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Research Article

Ground Deformation Control In Ankara Batıkent Mesa Region: Metro Line Control

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Abstract

Subway systems in large cities play a crucial role in enhancing the sustainability and livability levels of urban areas by offering a solution to heavy traffic and transportation problems. Subway tunnels are critical transportation infrastructures that are constructed to serve residential areas, and thus, they have a direct relationship with residential areas in terms of construction and operation. This study is designed to generate precise data by analyzing ground deformation of metro systems using the Persistent Scatterer (PSI) Interferometry method and utilizing free dataThe Batıkent-Törekent metro line in Ankara is identified with the M3 code. At the location where M3 metro passes, ground deformation has been detected. In the analysis of the relevant location, both ascending and descending Sentinel-1 satellite datasets were used. The StaMPS (Stanford Method for Persistent Scatterers)/PSI (approach was utilized in the study. It was found that the results obtained from the ascending datasets were more sensitive. Observations were made in two different periods using ascending datasets: 2015-2016 and 2017-2022. Deformations were observed in the Line of Sight (LOS) direction in the locations where rail systems and tunnels were present. Eight months after the observation, due to the ground deformation in the area, passenger safety was at risk, and a ground strengthening work was carried out, resulting in a 16-day shutdown of the metro system in this location. The results of this study provide concrete contributions to the literature on the possibility of accurate ground measurement using free data.

Keywords: Ground deformation, Railway monitoring, Batıkent, Time series

Introduction

StaMPS/PSI approach enables the determination of ground surface deformations in urban environments. This method utilizes a basic technique known as Persistent Scattering Interferometry (PSInSAR) to monitor surface motion. StaMPS employs PSI and Small Baseline techniques to measure displacements from time series Synthetic Aperture Radar (SAR) data and provides freely available software for research purposes with a large user community (Hooper, et al., 2012). This approach works well with StaMPS/PSI Copernicus Sentinel 1 images, with open-source code, and allows processing of data obtained from tracking monostatic (PM) operating modes (Ferretti, et al., 2001). It is particularly useful for urban PS-InSAR applications that deal with slow motion phenomena, such as ground subsidence in urban environments, and can accurately measure most ground deformations (Crosetto, M., et al. 2016). The use of this approach can enable the prediction of deformation formation without incurring high costs.

Various deformation findings can be displayed, such as the quality of the produced time series, a validation result using piezometric data, and a thermal expansion scenario (Crosetto et al., 2016). Sentinel-1 improves revisit time, geographic coverage and SAR image quality of previous European Space Agency missions. The Sentinel-1's InterferometricWide Swath (IWS) mode provides a range of 250 km with a 6-day repeat cycle for 1A and 1B (ESA, 2023).

Relationship between ground deformation and rail systems is an important issue in the design, construction, and operation of both metro and high-speed train lines (Gama, et al., 2020). Ground deformation can affect the stability and safety of rail systems and is particularly important for high-speed trains. In recent years, there has been an increase in research on ground deformation in rail systems, with remote sensing techniques being used in these studies (Kim, et al., 2002).). These techniques include radar satellite images, laser scanning data, and aerial photographs. Remote sensing techniques using radar satellite images are frequently used to obtain high-resolution ground deformation data. PSI technology is used for remote monitoring of ground deformation in high-speed train lines (Wu, et al., 2017). Furthermore, the PSI technique can also be used to monitor deformations caused by natural disasters such as earthquakes or landslides on the ground (Crosetto et al., 2016).

Materials and Methods

Purpose of this research is to investigate ground deformations in the Ankara Province, with a particular focus on the Batıkent Mesa Metro station, using PSI technique. The aim is to provide highly sensitive information about ground deformations in large areas over time. To obtain runtime series, the StaMPS software package integrated with the SNAP platform was utilized (Bau X. et al. 2022). Following this, the PSI points were transferred to Matlab for analysis, which resulted in the identification of five deformation points. The Sentinel-1 imaging system consists of a cluster of satellites orbiting the Earth's poles, providing synthetic aperture radar (SAR) images in C-band that can be acquired day or night and irrespective of weather conditions. These images are available free of charge to researchers and other interested parties (Iglesias R.et al, 2015). The antenna is designed to face at an angle with respect to the flight direction and at an angle with respect to the ground, which enables the use of time differences between two separate locations to distinguish between them (Panitz C. et al, 2010; Razi P. et al, 2018). To process and analyze the Sentinel-1 SAR data, the European Space Agency (ESA) developed the Sentinel Application Platform (SNAP), an open-source platform. The S1Tbx toolkit specifically focuses on Sentinel-1 SAR data, allowing it to be accessed by other Java programs as a library (Razi P. et al, 2018). Furthermore, StaMPS is a widely used technique for processing SAR data and is capable of generating highly accurate and detailed deformation maps for various applications.

StaMPS software package provides a set of codes used to obtain runtime series integrated with the SNAP platform. This system can also be installed on Linux. it even has a very active committee so that the problems can be easily overcome. Over Mexico City, SNAP-StaMPS combined processing was successfully demonstrated for Sentinel-1 TOPS interferometric time series analysis. Ground collapses caused by excessive groundwater consumption allow this city to be seen over time (Sumantyo J.T.S., 2016).

Batıkent is a neighborhood located in the northwestern part of Ankara, the capital city of Turkey. The area is situated on the Ankara Complex, which is comprised of Neogene-aged volcanic, volcaniclastic, and sedimentary rocks (Erdem et al., 2014). These rocks are primarily composed of tuffs, basalts, and andesites. The volcanic rocks are found in the form of lava flows and pyroclastic deposits, while the sedimentary rocks consist of marls, sandstones, and conglomerates (Sarıkaya et al., 2012). The volcaniclastic rocks are comprised of tuff and agglomerate deposits. The geological formation of the area has influenced the engineering properties of the rocks, which are generally characterized by their low strength and high permeability (Özgür and Koçyiğit, 2009). It is stated that during the construction of the Batıkent metro line, deformation problems were encountered due to the low bearing capacity and high-water content of the soil. To solve these problems, soil improvement techniques and particularly the use of geotextiles are recommended (Yıldırım, 2015).

In the process of selecting the image sets, the Batıkent Mesa zone was selected by considering the development of the rail systems. Images from Sentinel-1 were chosen to capture the network of rail systems currently under development and construction in various regions. Both the 2015-2016 and 2017-2022 time periods were used for the analysis of this study and the comparison of the images.
Both the 2015-2016 and 2017-2022 time periods were used for the analysis of this study and the comparison of the images. According to perpendicular baseline method 68 ascending and 68 descending datasets with a maximum orbital difference of 200 meters were created. Considering the geographical location of the area to be studied, the sub-datasets in Table 1 were created to be used in the PSI method.

Table 1Ascending&descending Sentinel-1 Metadata

Orbit	*Track*	*Number of S1 Image*	*Start/Stop Periot*	*Number of Bursts*	*Sub-Swath*	*Master data*
Ascending	87	68	2017.06.27/2022.01.15	4-5	IW1	2019.08.16
Descending	65	68	2017.06.16/2022.01.16	1-2	IW2	2019.06.04
Observation1	87	20	2015.01.12/2016.05.19	4-5	IW1	2015.08.19
Observation2	87	63	2016.07.08/2022.08.30	4-5	IW1	2018.08.27

First, we examined the general structure of Ankara province. In these general interferometry studies, the threshold value was determined as 0.37 for both increasing and decreasing images. With a lower threshold value, insufficient PS scores were obtained for analysis, especially in rural areas. At a higher threshold, a higher PS score was obtained. An optimal value was deemed necessary, as excessive PS points adversely affect computer time and trend curves. After determining the appropriate threshold value for this, the ground deformation results in Figure 1 and Figure 2 are examined.

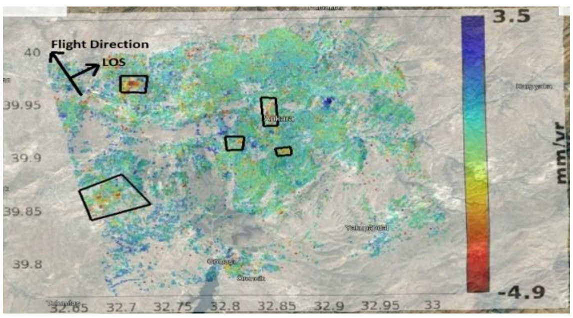

Fig. 1 Ascending ground deformation of Ankara

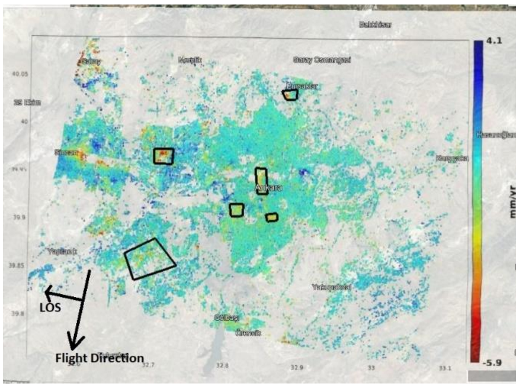

Fig. 2 Descending ground deformation of Ankara

Because the ascending and descending directions are different, there may be differences in the frame edges of the resulting images. Green to red areas in the image represent collapse. The areas from green to blue represent uplift. In research, collapses are considered direct deformation, while this is not the case for uplift. There is a definite need for tesserial research (Yasar et al., 2022). When Figure 1 and Figure 2 visuals are examined, five different deformation zones are seen in the common areas. However, when these images are compared, the deformation regions are more prominent and sharper in the increasing images in Figure 1. In contrast, the deformation regions are less distinguishable and weaker in the descending images in Figure 2. This difference is due to the Line of Sight (LOS) difference. We can see this difference in Figure 3.

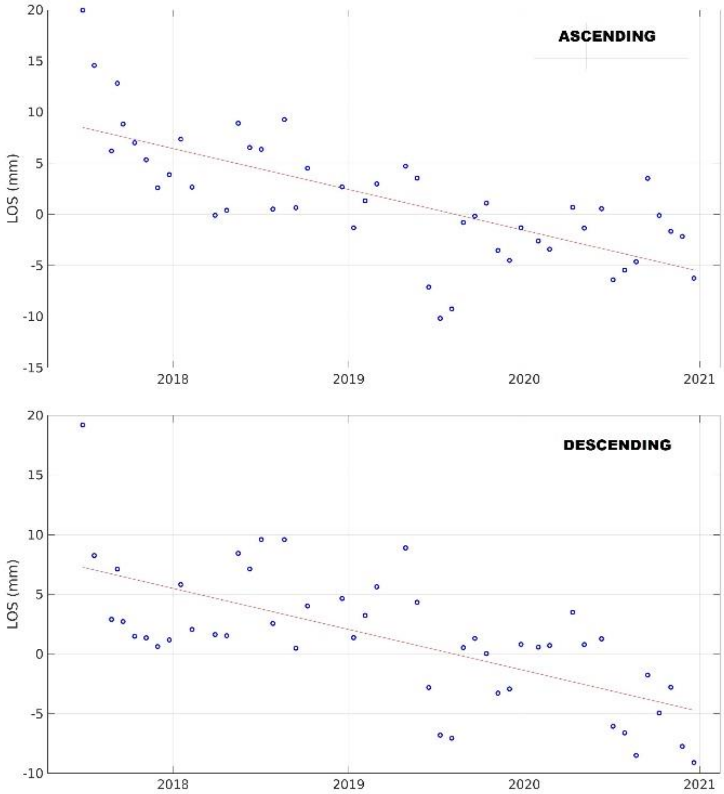

Fig. 3. Ascending (up) & descending (down) LOS Diagrams

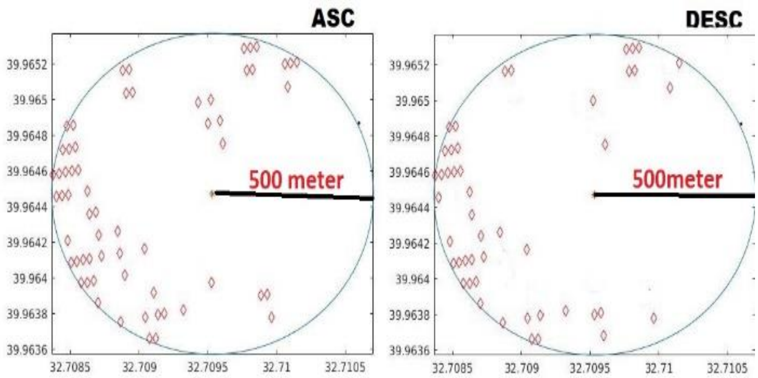

Fig.4. Extracted PS points from both datasets in Matlab

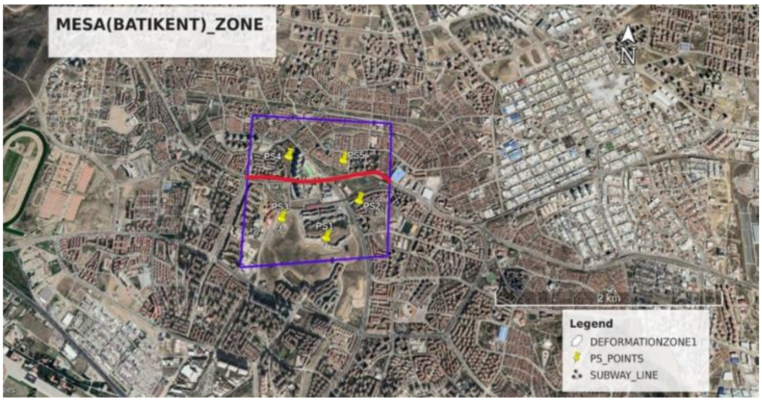

Fig. 5. PS locations for time series

The coordinates of the set of PS candidate positions obtained by StaMPS/PSI technique in the Matlab environment. We can transfer them to the Google-Earth environment for observation. Since LOS provides an important parameter both determination deformation areas and extract time series from PS points. Mesa zone is one of the areas where deformation is observed intensively in the general interferometry study of Ankara. An area with a radius of 500 meters was determined around the metro line then the PS points were selected to be used in time series analysis within this area.

Five separate PS points associated with the Mesa area were obtained using Google Earth at an altitude of 2,000 meters. Figure 5 shows the location of Points P4 and PS5, which can be found in the community north of the metro line. It can be reached by going southeast on the PS2 Metro line through a residential area. The location of PS3 can be found within the borders of the Social Security Administration (SSI) Batıkent Service facility. It is located on a unused wasteland south of the PS1 Metro line.

As seen in Figure 5, the Mesa zone is located in the southwestern part of Ankara. The Törekent-Kızılay metro passes from the place where it is located. In this mostly residential area, serious deformations were observed in both the first and second observations. Based on these deformations, five reference PS points were selected. A precise time series analysis of the region was made according to these PS points. Images of the time series deformation of the Batıkent Mesa zone are included.

The yellow and red areas in Figure 6 show LOS vertical deformation. Blue and green colors do not represent any deformation. Deformations based on both the first and second observations can be seen in Figure 6.

Results

The locations of the PS points selected for the Mesa region are displayed in Figure 5. PS1 is situated in a sparsely populated area near the city and south of the metro line. The results of the first and second observations conducted at this site are illustrated in Figure 7.

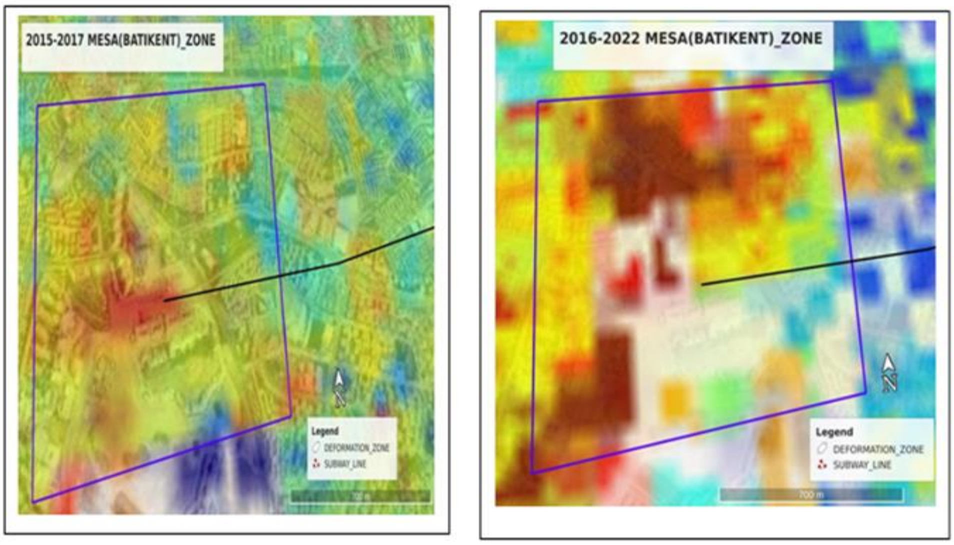

Fig. 6. First (Left) and second (second) observation

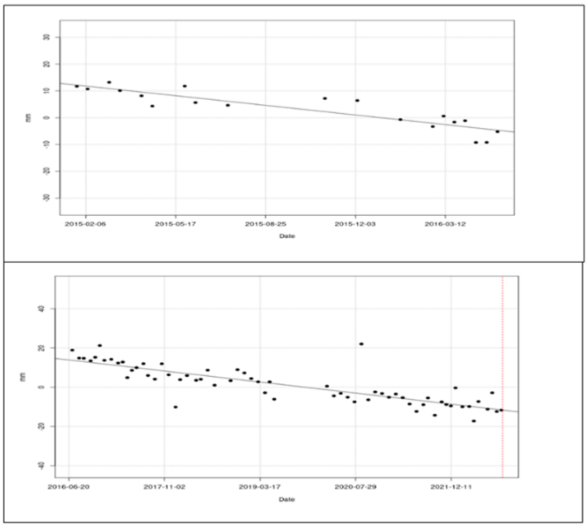

Fig. 7. PS1 Time series of first(up) and second (down)

As illustrated in Figure 7, a consistent deformation was observed in both the first and second observations of the Mesa zone, indicating a continuous displacement since 2015. The total displacement for the PS1 point during the first observation (upper) was estimated to be 15 millimeters, whereas the second observation (lower) recorded a displacement of about 25 millimeters.

The second observation point (PS2) selected for the time series is located near the first selected point (PS1) and is shown in Figure 5. It can be accessed by heading south from the Mesa metro station. The time series data collected from the second observation point in the Mesa region is presented in Figure 8.

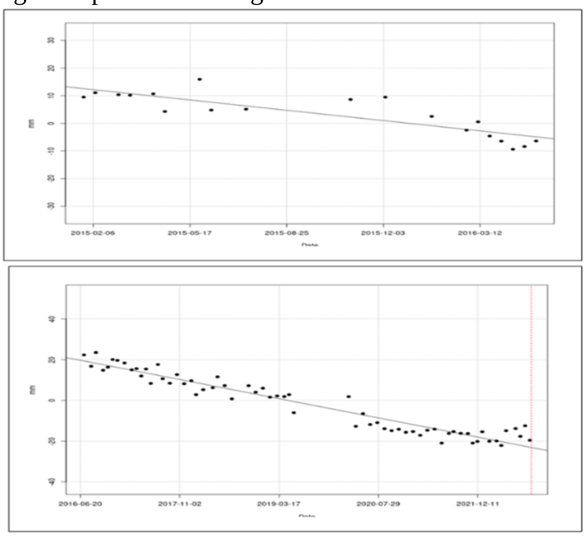

Fig. 8. PS2 Time series of first (up) and second (down)

In this section, the third observation point, similar to the previous two observations, is located south of the Torekent metro line. While there is a public building in the immediate vicinity of its location, it has been noted that the land in its immediate vicinity is barren. The data for the PS3 point is distributed to both the first and second observations, and it is shown in Figure 9. The first observation in Figure 9 indicates a downward slope with respect to time, and the maximum amount of movement recorded during the observation period was approximately 15 millimeters. In the second observation, the same decreasing trend with respect to time detected in the first observation was observed, and the maximum amount of movement experienced by the PS3 point during the observation period was determined to be approximately 35 millimeters.

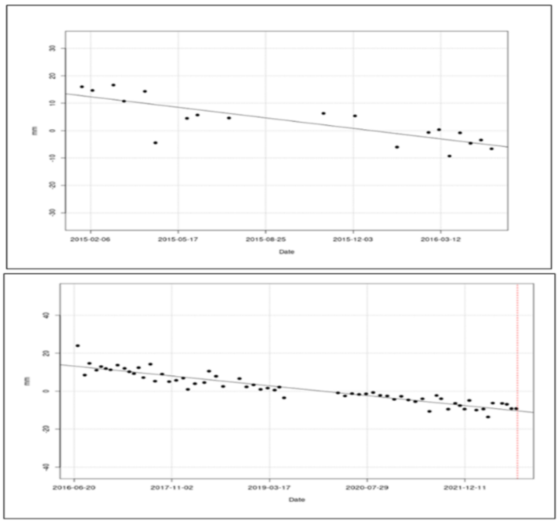

Fig. 9. PS3 Time series of first (up) and second (down)

In Figure 9, the first observation shows a downward trend in movement over time, with a maximum displacement of approximately 15 millimeters during the observation period from 2015 to 2016. The second observation also shows a similar decreasing trend, with a maximum displacement of approximately 35 millimeters for the PS3 point between the last quarter of 2016 and 2022.

The PS4 point, which is located south of the metro line route, is in close proximity to a mall and a residential area, as depicted in Figure 5. The deformation analysis for this point in the first and second observations is shown in Figure 10.

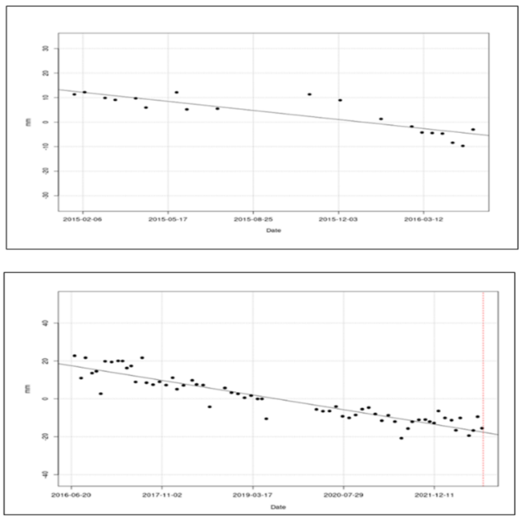

Fig. 10. PS4 Time series of first (up) and second (down)

During the first observation period, which covered the years 2015 and 2016, the maximum displacement observed was 15 millimeters. In the second observation period, which covered the last quarter of 2016 and the years up to 2022, the displacement was measured to be around 40 millimeters. The final observation point in the Mesa region is PS5, located south of the Törekent metro station, just like the previous observation point. This location is a residential area, and the distance to the Mesa metro station is approximately 200 meters.

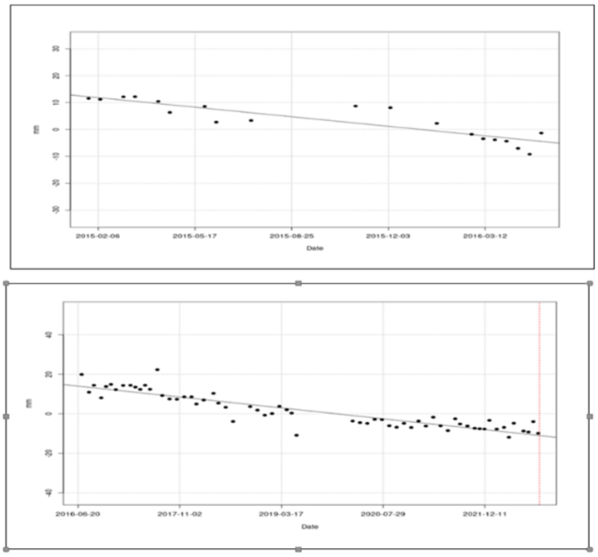

Fig. 11. PS5 Time series of first(up) and second (down)

The results of the deformation analysis at the PS5 point are illustrated in Figure 11. According to the analysis, the deformation was approximately 8 millimeters during the observation period from the first quarter of 2015 to the first quarter of 2016. In the second observation, which was carried out later, the deformation was measured at about 30 millimeters. This value represents the total displacement for the period covering the last quarter of 2016. It is noteworthy that at this measurement point, less deformation was detected compared to the other measurement points. PS5 Time series of first (up) and second (down).

Discussion and Conclusion

Time series analysis was conducted on the deformation-exposed areas of the region between PS points PS1 to PS5. It was determined that ground improvement is necessary for the Mesa zone. As a result of the examination and survey carried out by the Electric Gas Bus General Directorate of Ankara Metropolitan Municipality on the completed line, which is the continuation of the Kızılay-Batikent Metro built by the Ministry of Transport and Infrastructure, measures have been implemented to reduce travel speed and comfort while increasing passenger safety. The announcement that the new line to be built requires ground improvement is consistent with the detection of deformation in the examined region. The Electricity Gas Bus General Directorate of Ankara Metropolitan Municipality has mapped and presented the areas that require improvement. Figure 12 shows the evaluation regions of the Electricity Gas Bus General Directorate.

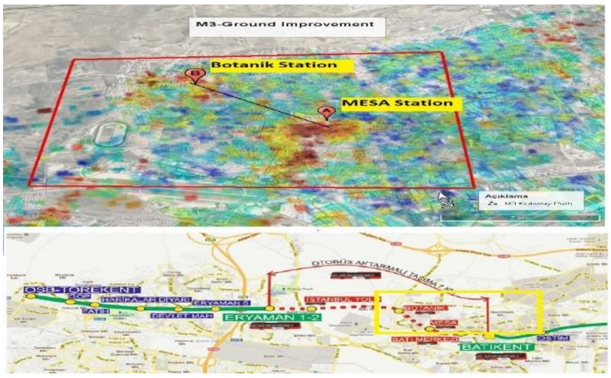

Fig. 12. PSI result (up) and stopped subway points (down)

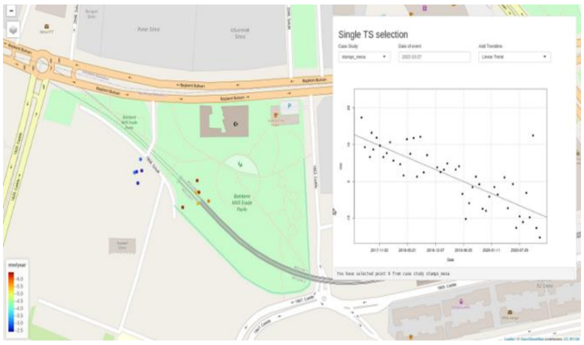

Fig 13. PS points in R Studio environment

Figure 13 shows the PS points located directly above the metro line in the R Studio visualizer environment. These areas have been deformed as a result of the tunnel, allowing for on-site observation by addressing the locations of the PS points. In the Mesa region, numerous deformations were identified in the in-situ study. The asphalt road located just above the subway tunnel has collapsed over time, although these depressions have been repaired. However, deformations were observed on the walls of the mosque situated north of the subway tunnel, with the most apparent of these deformations originating from the tunnel shown in Figure 14. In the parking area north of the tunnel, the pavement was separated from the retaining wall and opened approximately 50 centimeters towards the tunnel. Furthermore, a part of the walking path has collapsed 40 centimeters in an area of approximately 30 square meters.

Fig. 14 Tesseral images of R Studio points (08.07.2022)

As indicated in Table 1, the latest dataset used in this study pertains to January 2022. Following the interferometry study conducted in the Mesa and Botanik regions of Batıkent, where significant ground deformation was observed, the local government carried out soil reinforcement works in these areas eight months later. This was due to the deformation detected through the PSI results, which correlated well with the in-situ observations and the decisions made by the local government. As a result, this study has provided a concrete contribution to the literature, demonstrating that ground deformation can be accurately determined using free satellite data and open-source codes. This study also highlights the practical application of the PSI technique in detecting ground deformations, which can inform decision-making and enable timely actions to be taken, as demonstrated by the intervention of the local government in this case.

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