OPEN JOURNAL SYSTEMS
ISSN:2237-2202

Available on line at Directory of Open Access Journals
Journal of Hyperspectral Remote Sensing v.9, n.3 (2019) 108-115

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Journal of Hyperspectral Remote Sensing
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Persistent Scatterer Interferometry analysis of multi-temporal Sentinel-1 radar imagery to detect ground subsidence in the city of Tirana, Albania

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Received 12 September 2019, accepted 28 November 2019

Abstract

Persistent Scatterer Interferometry (PSI) analysis of Sentinel-1 C-band radar spaceborne imagery was carried out to detect ground subsidence zones in the city of Tirana, Albania. Fifty-eight Sentinel-1A Interferometric Wide (IW) images of the time period January 2017 – December 2018, with a temporal resolution of 12 days, were used as input to the PSI. The PSI technique can detect millimeter-scale ground motion. The results show a zone of ground subsidence of about 7 mm/year along a segment of the Tirana Outer Ring road, where numerous tall buildings have been constructed in the last twenty years. In the northern part of the Kamza municipality a ground subsidence of about 2-3 mm/year is observed. In the western part of the Kamza municipality, it is also observed a ground subsidence of about 7 mm/year. In general, the areas where ground subsidence was detected from the PSI analysis, are characterized by urban expansion in the last thirty years. The ground subsidence could be a result of the lowering of the water table from the construction works or from over exploitation of groundwater resources. The study represents the first reported analysis of the Sentinel-1 imagery for ground motion detection in the city of Tirana. Further monitoring and detailed studies on the causes of the ground subsidence in this important urban area are necessary.
Keywords: Sentinel-1, remote sensing, ground subsidence, persistent scatterers

1. Introduction

The interferometric analysis of multi-temporal radar imagery is an important source for the detection and monitoring of ground subsidence in the urban areas (e.g., Ferretti et al., 2001; Kampes, 2006; Crosetto et al., 2010). However, the limited availability of radar imagery with frequent revisiting time of the same area, has hindered the wide applicability of the technology.

The advent of the Sentinel-1 Synthetic Aperture Radar (SAR) imagery from the European Space Agency (ESA) has opened new opportunities to the remote sensing community to make important contributions to the detection and monitoring of the ground subsidence hazard in urban areas (e.g., Sowter et al., 2016; Zhou et al., 2017; Delgado Blasco et al., 2019).

The Sentinel-1A was launched into orbit in April 2014 and the identical Sentinel 1B in April 2016. The Sentinel-1 records C-band (5.3 cm) radar imagery, with accurate orbit auxiliary data for interferometric analysis (e.g., Torres et al., 2012; Yagüe-Martínez et al., 2016). It has a revisiting time of 12 days (6 days if both Sentinel 1A and Sentinel 1B are considered), creating a dense multi-temporal dataset for interferometric studies (e.g., Haghighi and Motagh 2017; Kalia, 2018). The Sentinel-1 offers an improved data acquisition capability for deformation monitoring with respect to previous C-band sensors (ERS-1/2, Envisat, and Radarsat), considerably increasing the monitoring potential (Budillon et al., 2018).

This paper presents results on the interferometric analysis of multi-temporal Sentinel-1A data to detect ground subsidence zones in the Tirana city, Albania

2. Material and methods

Study area

Tirana is the largest city and the capital of Albania, a country in southeastern Europe (Figure 1). The city of Tirana has had a considerable urban expansion in the last thirty years (Figure 2), (e.g., Pojani, 2013; Dino et al., 2017; Imami et al., 2018). The multi-temporal Sentinel-1A data of the time period January 2017 – December 2018 were analyzed using the Persistent Scatterer Interferometry (PSI) technique for the detection of millimeter-scale ground deformation. The study represents the first reported analysis of the Sentinel-1 data for ground motion detection in the city of Tirana, and can serve as a basis for further monitoring of the ground subsidence hazard in this urban area.

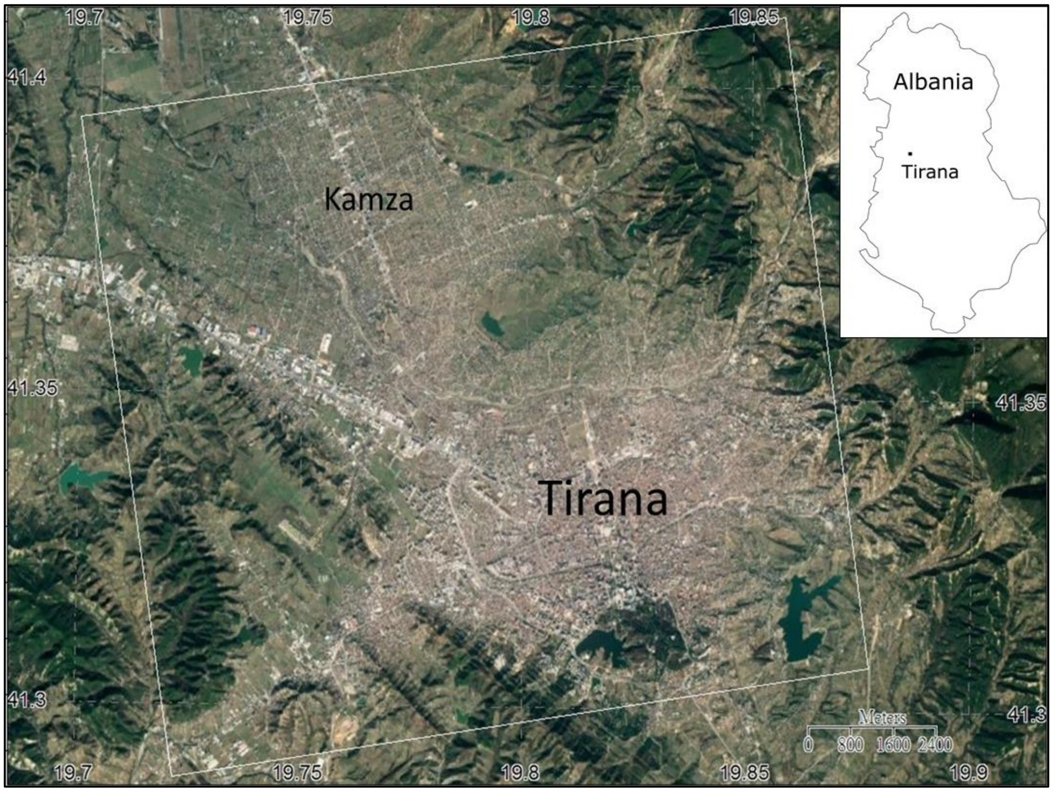

Figure 1 - The extent of the study area (white line rectangle) plotted on a satellite image from Google Earth™. The inset shows a schematic map of Albania with the location of the city of Tirana.

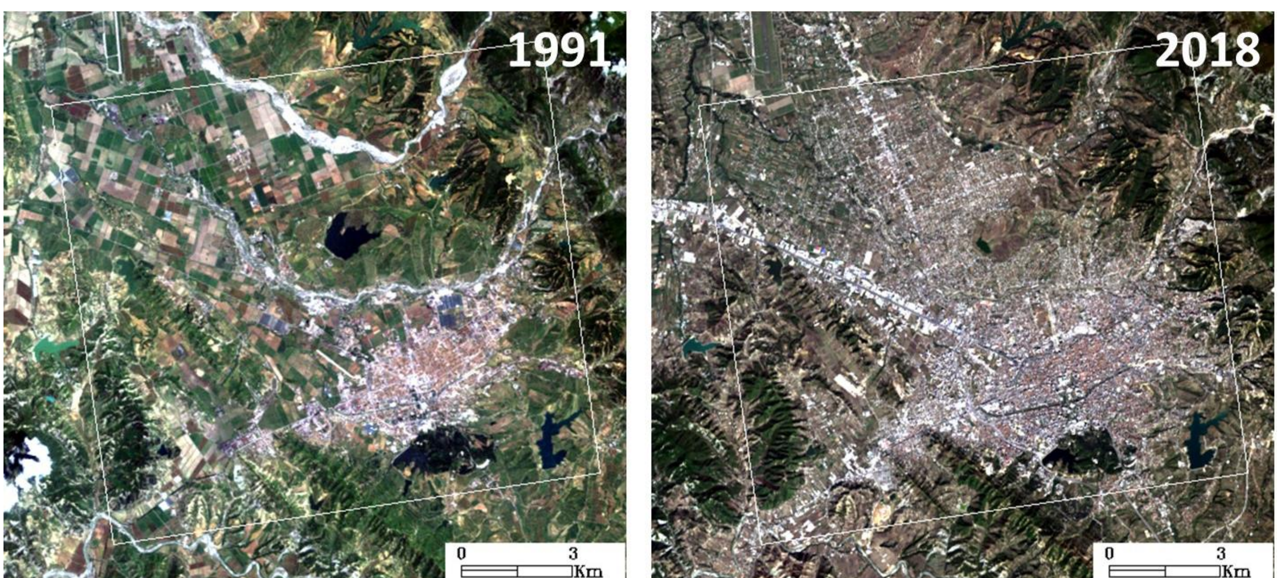

Figure 2 - The city of Tirana on Landsat images of June 1991 and October 2018. Note the expansion of the urban area in this time period. The white color rectangle showing the extent of the study area, is superimposed onto the images for reference.

The Sentinel-1 IW data

The Interferometric Wide swath mode (IW) is the standard mode of Sentinel-1 data acquisition, and due to availability more frequently used for ground deformation studies. The Sentinel-1 IW images are recorded using the Terrain Observation by Progressive Scans (TOPSAR) acquisition technology (De Zan and Guarnieri, 2006) which produces image data in sub-swaths. Within the sub-swath, the Sentinel-1 IW images are acquired by recording subsets of echoes of the SAR aperture, which are called *bursts* (e.g., Yagüe-Martínez et al., 2016). The Sentinel-1 IW images have a swath of 250 km, and ground resolution of 5m × 20m. The data are distributed by the European Space Agency (ESA) in scenes of approximately 150 km in the azimuth (along track) direction.

In this study, the multi-temporal stack of radar imagery for interferometric analysis consisted of 58 Single-Look Complex (SLC) Sentinel-1A Interferometric Wide swath mode (IW) images covering the time period of January 2017 – December 2018, acquired in ascending orbit 175 in VV (vertical transmitting, vertical receiving) and VH (vertical transmitting, horizontal receiving) polarizations. The VV polarization SLC images were processed for the ground subsidence detection in the urban study area of Tirana, Albania.

The Persistent Scatterer Interferometry technique

The two main techniques for ground deformation studies from the analysis of multi-temporal radar imagery comprise the Persistent Scatterer Interferometry (PSI), (Ferretti et al., 2001) and the Small Subset Baseline (SBAS), (Berardino et al., 2002). As the focus of the study is an urban area, the Persistent Scatterer Interferometry (PSI) method was chosen. The PSI is based on the Differential Interferometric Synthetic Aperture Radar (DInSAR) techniques.

The DInSAR exploits the information contained in the radar phase (φ) of at least two complex SAR images acquired in different times over the same area, which are used to form an interferometric pair (Crosetto et al., 2016). The SAR images forming the interferometric pair are usually acquired from the same sensor. Let us consider two complex radar images T_1 and T_2 recorded by the same SAR sensor at times t_1 and t_2. The change in the radar phase (φ) at ground target P, between the two measurements, unexplained from other factors (different positions of the sensor at times t_1 and t_2, noise in the data, atmospheric distortions, topography etc.,), is the result of ground displacement (φ_{Displ}) (Figure 3). The DInSAR technique (e.g., Hanssen, 2001) has been extensively exploited in the field of seismology.

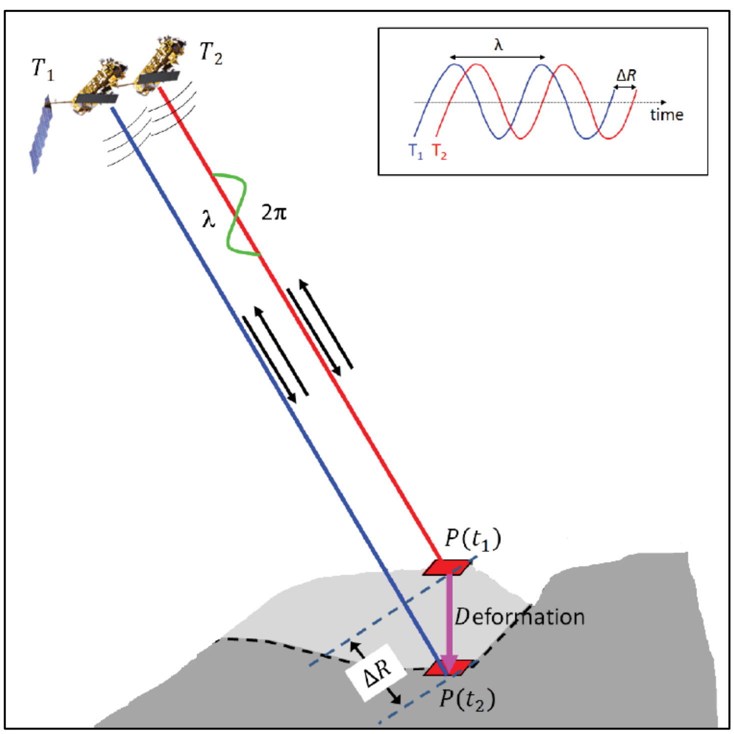

Figure 3 - Schematic representation of the DInSAR basic concept. The phase difference of two radar measurements T_1 and T_2 of a ground target P, recorded at time t_1 and t_2, due to a subsidence occurring within this time period at the ground target from position $P(t_1)$ to position $P(t_2)$ (modified from Sousa and Bastos, 2013).

In order to better separate the φ_{Displ} from the other factors having an impact on the radar phase, and to achieve millimeter-scale detection of the ground deformation, the PSI technique exploits multiple SAR images acquired over the same area. The PSI (Ferretti et al., 2001) is also described in considerable detail in several books (e.g., Kampes, 2006; Ketelaar, 2009). A recent review of the PSI applications is given in Crosetto et al. (2016). The PSI technique can detect mm-scale ground motion (ground subsidence, uplift) by analysis of a multi-temporal stack of radar imagery using persistent scatterer objects of the radar pulse, such as for example built-up areas. For reliable results a dataset of at least 15-20 C-band radar images is necessary to perform a PSI analysis. However, the redundancy is considered desirable for the PSI technique, and a larger number of radar images is usually employed (e.g., Monserrat et al., 2011). In addition, the temporal resolution is important.

Data analysis

The 58 Sentinel-1A SLC radar images were used as input to the PSI analysis. To form the interferometric stack of the study area for further processing, the 58 Sentinel-1A VV SLC images were initially de-bursted, and spatially subsetted to the extent of the study area. One of the images of the interferometric stack (acquired on 11 April 2018) was chosen as the master image. All other images were coregistered to the master image. A time-position plot of the Sentinel-1A images in relation to the master image is shown in Figure 4. Subsequently, 57 differential interferograms were formed between the master and each of the other images. A Digital Elevation Model (DEM) from the SRTM mission with spatial resolution of approximately 30 m was used to flatten the interferograms.

The resulting 57 flattened interferograms were used as input to an inversion process to find coherent Persistent Scatterers (PS). Amplitude-based methods (Ferretti et al., 2001; Kampes and Adam, 2003) analyze interferograms on a pixel-by-pixel basis to identify reliable PS in urban terrain (Lauknes et al., 2010). At these PS locations is estimated the ground deformation, as a displacement of the ground in relation to the sensor, or projected as vertical displacement. The large number of the analyzed radar images reduces the effects of the sensor noise and atmospheric distortion to the phase component. The results were geocoded and presented in a map format.

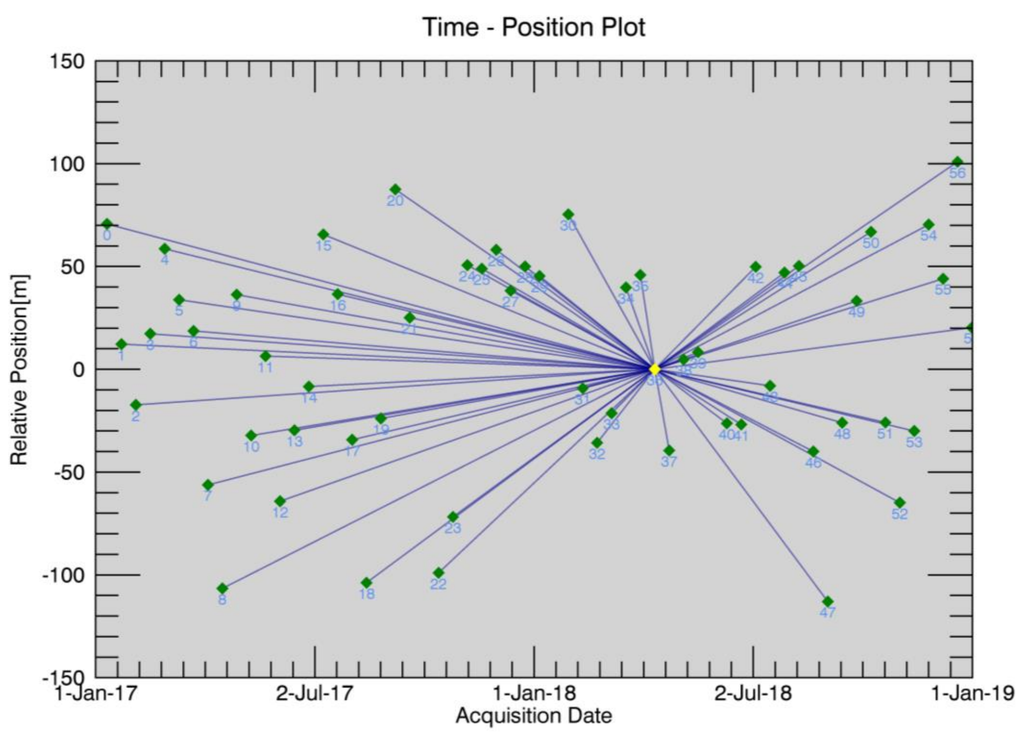

Figure 4 - Graph showing the temporal and the relative spatial position of the Sentinel-1A master image and the other Sentinel-1A 57 images used to carry out the PSI analysis for the study area.

3. Results and discussion

The results achieved by the PSI analysis of the 2017-2018 Sentinel-1A IW interferometric stack for the Tirana city area are shown in Figure 5. A ground subsidence zone with a vertical displacement velocity of about 7 mm/year is detected at Yzberish, along a segment of the Tirana Outer Ring road (Figures 5 and 6). This ground subsidence zone is also noted by PSI analysis of multi-temporal COSMO-SkyMed X-band radar data of the years 2011-2014 (Wasowski et al., 2015). At Yzberish a rapid urbanization with the construction of a number of tall buildings has taken place in the last twenty years. In addition, a relatively sparsely populated area in the northwestern part of the study area also shows ground subsidence of about 7 mm/year (Figure 5). Ground subsidence of the order of 2-3 mm/year is also indicated in the northern part of the Kamza municipality (Figures 5). In the Kamza municipality has taken place an extensive transformation from a farmland to an urban area in the last thirty years. This can also be noted in the Landsat images of 1991 and 2018 (Figure 2).

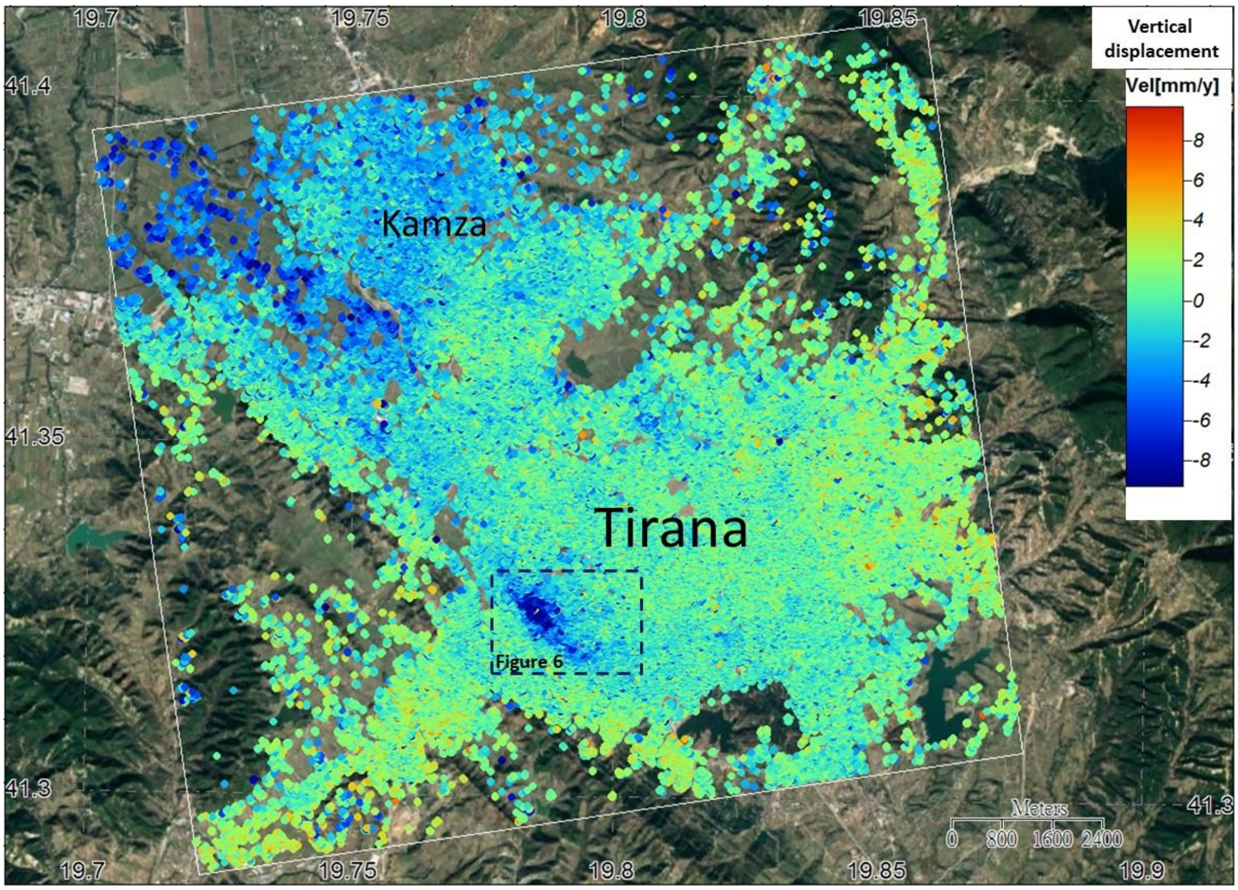

Figure 5 - Results of the PSI analysis of the Sentinel-1A imagery of the 2017-2018 period for the study area, the city of Tirana, Albania. Light blue to deep blue colors show minimal to stronger land subsidence in this time period, presented as vertical displacement velocity in mm/year. The dashed line rectangle indicates the approximate location of Figure 6.

There is a considerable expansion of the urban area in the city of Tirana in the last thirty years (Figure 2), (e.g., Pojani, 2013; Dino et al., 2017; Imami et al., 2018). A number of studies have focused on the ground subsidence hazard caused by processes related to the urban expansion or urban sprawl (e.g., Abidin et al., 2011; Yin et al., 2011; Chen et al., 2012; Notti et al., 2016). There is a correlation in the case of Tirana, of the subsidence zones and the urban expansion (urban sprawl), (*see* Figure 2 and Figure 5). Not all areas of urban expansion show ground subsidence, but the zones of ground subsidence occur generally in areas of urban expansion. The reason for the subsidence could be the lowering of the water table due to the construction works, and probably also from the overexploitation of groundwater resources. However, specific studies are needed to identify the causes of ground subsidence, and to recommend appropriate mitigation measures.

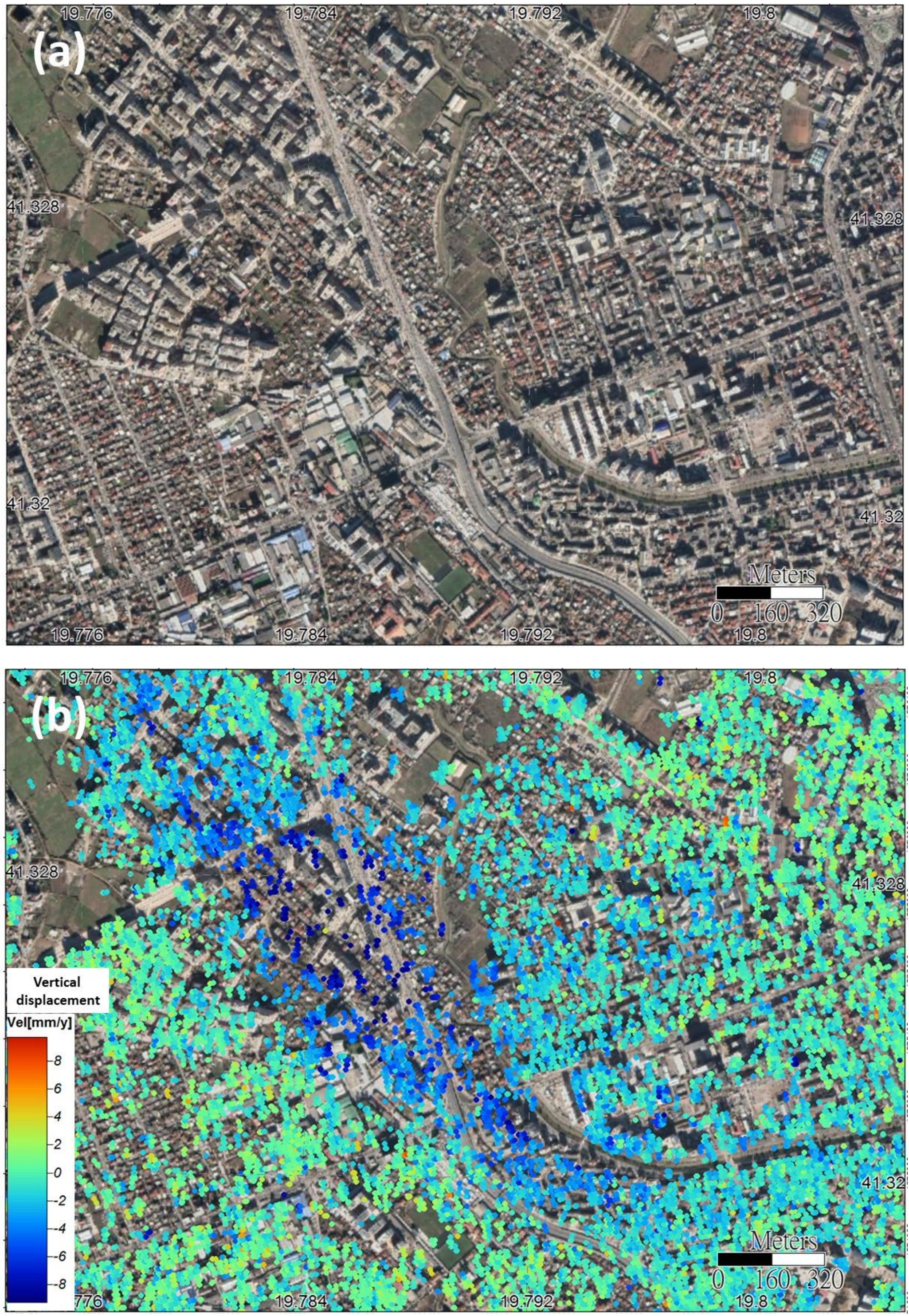

Figure 6 - Ground subsidence along a segment of the Tirana Outer Ring road (at Yzberish area). The area is characterized by recent urban expansion and tall buildings. (a) High spatial resolution satellite image of the area from Google Earth™. (b) The satellite image with the persistent scatterers plotted on it, showing the vertical displacement velocity in mm/year.

4. Conclusions

Based on the analysis of Sentinel-1A radar imagery of 2017-2018 the city of Tirana is relatively stable for what regards the ground subsidence hazard. The most problematic is ground subsidence of about 7 mm/year in the area of Yzberish, along parts of the Tirana Outer Ring road. This ground subsidence was also active several years before, as indicated by PSI analysis of COSMO-SkyMed X-band radar imagery of the years 2011-2014 (Wasowski et al., 2015). In the western part of the Kamza municipality, it is observed a ground subsidence of about 7 mm/year. In the northern part of the Kamza municipality it is noted a 2-3 mm/year ground subsidence. The observed ground subsidence occurs generally in zones of recent urban expansion. There seems to be a general case of subsidence in the urban areas due to the process of the compaction of clays (e.g., Cui, 2018), as a result of groundwater removal (lowering of the groundwater table). However, detailed studies on the causes of the ground subsidence are needed. Further monitoring of the ground subsidence in this important urban area is necessary.

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