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MULTI-SENSOR AND MULTI-TEMPORAL OPTICAL/SAR GIS DATA INTEGRATION FOR URBAN SPRAWL MONITORING OF THE DISTRICT OF ROME: A GEOSTATISTICAL APPROACH

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KEY POINTS

- *UAP Index, SENTINEL-1B, SENTINEL-2A, PLEIADES, COSMOSKYMED, GIS, Urban Sprawl*

1 PREMISE

Nowadays continuous monitoring of urban areas is required to a) keep track of the loss of natural zones due to urban development and b) support urban planning activities. Urban areas are particularly vulnerable, not only because of the concentration of population but also due to the interplay that exists between people, infrastructures and natural or man-made risks. Mainly based on the continuation of our past study, carried out since the early 1980s at the European Space Agency, the present analysis, always in progress, is conducted to examine past and current effects of the urbanization process occurred over the large Roman urban area. Overlays of optical/radar satellite images, collected over a three years period, were validated via Geographic Information System (GIS) techniques, in a particular procedure applied to urban land/agricultural transformations.

2 STUDY AREA

Rome is the largest city and commune in Italy (1287 km^2) and it is also one of the fast growing urban agglomeration in the world: this growth has unprecedented effects on sprawl and population dynamics. In the last decades remarkable urban sprawl took place in Rome, especially along the consular roads, which are still the principal infrastructures available for transportation, causing significant environmental impacts, whereby natural surfaces were replaced by buildings, with the consequence of disappearance of vegetated areas, increased soil sealing and atmospheric pollution. As shown by Martino & Loret (2017) the road network constitutes in fact the key geographic object spatially structuring the urban growth of Rome and represents a good target for any multi-temporal satellite view.

3 MATERIALS & METHODS

Each mission (*see* Table 1) used its own unique suite of instruments to monitor the territory and a wealth of interesting properties of the area of interest was gathered from their combined results. Processing techniques were used to get each image from its original format into a projected map (UTM ED-1950/33N) and consequently vectorized in order to obtain GIS compatible formats (.shp files). A GIS multi-relational database was built and integrated with the available remotely sensed data. A workspace has been therefore created for scientific management and orientated thematic information.

The base layer contains information on the features identified in the selected area of interest (vegetated, urbanized, and so on). The basic recorded attributes are "type" and "area" essential to define the type of

urban areas (layer of buildings), in order to analyze the density in that area.

Work steps can be summarized as follows:

- Optical/RADAR images processing: geo-referencing and geometric correction;
- Radar data: Sigma 0 bands, speckle divergence and coherence bands extraction;
- Definition of the Areas of Interest (AOIs) and subsets (image cropping) creation;
- Optical supervised and SAR Random Forest (RF) classifications vs Corine Land Cover (CLC) model;
- Vectorization of surface values and grid alignment;
- Urban growth analysis trough the Kernel Density Estimation (KDE) function;
- Urban Area Profile Index (UAPI) application, modeling and multi-temporal correlation;
- Interpretation and validation of results.

Available imagery enabled a direct comparison of different areas of interest across the surface of the city, allowing visual interpretation and validation for urban growth.

Table 1. Optical/radar remote sensing datsets

Satellite	Sensor	Product type	Processing level	Acquisition mode	Resolution	Year	Nr.of images
Pléiades	HiRI	MS + PAN	1 projected	--	2/0,5m	2015/16	12
SENTINEL-2A/B	MSI	MS	L1C	--	10m	2015/16	2
CSK	SAR	X-band	L1A SCS_B	SM Himage	3m	2015	2
SENTINEL-1A/B	SAR	C-band	L1 GRD	IWS	10m	2017	2

4 RESULTS & DISCUSSIONS

Image data were concurrently processed and fused into the GIS multi-relational database thus allowing an easier discrimination of the urban landscapes, especially in a dense and heterogeneous area such as the district of Rome (Martino, 2015). This in fact allowed detection of individual features, such as large buildings, roads and small fields, namely to spot an awful lot of new details that are crucial in terms of land-use change applications. For optical sensors and following identification of the main spectral classes, ad-hoc corrections were applied for improving difficult target discrimination when same radiance values occurred, as in the case of tiled roofs presenting rural field like spectral response.

Survey of the urbanized classes has been executed to understand the evolution of surface expansion (*see* table 2) and the densely populated areas. On the other hand sensing geometry of radar and especially side looking led to some difficulties in mapping urban areas due to shadowing effects.

Despite this radar imagery permitted accurate building detection (raw); mathematical morphology (enriched) was applied on results in order to discriminate complex urban soil textures and perform surface and density statistics (Garioud, 2017).

Table 2. Variation of the surface extension of the district of Rome per sensor

	Urban soil				Buildings only		
SENSOR	S-1A/B	S-2A/B	CSK	CSK + Pleiades	CSK (raw)	Pleiades	CSK + Pleiades

SURFACE (Km^2)	309,95	354,47	300,78	359,75	186,95	188,85	288,42

Worth to highlight how common limitations in urban growth analysis such as lack of classification accuracy, difficult target discrimination or overestimation of urban classes, were however prevented by the joint use (product level fusion) of optical and radar GIS datasets. Urban areas derived from the afore-mentioned classifications were processed in density classes and analyzed through the UAP Index procedure. UAP index has been defined in order to produce a quantitative descriptive summary of the spatial arrangement of the different land uses, which allows an easily understanding of the environmental or multi-temporal framework of the territory (Loret, 2012).

The Urban Area Profile Index formula is:

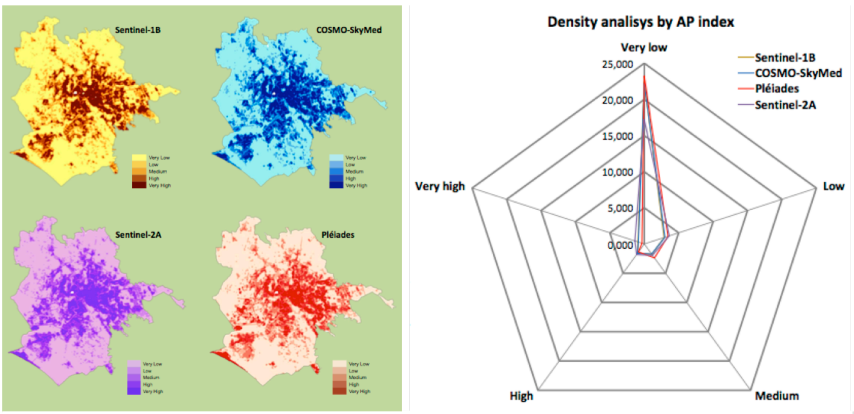
$$UAPi = \sum_i \frac{Sx(Ci/Ct)}{St} \qquad (1)$$

Where:

UAPi is the area profile index for the density class i and the land use x, Sx is the total area for the specific land use (x), Ci is the number of cells in density class i, Ct is the total area cells and St is the total municipal area. A logical model has been adopted to evaluate the UAP index.

UAP index, as shown in (1), is therefore based on the measurement of spatial relationships among the density distribution of each land use and on the comparison of each distribution with the total amount of each specific land use area.

When discussing density values (*see* Figure 1), the comparison between the UAP indexes calculated from optical and radar data indicated a clear density decrease in the "very low" values, which seems to suggest a form of compacting and welding of the urban territory within the 2 years' time difference between acquisitions. More in general the urbanization trend is positive within the study area and slowly filling up (compaction of the dispersal areas) the gaps left by the sprawl phenomena previously occurred. Remarkable urban sprawl took place especially along the consular roads (connecting the city center with external areas), in particular in the eastern part.



		Density by AP index			
	sensor	Pléiades	COSMO-SkyMed	Sentinel-1B	Sentinel-2A
classes value	Very low	23,249	22,287	22,426	17,227
	Low	3,431	2,991	2,878	3,626
	Medium	2,392	1,723	1,764	1,935
	High	1,360	1,604	1,534	1,821
	Very high	0,337	0,857	0,911	1,363

Figure 1. Urban density maps and analysis of the UAP index values per mission

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