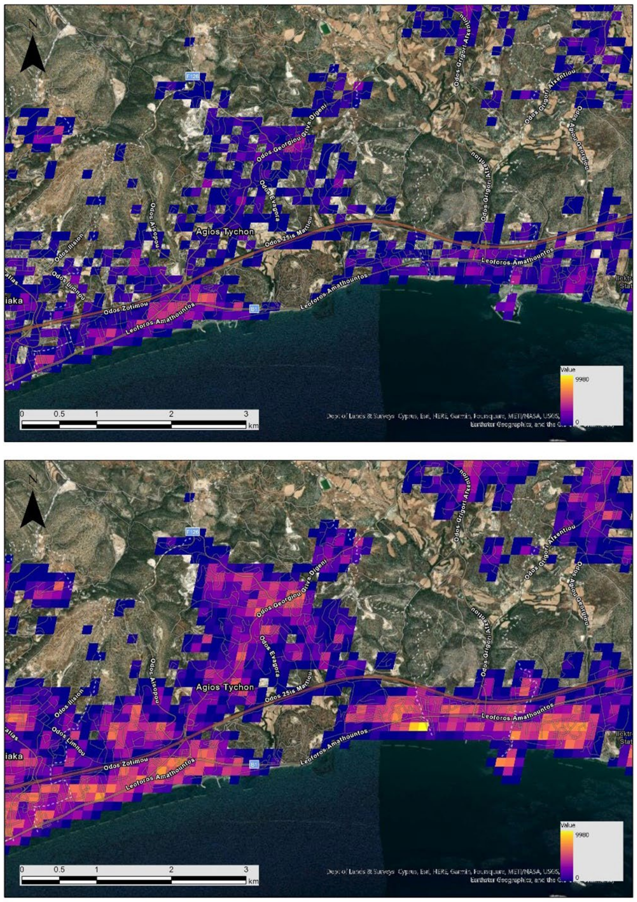

Figure 2 Built-up areas between 1975 (top) and 2020 (bottom) products near the Amathus archaeological site, in Limassol, Cyprus.

The increase of urbanization in this period around specific areas such as (a) Amathus archaeological site in Limassol and (b) Nea Paphos and Tombs of the Kings in Paphos district (UNESCO World Heritage Sites), is shown in Fig. 2 and 3.

Significant changes in the surrounding area of the Amathus archaeological site (Figure 2) are observed by comparison the data products of 1975 (Figure 2, top) and 2020 (Figure 2, bottom). Simillar observations are also reported for the sites in Paphos district (Figure 3). This result is also compatible with the results generated in [6] using supervised classification method on Landsat images.

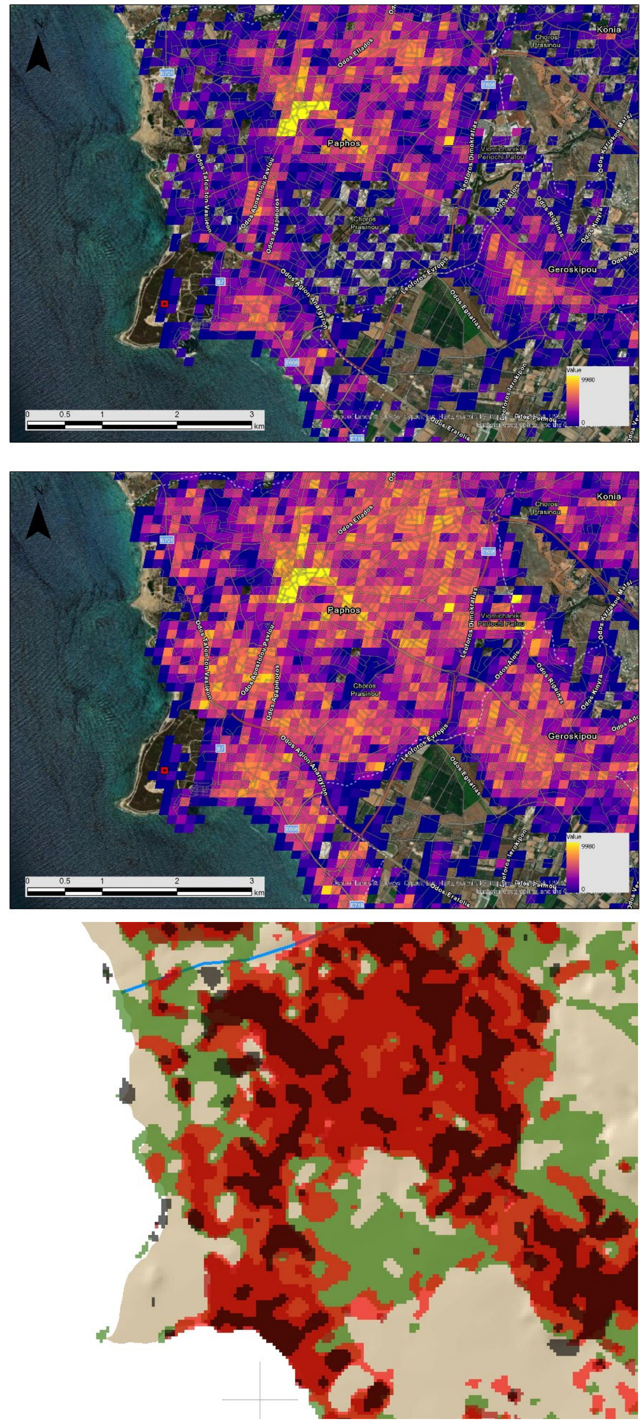

Figure 3: Built-up areas between 1975 (top) and 2020 (middle) products near the Nea Paphos and Tombs of the Kings archaeological sites, in Paphos, Cyprus as mapped from the GHSL. On the bottom is the result of a supervised classification using Landsat imagery from 1984 to 2010. Black colour indicate urban year interval) areas in 1984; orange colour the urban areas of 1990; red colour the urban areas of 2000 and green colour the urban areas of 2010 [6].

The built-up areas have been extracted from the two products obtained in 2020 and in 1975. A difference map was then created and is shown in Figure 4.

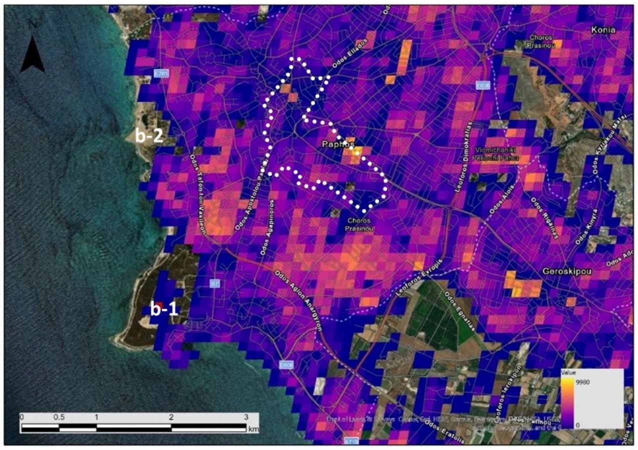

Figure 4: Difference between the built-up areas from 1975 to 2020 near the Nea Paphos (here b-1) and Tombs of the Kings (here b-2) archaeological sites, in Paphos, Cyprus (same scenery presented in Figures 5 and 6).

The increase in bult-up areas can be found near the Paphos city center (white dotted line at Figure 4), while in general changes are observed in the entire landscape of the modern city. These changes have taken place in a proximity to the Nea Paphos and Tombs of the Kings archaeological sites (here b-1and b-2).
At the same time pseudo color composites using the different GHS products can be elaborated to further support visual inspection, interpretation, and mapping of the built-up areas through time. In Figure 5, an example of such pseudo color composite can be seen using the 1975, 1990 and 2020 products. Red band refers to the product 2020, green band to the product 1990 and blue band to the product 1975. White pixels indicate areas that have changed significantly during the whole period that was studied (center of the Paphos city). Red color pixels indicate areas that have increased the percentage of bult-up areas during the period 1990 to 2020.

Figure 5: RGB pseudo color composite near the Nea Paphos and Tombs of the Kings archaeological sites, in Paphos, Cyprus. Red band refers to the product of 2020, green band refers to the products of 1990 and blue band refers to the product of 1975.

Similar observations can be made using entire datasets and performing the PCA analysis. Figure 6 shows the first three principal components (PC) as follows: PC1 with the red band, PC2 with the green band and PC3 with the blue band. It can be observed that areas within and close to the town center have significantly changed during the whole period from 1975 to 2020 (red and magenta pixels). Some of these areas are in a very closed proximity with the Nea Paphos archaeological site on the eastern part.

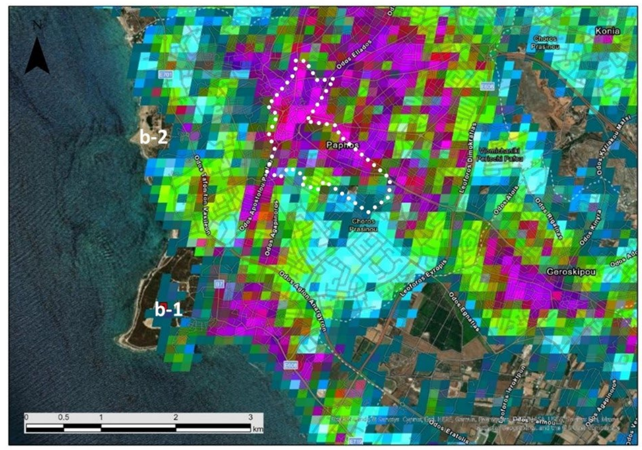

Figure 6: PCA analysis using the GHS datasets for all the selected years. PC1 is depicted with the red band, PC2 with the green band and PC3 with the blue band.

6. DISCUSSION

Some observations can be made on these two examples. As far as Amathus site is concerned, the changes can be observed in terms of extension of the surface occupied by built-up surface (new pixels) as well as in terms of density of those areas (the change in pixels colour intensity on the scale 1 to 10,000). Regarding Nea Paphos WHS, the extension of the surface occupied is relatively low but there is noticeable change of pixels intensity and hence of density of occupied surface within single pixel units. This is shown rather well in Figure 4 that represents the actual change in in new terrain occupancy by extension and characteristics.

Figure 5 and Figure 6 provide an even better insight on the impact of changes, especially in the vicinity of archaeological sites. These changes are also aligned with previous investigations [3-4] indicating an increase of urbanization process in the last years in Cyprus. While new constructions can support local economy, a major problem is generated when these constructions, such as in the case of Limassol with new sky-towers, or in Paphos with extensive large-scale construction projects, are happening in short period, with no time left to the local stakeholders to proceed with the necessary proper documentation surveys.

The effects of sudden hazards, either natural such as earthquakes or anthropogenic like armed conflict, could cause damages of a more obvious kind, requesting for an emergency response in terms of investment, planning and management. By contrast, the impact of urban sprawl or the impact of poorly planned development within the existing urban texture, can occur rather slowly, sometimes over a several decades. Often, the real degree of this kind of impact is captured only after a long time of observations and it can cause a permanent alteration of the site and its surrounding landscape. Without a proper methodology for documentation and research, the cultural heritage assets, especially archaeological remains found in proximity of modern urban contexts, could in some cases be irreversibly destroyed.

In this framework, the use of multi-temporal satellite data, or satellite-based ready products such as GHSL showcased here, could offer a more holistic visualization of landscape changes, in dimensions of both time and space. In countries like Cyprus, such a support could provide a better understanding on the scale of the changes that took place in a specific period of time and on the potential impact of such modifications to the overall landscape. An improved knowledge of the effects could hence contribute to a more informed decisioning process when it comes to the management, and finally to the preservation and maintenance, of the cultural heritage monuments and sites.

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