Advantages of Identifying Urban Footprint using Sentinel-1

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Key words: Urban Footprint Mapping, Remote Sensing, Sentinel-1

SUMMARY

This article shows the result obtained for generating the urban footprint. The case study is based on Sentinel-1 images, having as objective the city of Bucharest. Based on coregistration and calculating coherence operations, and also applying raster mathematical operations, the relevant results in the studied area were obtained. It is also highlighted the possibility of using those results in urban development studies and spatial planning. ESA's free software solution responds successfully to the requirements of satellite imagery and the obtained results can be integrated successfully with other elements in software products such as ArcGIS Pro.

REZUMAT

Acest articol prezintă rezultatul obținut pentru generarea amprentei urbane. Studiul de caz se bazează pe imaginile Sentinel-1, având ca obiectiv orașul București. Bazându-se pe prelucrarea și pe aplicarea operațiilor matematice raster specifice, s-au obținut rezultate relevante în zona studiată. Este subliniată, de asemenea, posibilitatea utilizării acestor rezultate în studiile de dezvoltare urbană și în planificarea spațială. Solutia software free de la ESA răspunde cu succes pentru obținerea rezultatelor pe baza imaginilor satelitare, iar rezultatele obţinute se pot integra cu succes împreună cu alte elemente în produse software precum ArcGIS Pro.

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1. INTRODUCTION

Satellite imagery is one of the best ways in order to get fast and detailed information, having an important role in the decision making and developing spatial analysis and processes.
Urban monitoring is an actual trend because an increasing number of people live in urban areas and the major cities are growing, covering more and more land. From 2011 to 2050 world's urban population is expected to grow from 3.6 billion to 6.3 billion and 83 % of governments are concerned about their population distribution in the country. [6]
Urban mapping from the spatial planning viewpoint has become more important with the growing of urban areas due to population increasing around metropolitan areas in developing countries. A similar case is the area around Bucharest, Romania, where the built-up areas were increased very much. A higher urbanization is the cause of environmental pollution, traffic congestion and the destruction of natural resources.
Geospatial information provided by satellite imagery is very important for planning and identifying suitable locations for human settlements and infrastructure development. It is recommended the integration of satellite-based information with other socio-economic and field environmental datasets. Using this integrate information, the city planners can broad their understanding of urban ecology necessary for them to design smart cities resilient to the impacts of climate change. [13]

2. SENTINEL-1

Sentinel-1 satellite images was funded by European Union and was carried out by the ESA in Copernicus Programme and in present they are provided for free and open access.
Sentinel-1 is in orbit since April 2014 and the most common is the Interferometric Wide (IW) swath mode. There are GRD data products available, with VV+VH polarisation. [7] The main data products are mentioned in figure 1.

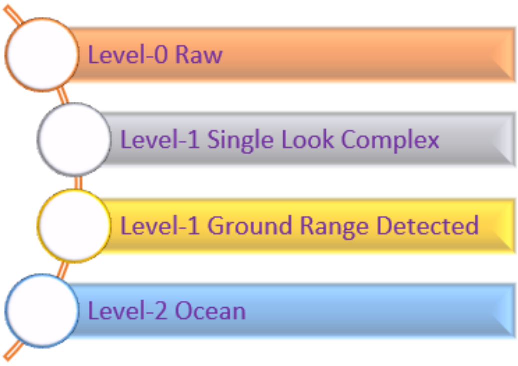

Figure 1 - Sentinel-1 Data Products (according to [9])

Level-1 Single Look Complex (SLC) products consist of focused SAR data, geo-referenced using orbit and attitude data from the satellite, and provided in slant-range geometry. Slant range is the natural radar range observation coordinate, defined as the line-of-sight from the radar to each reflecting object. The products are in zero-Doppler orientation where each row of pixels represents points along a line perpendicular to the sub-satellite track. [9] The Swath Timing data set record in SLC products contains information about the bursts including dimensions, timing and location that can be used to merge the bursts and swaths together.

Table 1 – Sentinel-1 parameters (according to [9])

Satellite	Sentinel-1
Centre Frequency (GHz)	5.405
Polarization	VV
Incidence angle range	29.1 - 46
Swath Mode	Interferometric Wide swath (IW)
Swath width(km)	250
Spatial resolution (single look)(m)	5 × 20
Product used	Level-1 SLC Product

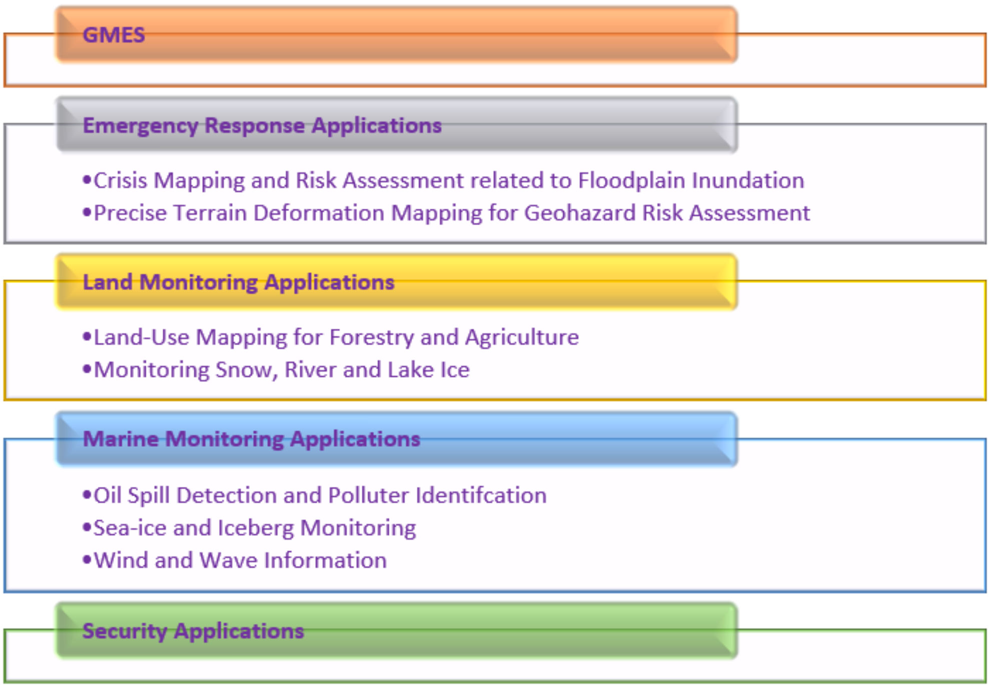

Figure 2 – Examples of Sentinel-1 Applications (adapted from [9])

According with [5], there are the following types of change detection algorithms developed and tested over the years. The main algorithms, highlighting different aspects of the process, are presented in figure 3.
The condition for obtaining good results is that the multitemporal images to be preprocessed to ascertain that they are spatially and radiometrically comparable. This step is accomplished by image-to image registration, the corresponding pixels in the images referring to the same geographic location. This step can be difficult when the images have a high spatial resolution or contain high frequency components. The two spatial resolutions for SAR - range and azimuth resolutions - are different from azimuth and range direction. Range resolution depends on bandwidth and he azimuth resolution, due to the moving platform causing Doppler shift, depending on the antenna length in the along-track direction. [2] In the analysis of change detection, an inaccurate image-to-image registration is one of the main source of errors and can lead to a significant degradation in accuracy. [5]

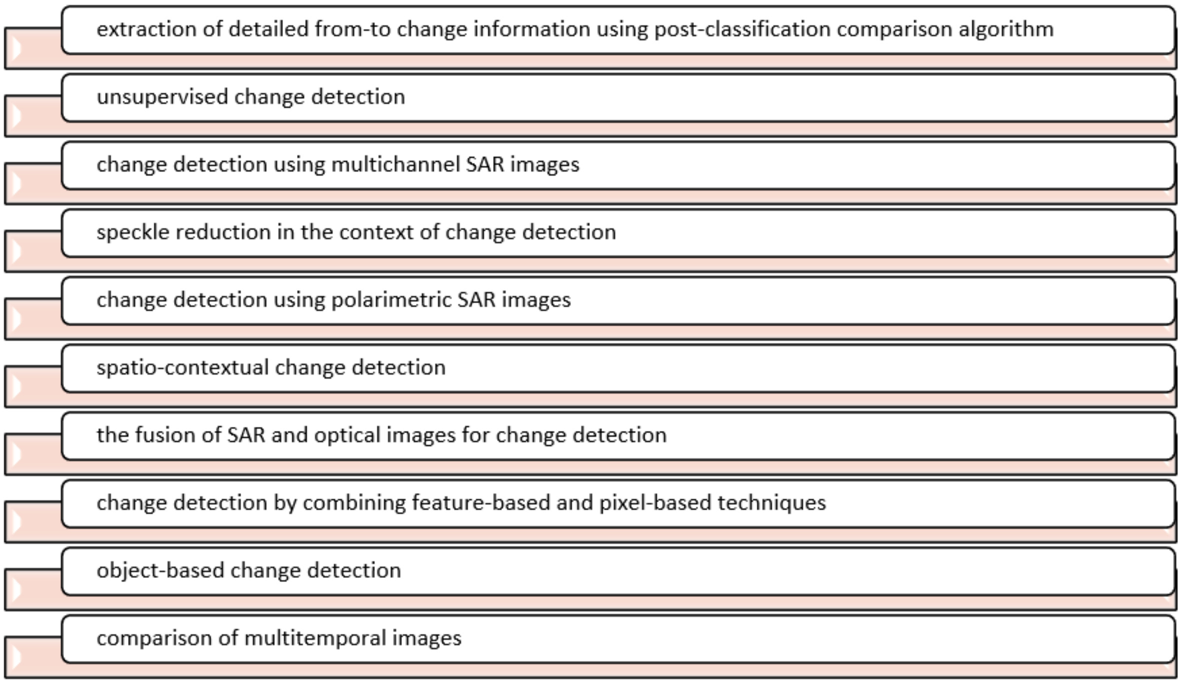

Figure 3 – The main types of change detection algorithms (according with [5])

3. CASE STUDY

The study area is located in and around Bucharest, capital of Romania. (figure 4) Population of Bucharest as of 2017 is 1826506. [8] It is an area having a fast growth in Romania, and therefore having increasing population (figure 5 and 6) and change of landscape. The spatial planning studies can be very useful in such areas in continuous development.[10]
The reference data for the administrative boundaries were taken from INIS geoportal – Romania National Agency of Cadastre and Land Registration. [11]

(http://geoportal.ancpi.ro/geoportal/catalog/download/download.page)

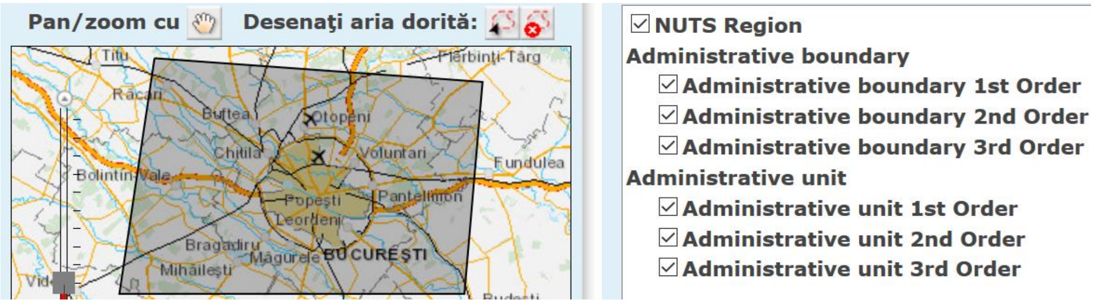

Figure 4 – Downloaded Data as shp file

Rezultatele cautarii - Populatia rezidenta la 1 ianuarie pe grupe de varsta si varste, sexe si medii de rezidenta, macroregiuni, regiuni de dezvoltare si judete				
Varste si grupe de varsta	Sexe	Medii de rezidenta	Macroregiuni, regiuni de dezvoltare si judete	Ani Anul 2017 UM: Numar persoane Numar persoane
Total	Total	Urban	Municipiul Bucuresti	1826506

Figure 5 – Population of Bucharest (according to [8])

Rezultatele cautarii - Populatia rezidenta la 1 ianuarie pe grupe de varsta si varste, sexe si medii de rezidenta, macroregiuni, regiuni de dezvoltare si judete				
Varste si grupe de varsta	Sexe	Medii de rezidenta	Macroregiuni, regiuni de dezvoltare si judete	Ani Anul 2017 UM: Numar persoane Numar persoane
Total	Total	Total	Ilfov	460355

Figure 6 – Population of Ilfov County (according to [8])

According with [14], Sentinel-1 data offer promissing results for SM & IW modes. Having images from ascending and descending orbits or when those are also available in two polarizations, the results are over 80% urban detection. There are still some problems with low density builtup extraction (individual houses surrounded by gardens). The combination of spectral, spatial and temporal requirements determines in turn some constraints on the data sets and the algorithms that can be used. [14]

In the case study Level-1 Single Look Complex (SLC) products with VV polarization are used. IW mode was chosen because bursts are synchronized from pass to pass to ensure the alignment of interferometric pairs, and it is Sentinel-1's primary operational mode over land. [4]

SLC data is including complex imagery with amplitude and phase information. Phase information is significant as the fraction of a single SAR wavelength, and distance information about the Earth's terrain is extracted from phase difference between observations of the same area. [4] Another advantage of SLC data is having polarized bands:

- typical single-pole system - transmits horizontally or vertically wave and received the same (VV or HH)
- dual-pole system - VV and VH imagery.

Thermal noise which would affect the quality of an image needs to be removed. Calibration is necessary for the comparison of SAR images acquired with different sensors, or acquired from the same sensor but at different times. Calibration is applied to provide imagery in which the pixel values can be directly related to the radar backscatter of the scene, converting the pixel data to actual backscattering values.

The product is composed by focused SAR data in the slant range geometry, with phase and amplitude information. The coherence was measured and processed through Sentinel-1 toolbox (S1TBX), developed by ESA. The workflow is described in figure 7.

Co-registration process is used in order to combine two images having the same polarization and projection system, that were taken at different points in time and altitude. This method is used mostly for InSAR processing. [7] The images were first splitted into 3 sub-swaths, to have a faster processing. Sub-swath which consist of the studied area was selected. Because acquisition mode of S1 produces bursts or subsets of swath, in order to merge them into one continuous image, it was made a deburst operation, with VV polarization. The digital elevation model SRTM is 3 sec and was used a bilinear interpolation with coordinate system WGS-84.

Due to topographical variations of a scene and the tilt of the satellite sensor distances can be distorted in the SAR images. Terrain corrections are intended to compensate for these distortions so that the geometric representation of the image will be as close as possible to the real world. Then, the geometry of topographical distortions in SAR imagery was corrected. [4]

Table 2 - Characteristics of the Sentinel-1 IW measurement mode [9]

Parameter	Interferometric Wide-swath mode (IW)
Polarisation	Dual (HH+HV, VV+VH)
Access (incidence angles)	31° – 46°
Azimuth resolution	20 m
Ground range	5 m
Azimuth and range	Single
Swath	250 km
Maximum Noise-Equivalent Sigma Zero (NESZ)	−22 dB
Radiometric stability	0.5 dB (3cT)
Radiometric	1 dB (3cT)
Phase error	5°

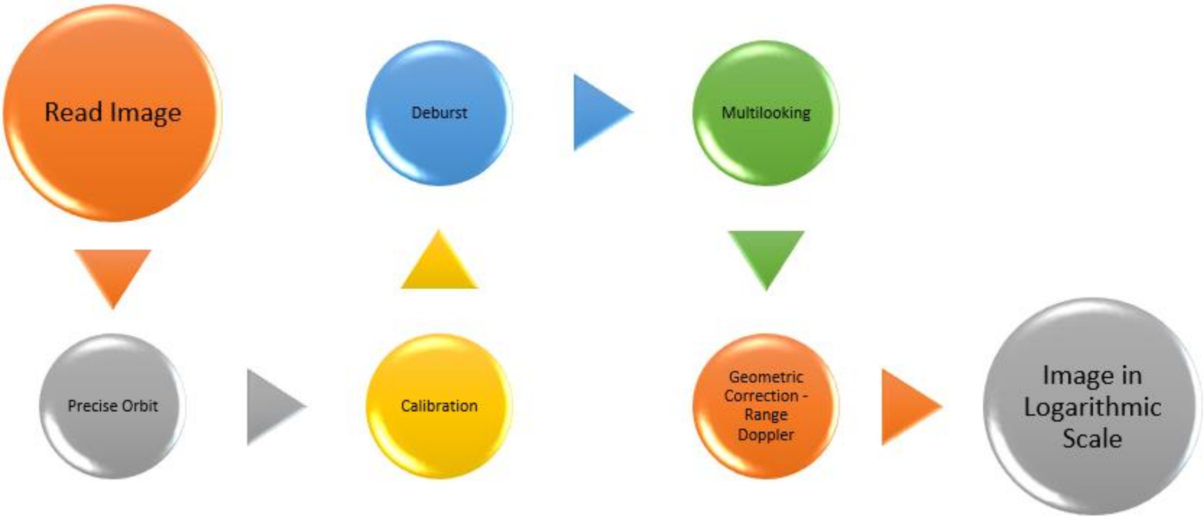

Figure 7– Workflow for each image – main steps

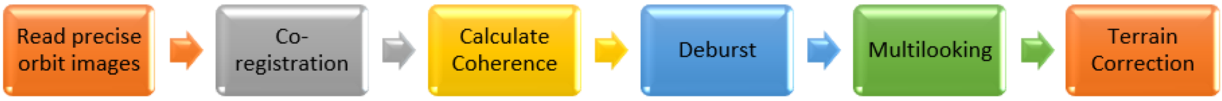

Figure 8 – Creating coherence image – main steps

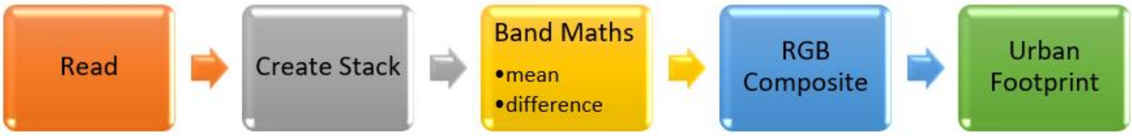

Figure 9 – Workflow - obtaining the urban footprint – main steps

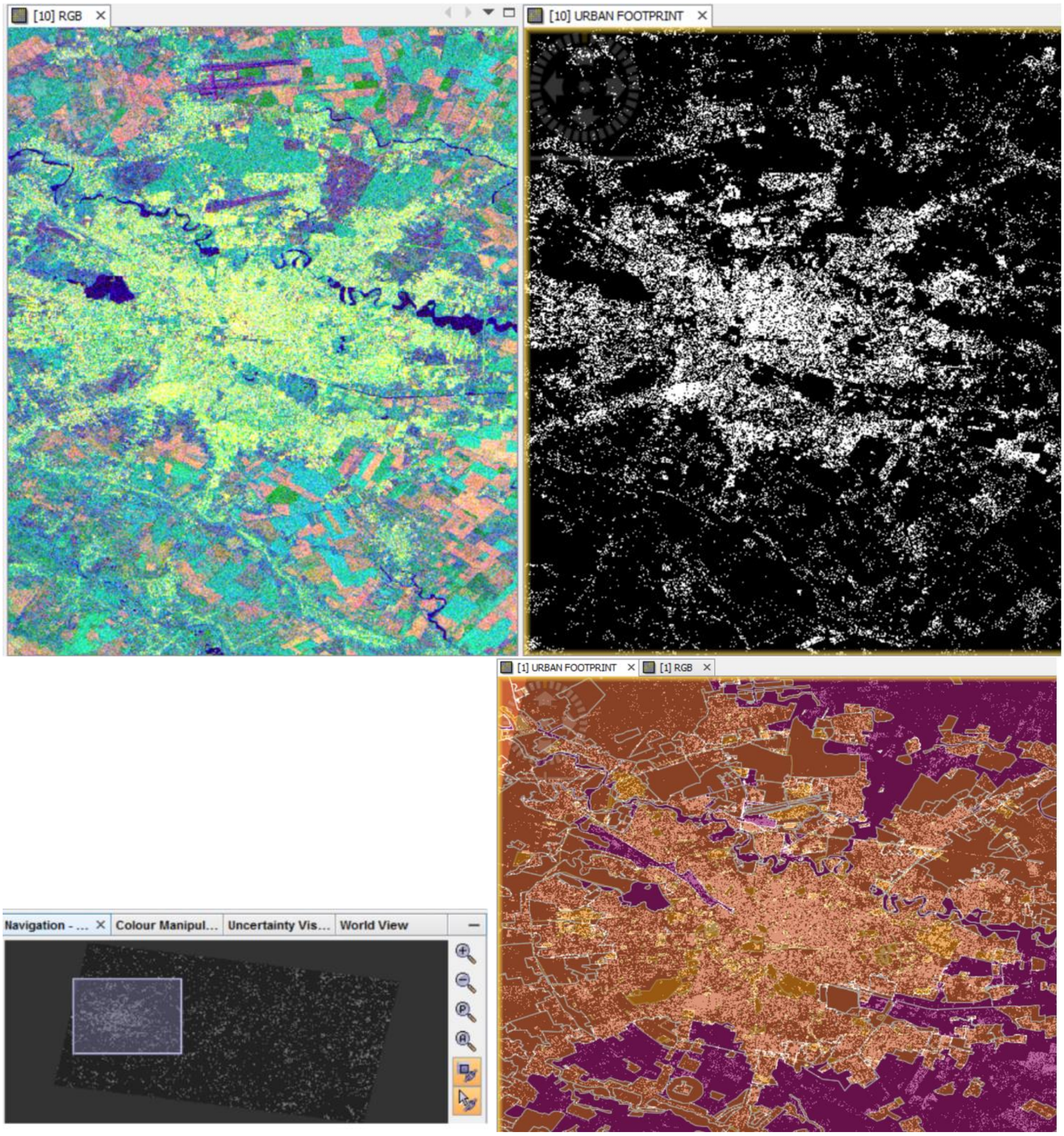

Figure 10 – Urban Footprint

According with [7], the areas with high coherence in the RGB composite are those areas that are stable between two acquisitions, e.g., urban areas, bare soil. The areas having a low coherence are emphasizing areas that has been changed between two acquisitions, e.g., volume decorrelation, forest areas.

A high backscatter means double bounce, volume scattering, e.g., urban and forest areas, but a low backscatter means single bounce, e.g., agriculture, bare soil.
Based on this, red colored areas have low backscatter and high coherence values, meaning agriculture / bare soil and yellow colored areas have high backscatter and high coherence values, being urban areas. Using threshold values for backscatter/coherence we obtained the urban masks.
According to [14], "very high spatial resolution" means a pixel posting of 1 m or less, "high resolution" from 3 to 5 m, "medium resolution" from 10 to 100 m, and "moderate resolution" more than 100 m (typically 250, 500 or 1000 m). In figure 11 is emphasized the correlation between spatial and spectral resolution of EO data.

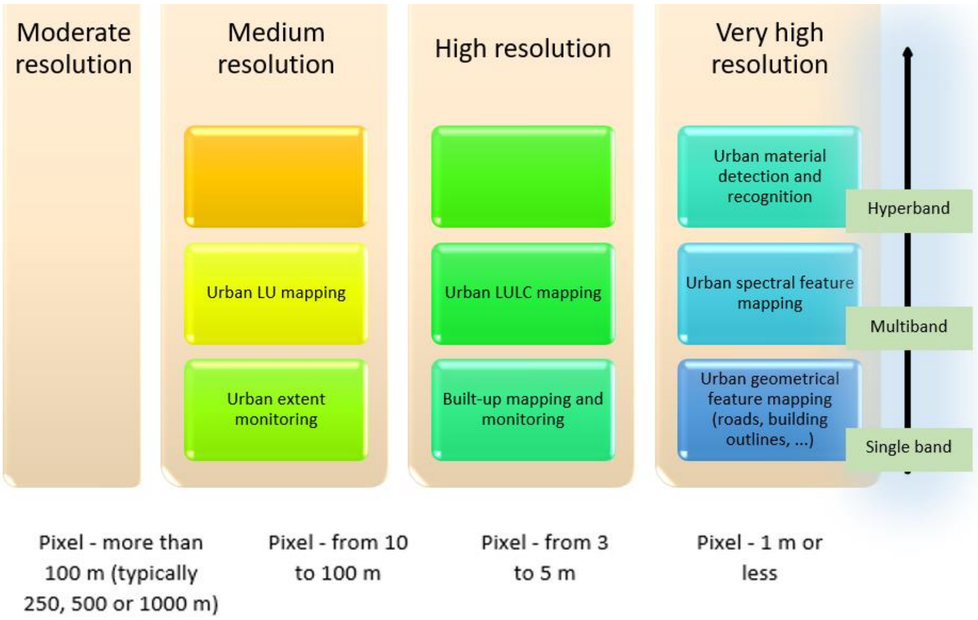

Figure 11 - Correlation between spatial and spectral resolution of EO data and the mapping task (adapted from [14])

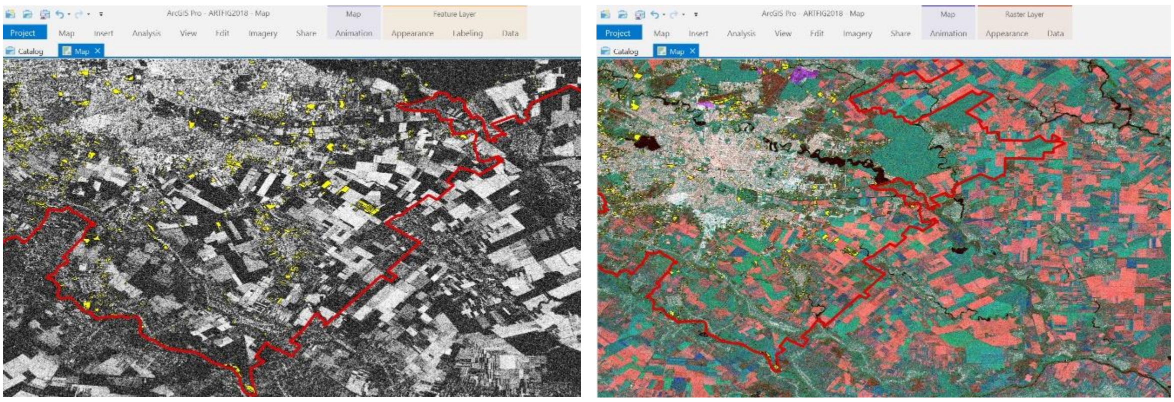

Figure 12 – Data Integration in ArcGIS Pro: Bucharest Boundary and 2006-2012 Changes (Copernicus) Overlayed on Urban Footprint

Using of satellite imagery is powerful in demarcating urban extents and its skeletal structure. [13] Municipalities need to control the urban sprawl, which is exacerbated by the lack of timely spatial information on urban expansion rates. Satellite imagery can be used to provide up-to-date geospatial information on the spatial structure and boundaries of cities.

4. CONCLUSIONS

Built-up areas could be well extracted from Sentinel-1 IW mode imagery, but crowded built-up areas are easier to detect than detached houses. According with [6] , having dual polarisation the results are improved for detecting buildings at different orientation angles. Using multi source data, results can be improved, as the following: the results could be validated through fieldwork by collecting ground control points, especially in the Bucharest boundary area using the Global Navigation Satellite System (GNSS) technology; the results can be improved by flights with Unmanned Aerial Vehicle (UAV) or/and swinglet CAM (SenseFly), having a higher spatial resolution (0.06 m) [1], that can make possible to obtain better data about the boundary. Timely information on urban expansion provided by satellite imagery is vital in ensuring integrated spatial planning and land use management. Free data is a main advantage of ESA Sentinel-1. Starting from such integrated data, further development studies based on real urban footprint and urban development predictions can be made.

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BIOGRAPHICAL NOTES

Ana-Cornelia Badea is surveyor, Associate Professor at the Faculty of Geodesy. In 2008 she received his PhD in Geodesy – Civil Engineering with distinction "Cum Laude" and in 2017 Habilitation in Geodetic Engineering (Thesis Title "3D Modeling of the Real World – Cadastre, Real Estate Registration and GIS for Sustainable Development"). She is the President of Editorial Board of Journal of Geodesy (http://www.ugr2014.ro/Revista-UGR) and FIG Representative for Faculty of Geodesy, TUCEB. She is member of the Surveyors Union of Romania, founding member of Romanian Surveyors Order, member of Romanian Society of Photogrammetry and Remote Sensing. She holds courses of "Cadastre and GIS Applications in Urban Areas", "2D, 3D Concepts and GIS Analysis" and "Computerization of Land Registry Operations" at masteral level. She is author and co-author of over 90 scientific papers at national and international conferences and 10 books.

Gheorghe Badea is Professor at the Faculty of Geodesy, Technical University of Civil Engineering. He received his PhD in Geodesy - Thesis Title: "Some Results in the Study of Using Cadastral Data in Land Information Systems". He was also Advisory Expert and Counselor at National Agency of Cadastre and Land Registration, Romania, being involved in developing of "Technical rules for the implementation of ETRS89 in Romania and the proposed law on the adoption of a new cartographic projections in Romania". He provides teaching activities at three remarkable universities from Bucharest: Technical University of Civil Engineering, Bucharest, "Ion Mincu" - University of Architecture and Urbanism and University of Bucharest. Prof. Dr. Badea is member of the Surveyors Union of Romania, founding member of Surveyors Order of Romania, member of National Society Photogrammetry and Remote Sensing. He was involved in many research projects and technical commissions. From 2016 is Dean of the Faculty of Geodesy, Bucharest.

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