CAPABILITY OF SENTINEL-1 DATA FOR ASSET MONITORING USING PERSISTENT SCATTERER INTERFEROMETRY

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ÖZET:

Son yıllardaki araştırmalar İstanbul'un yakın zamanda hızlı bir şekilde büyüdüğünü ve ciddi bir kentleşme sorunuyla karşı karşıya olduğunu gösteriyor. Artan popülasyon, konutların yoğunlaşmasına ve doğal sonucu olarak da akarsuların ve su kaynaklarının üzerine veya çevresine yapı izinlerinin alınmasına neden olmuştur. Kentsel arazi yetersizliği yaygın olarak sürdürülebilir kalkınmaya tehdit olarak kabul edilir. Daha önce görülmemiş derecedeki bu hızlı ve büyük şehirleşme, yapı alanlarındaki mülklerin aşınmasına ve çökmesine neden olmaktadır. Bu sebeple, karar vericiler için yapıların sağlığının izlenmesinin önemi son zamanlarda daha çok öne çıkmıştır. Bu çalışmada, ücretsiz kullanıma açık olan Sentinel-1 uydusunun İstanbul'daki yerleşim alanlarındaki yapı sağlığının izlenmesinde Persistent Scatterer Interferometry (PSI) tekniği ile kullanıp kullanılamayacağı tartışılacaktır. Bu amaçla, Mayıs 2015-Şubat 2018 tarihlerini kapsayan 6-gün zamansal çözünürlüklü Sentinel-1 görüntüleri kullanılmıştır. Çalışma özellikle iki alana yoğunlaşmıştır: Alibeyköy Otobüs Terminali ve Ataköy konutları. Seçili alanlardaki zaman serilerine bağlı deformasyonu içeren PSI analizlerinin sonuçları gazete makaleleri ile desteklenmektedir.

ABSTRACT:

Evidence suggests that Istanbul has grown recently at a rapid rate and is facing a serious urbanization problem. Furthermore, increasing population has resulted in dense housing, causing permissions to construct within or around streambeds and water sources. Urban land scarcity is widely then acknowledged as a threat to sustainable development. This unprecedently fast and large urbanization causes widespread deterioration and collapse of assets around the construction sites. Therefore, the importance of global structural health monitoring is recently highlighted as a tool to aid managers. In this paper, the use of free-available Sentinel-1 data on the remote condition monitoring of built-up areas in Istanbul will be examined with the help of Persistent Scatterer Interferometry (PSI) technique. For this purpose, a large 3-years Sentinel-1 image stack covering May 2015 – February 2018 with a temporal resolution of 6-days is employed. Specifically, two new construction sites are chosen: Alibeykoy bus terminal construction and Atakoy housing estate. The outcomes of the PSI analysis including the deformation time series over the selected areas are supported by newspaper article.

1. INTRODUCTION

Istanbul, which is home to many empires, is a unique city that connects the two continents also have a fascinating view surrounded by the sea on three sides. Not only the favorable geographical location of the city but also the economic, industrial and construction sectors which are under development give rise to increase in population rapidly. In addition to natural growth, Istanbul is also growing out of all kinds of planning and controlling because of migration. The rapidly growing population lead to problems related to urban sustainability, urban growth, and more importantly lack of land. As a result of rapidly growing population and lack of land, the urbanization in Istanbul mainly bring about requirement of housings, workplaces, industries, terminals and airports. These constructions, which are not in coherent with each other, lead to damage to natural resources and ecological balance also result in unplanned growth (Mekânsal Planlama Genel Müdürlüğü, 2018).

Therefore, there is a need to monitor and find solutions with minimum cost to expand cities in sustainable way. Developing cities have challenges in maintaining and providing conventional information on assets such as, bridges, housing, airport, industries, terminals and etc. (Othman, 2013). Sustainability and ecological balance have been neglected in unplanned growth of Istanbul, and consequently it has become impossible to avoid damages, specifically unhealthy structures and depletion of ground water. The size and distribution of the damages in Istanbul are closely related to the geological and geotechnical properties of the ground as well as the construction quality. It is known that active and passive potential landslides and earthquakes in Istanbul cause flow and slippage. The other significant issue that caused the flow and slippage on the assets is the reclamation of the stream bed in consequence of the reconstruction permit due to massive development demand.

The structural health monitoring of these assets could be made by using data collected from sensors which are integrated into structures, such as GNSS, leveling and photogrammetric methods. These traditional methods, which requires labor force, are generally time consuming and not cost-effective in spite of their validity and sensitivity (Erten and Rossi, 2019). However Remote Sensing (RS) is a powerful tool used in various scales to measure the change in objects with the interpretation of images obtained from air- and space-borne sensors without physical contact. In recent years, Persistent Scatterer Interferometry (PSI) which is one of the most effective remote sensing methods is used to monitor structural health of the assets. PSI is based on the analysis of the time series of the Synthetic Aperture Radar (SAR) data proceed by interferometric methods. PSI is utilized to determine Line of Sight (LOS) deformation measurements of Persistent Scatterer (PS) points on ground using multi-temporal SAR images. With this method, the amount of spatial deformation can be observed with a sensitivity of mm-cm / year (Selvakumaran et al., 2018). Man-made assets, which contain dominant regular structured objects that lead to persistent and strong signals, providing lots of PS points, hence, are good candidate for PSI method (Yang et al., 2016). The reasons and advantages of the PSI method used for the detection of surface deformations are as follows: (1) to obtain high spatial resolution results in large areas; (2) to determine the amount of deformation in high sensitivity; (3) availability of a large SAR archive since the 90s (Crosetto et al., 2014).

In this study, vertical deformation of the areas at risk in Istanbul and its surroundings was observed using PSI technique which is a method for analyzing the position of the fixed scatters in time. These observations were carried out using the images obtained every 6 days in the VV polarization of the Sentinel-1 data. The vertical deformations in the risk-bearing areas was observed in time using 122 images covering May 2015 - February 2018. Particularly, the Atakoy housing site in Bakirkoy and the mobile bus station in Alibeykoy were selected to analyze.

2. METHODOLOGY AND DATASET

Sentinel-1 sensors have provided the most frequent SAR data for temporal monitoring. The 6-day temporal resolution and ~20m spatial resolution of Sentinel data allow deformation monitoring at individual PSs (Copernicus, 2018). From May 2015 to February 2018, a total of 122 images were collected over Istanbul. Interferometric Wide (IW) swath mode Single Look Complex (SLC) VV polarized images were downloaded via Copernicus Open Access Hub (Copernicus, 2018). The standard PSI technique proposed by Ferretti et al., (2001) is applied with the following steps: (1) differential interferogram generation, (2) residual height and primary velocity estimation, (3) atmospheric phase calibration and re-estimate velocity and (4) geocoding (Erten et al., 2019).

PSI processing has been employed via ESA RSS Cloud Toolbox which is a Virtual Machine provided by the ESA Research and service Support

In this study instead of entire frame, sub-areas covering ~5km x ~5 km in the azimuth and range directions, are analyzed (Figure 1).

3. ASSET MONITORING EXAMPLES

The rapid and uncontrolled urbanization process in Istanbul coupled with increasing population due to migration has pressured its healthy development, especially in the context of housing. Previously wetlands, marshy areas and small ponds have been filled in time and converted into construction sites for residences, even though they are not suitable for housing development. The problems of such housing and their damages have been often reported by national media (Cumhuriyet, 2019).

In this study two regions containing housing located on a stream bed (Figure 1) are studied in order to show the evolution in space and time of the vertical deformation using PSI technique. One of them is a mobile bus station in Alibeykoy, another one is TOKI Atakoy housing site in Bakirkoy. The main reason for choosing these regions is that there are creeks passing by where they are. Since the deformation amounts are higher than the stable structures around them, the determination of the deformation caused by the abrasive effects of the creeks has been observed more easily in these regions. In the selected regions, the amount of deformation increases as the PSs are getting closer to the creek side. Besides, the change in the flow rate, the amount of incoming water and the lack of regular maintenance of creeks can be shown as a reason for the deformation.

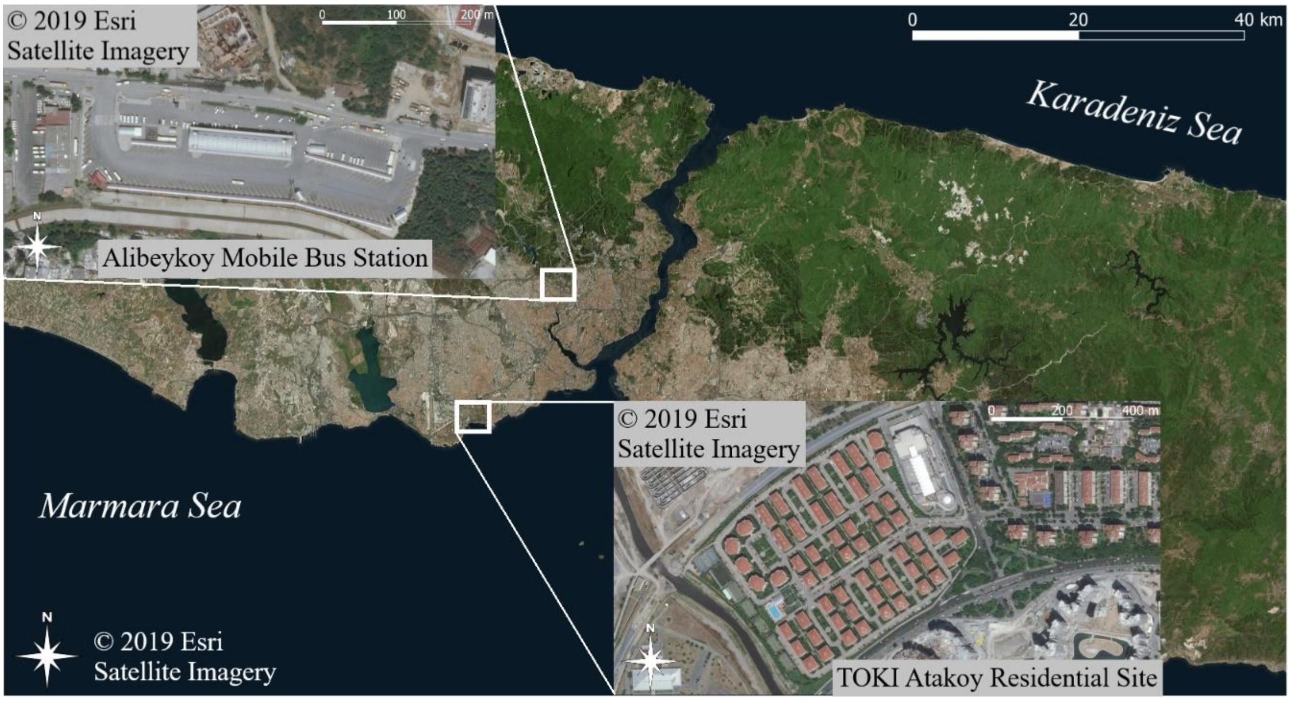

Figure 1. The Google Earth image of Istanbul and location of the two test sites

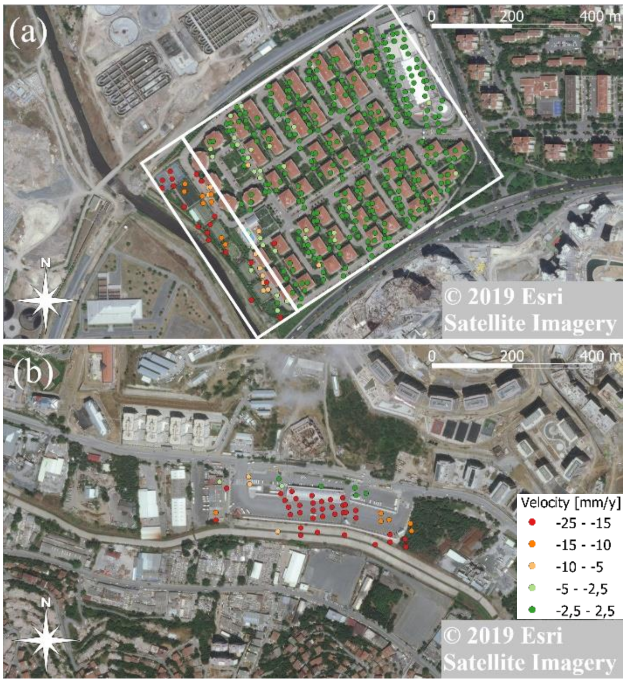

Figure 2. Persistent scatterers with their mean velocity superimposed over Google Earth images of the two test sites.

In order to understand how free available Sentinel-1 data could serve authorities to monitor assets, Figure 2(a) and Figure 3(a). show the average LOS velocity map of the selected regions for the three years using PSI technique. It can be easily seen from the figures that man-made objects provide enough PSs to monitor the assets. The positive and negative values shown in the legend correspond to the relative movement away from and towards to the Sentinel-1 satellite. Different colored PSs represent velocity graduation according to the legend (Top). The figures highlight how LOS velocity increases closer to the creeks. These quantitative analyses will be supported in the coming section in more detail by national media reports.

A) TOKI Atakoy Residential Site

TOKI Atakoy residential site, which is located on the first-degree earthquake zone, is divided by creek beds and dominated by the beach sand and alluvium soil structure. Although it has been determined as "high levels of liquefaction sensitivity" in Earthquake Master Plan (2003) and is extremely close to the source of the earthquake, it includes intensive housing (Kilic et al., 2014).

As seen in Figure 2(a), the serious deformation rate is observed on the west site of the residential site, where the creek is located. According to the Earthquake Master Plan (2003), not only the etching effect on the bank of the creek but also the risk of liquefaction on the ground could leverage the deformation on the west side of the housing area. Moreover Prof. Dr. Ali Elmas stated in the report submitted to the court; Atakoy housing was remained within the coastal line and the underground of this region is soft. This region cannot withstand a violent earthquake and so the area could collapse (Sputnik, 2017).

In Figure 2(a) the velocity measurements are divided into two regions so that we could provide a mean velocity of deformation for each of them. The region closer to the creek has a mean velocity of -12,520 mm/y with a standard deviation of 17,490 and the second region has a mean velocity of -1,293 mm / y with the standard deviation of 1,472. Interestingly it also shows a relatively high-density points in the second region with lower standard deviation compared to the first one. This annual average displacement difference cannot be attributed to a specific reason unless it has been examined on-site by field teams. However, as a result of the analysis, it is concluded that the second region is more stable compared to the first one.

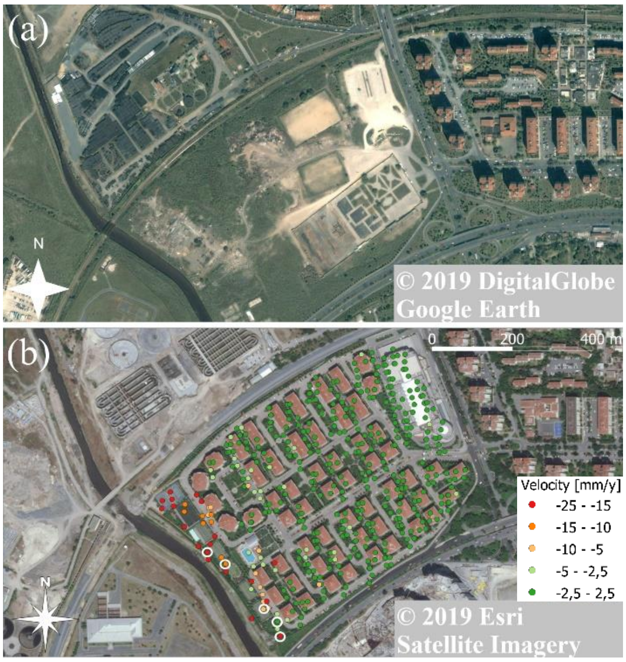

Figure 3. (a) Optical image of TOKI Atakoy residential area in 2001. (b) Same view in 2019, with overlying PSs (dots) representing the average 2015-2018 velocity measurements of displacement in mm/years. Ground subsidence is clearly visible closer to the creek.

The temporal housing situation of the TOKI Atakoy residential site, next to the Ayamama Creek, can be seen in Figure 3 using Google Earth image from 2001 (a) and Esri Satellite image from 2019 (b). According to the Preliminary Report prepared by the Chamber of Civil Engineers, all the buildings near Ayamama Creek were completed after the completion of the Mahmutbey-Yesilkoy connection road (IMO, 2009). In addition, the inability to absorb water due to surface water drainage and changes in the surface of the land (the change in the flow rate and the increase in the water flow rate and the amount of incoming water) had a negative impact, which was not initially present, on the Ayamama Creek. In line with the mentioned reasons above, PSI analysis underlines the detrition due to the Ayamama creek. The PS with the highest deformation rate is found next to the Ayamama creek (see Figure 2(a)).

Five PS points from Figure 3(b) -displaying the LOS velocity obtained from the PSI analysis superimposed over an Esri Satellite image- are selected in order to show the time-series of LOS measurements. Figure 4. shows the temporal trend of these PSs, whose locations can be seen in Figure 3(b). The y-axis of the graph contains LOS movement (mm), while the x-axis contains the date of the Sentinel-1 acquisitions. The linear estimated deformation profile along the PSs are also given in Figure 4. From the analysis, it is clear that the region close to the Ayamama creek is subsidizing at an average rate of -2,158 mm/y to -23,727 mm/y. Both man-made and natural activities (e.g. earthquake) leverage the gradual subsidence in this region.

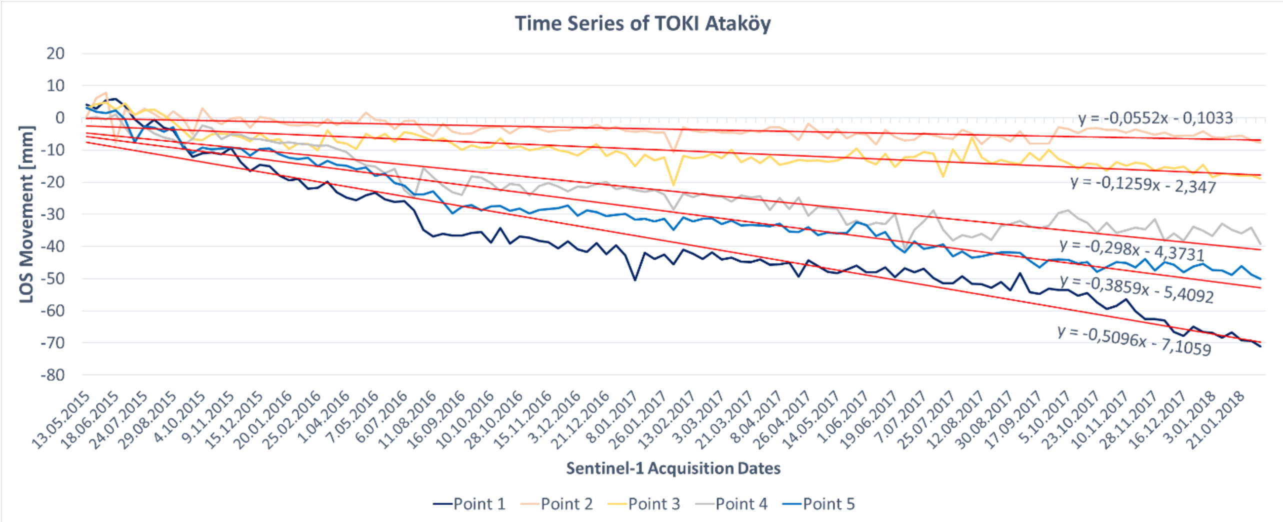

Figure 4. Movement of five PSs attributed to the Atakoy Residential site over time. The location of the PSs can be seen in Figure 3(b) with white circles.

B) Alibeykoy Mobile Bus Station

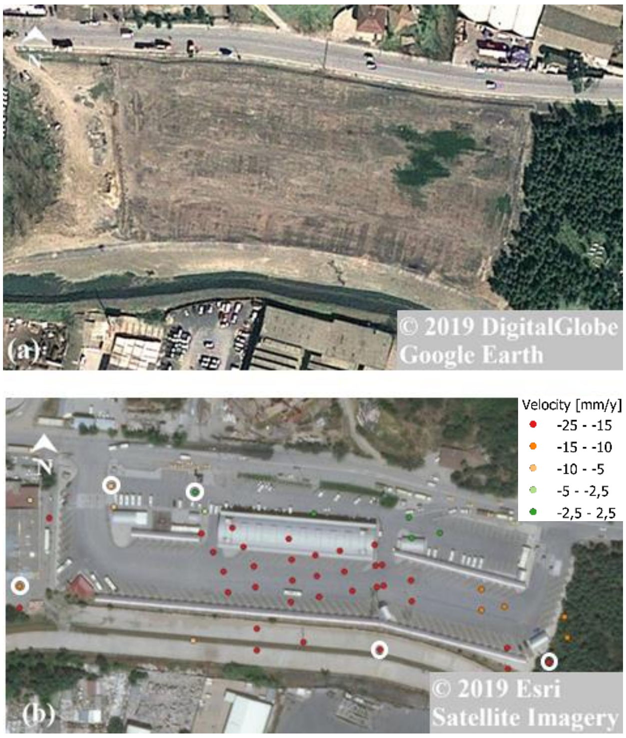

Figure 5. (a) Optical image of Alibeykoy Mobile Bus Station 2011. (b) Same view in 2019, with overlying PSs representing the average 2015-2018 velocity measurements of displacement in mm/years.

Alibeykoy Mobile Bus Station, located in Eyup district of Istanbul, is surrounded through Sultan Mehmet Boulevard in the south and Alibey stream in the north. Figure 5 displays the Alibeykoy Mobile Bus Station construction site on Google Earth Maps from 2011 and 2019, which has been operated since 2014. Owing to the fact that (Internet Haber, 2005) the Alibey Creek has caused frequent overflows in the past, the creek breeding activities have been initiated, specifically the asphalt road moved 50 meters to the creek with a 45-degree slope due to the frequent road subsidence. Istanbul Buyuksehir Belediye Meclisi (2012) survey reported that some part of the Alibeykoy region is under

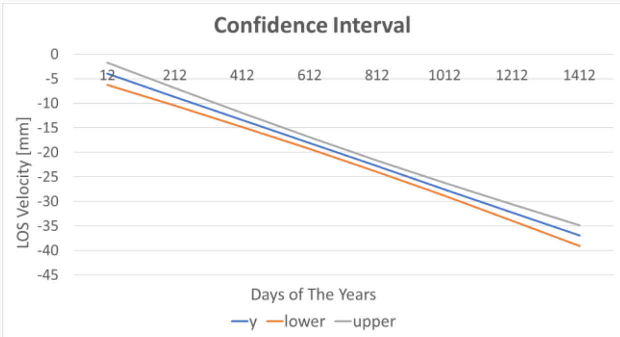

Figure 6. Linear regression analysis of LOS velocity measurements as a function of time with 95% confidence levels.

risk of liquefaction. Even though stream improvement accomplished in 2017, a road collapse has recently occurred in the boulevard on the top of the water course (Haber Eyup, 2017).

To assess the recent abrasion caused by Alibey creek within the framework of PSI, we plot the linear time-series analysis of LOS velocity measurements in Figure 7. Figure 7 shows the examples of deformation time series from the Alibeykoy dataset. The location of the corresponding PSs is shown in Figure 5.

Compared to the time series analysis in Figure 4, the seasonal fluctuations can be easily recognized in Figure 7. The difference highlights the effect of thermal expansion on industrial buildings. Although the thermal expansion modelling is ignored, it is worth nothing that the LOS velocity measurements in Figure 6 includes a residual thermal pattern. Without any thermal expansion correction, as a result of 3 years' time series analysis the annual velocity of deformation is -15,5 mm/y. Some of the PSs reached approximately -63 mm/y LOS displacement towards the sensor. The linear regression analysis of these 5 PSs LOS measurements, in total 615 samples, are given in Figure 6 with 95% confidence intervals.

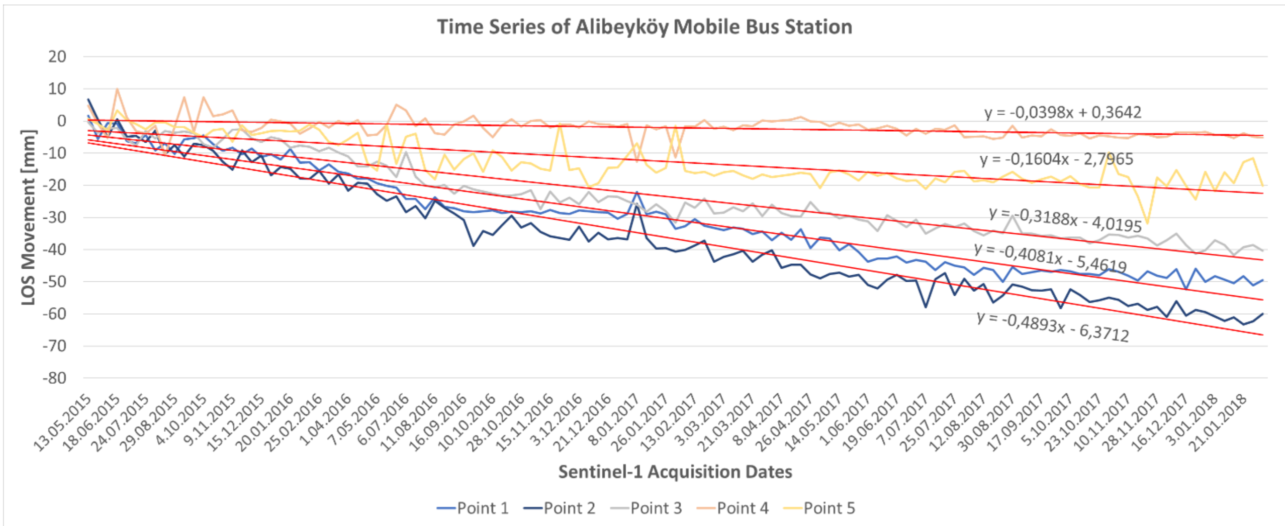

Figure 7. Movement of five PSs attributed to the Alibeykoy site over time. The location of the PSs can be seen in Figure 5(b) with white circles.

3. CONCLUSION

The rapid urban growth and significant land-use changes are alarming, and the need of policies intended to slow down urban concentration and conventional monitoring is urgent for authorities. In this context, PSI provide unique information in terms of the assets structure monitoring. The advantage of PSI in asset monitoring is coming from the fact that the scattering characteristics of man-made objects are in constant in time, regardless of polarization and wavelength of the SAR signal. Although PSI is already demonstrated operationally for asset monitoring, this paper focuses on the applicability of Sentinel-1 in dense urbanization, where a spatial resolution is a key point to monitor.

In order to show how PSI technique coupled with Sentinel-1 data can be used as an effective supportive measure for the maintenance of assets in developing cities, two regions of Istanbul were examined, where a sufficient number of PSs are achieved. Both regions are close to the creeks and were the former streamside sites transformed into housing areas. In both regions, it is possible to detect and monitor small vertical movements in the structure of the assets: houses and bus station. The outcomes of the study are supported by the media fact-check approach. Although the findings of the study are not compared with *in-situ* measurements, it has been underlined that the specific adaptation of PSI will reduce the asset monitoring cost for large areas with free-available Sentinel-1 data.

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