Zemin Mekaniği ve Geoteknik Mühendisliği
19. Ulusal Konferansı

17-18 Ekim 2024
Hacettepe Üniversitesi, Ankara

30 Ekim 2020 Depremi'ne ait Sentinel-1 Verileri Kullanılarak İzmir Deprem Master Planının İncelenmesi

REVIEW OF IZMIR EARTHQUAKE MASTER PLAN USING SENTINEL-1 DATA FROM 30TH OF OCTOBER, 2020 EARTHQUAKE

Ahmet Kaan Birinci[1], Fatma Begüm Kaya[2]

ÖZET

Son yıllarda uzaktan algılama teknolojisi çeşitli araştırma alanlarına giderek daha fazla entegre edilmektedir. İnterferometrik Sentetik Açıklıklı Radar (InSAR), yüzey deformasyonunu izlemek için kullanılan güçlü bir tekniktir. Bu çalışmada, 30 Ekim 2020 Sisam Depremi'nden elde edilen verilerle güncel İzmir Depremi Master Planının InSAR yöntemi kullanılarak incelenmesi sunulmaktadır. Sentinel-1'in deprem öncesi ve sonrasındaki görüntülemeleri, bölgenin interferometrik görüntülerini oluşturmak için kullanılmıştır. Daha iyi bir görüntüleme elde edebilmek için farklı adımlar ve filtreleme kullanılmıştır. Radar verileri işlendikten sonra İzmir'in tüm zemin yüzeylerinde Sisam 2020 Depremi'ne bağlı yüzey hareketleri elde edilmiştir. İzmir Deprem Senaryosu ve Master Planı'nda haritalanan alan içerisinde 98 farklı sahada yapılan 500 sondaj ve daha önceki saha inceleme raporları esas alınarak zemin tiplerine göre sınıflandırmalar yapılmıştır. Sonuçlar InSAR ile elde edilen interferometrik görütü ile İzmir Deprem Senaryosu ve Master Plan'ında sunulan haritayla belirli bölgelerde uyumluluk göstermektedir. Bu makalenin ana hedeflerinden biri master plan haritalama sonuçlarını, InSAR sonuçlarıyla desteklemek ve deformasyon sonuçları ile zemin büyütmelerinin ilişkili olup olmadığını keşfetmektir. Bu çalışmanın sonucu, uzaktan algılama teknolojisi (InSAR) kullanılarak, genel amaçlı incelemeler için jeolojik/jeoteknik haritalama sürecine önemli katkı sağlamaktadır.
Anahtar Kelimeler: Uzaktan Algılama, InSAR, Deprem, Geoteknik Haritalama, Deformasyon, Zemin Tipi

ABSTRACT

In recent years, remote sensing technology has increasingly utilized in various research fields. Interferometric Synthetic Aperture Radar (InSAR) is a technique for monitoring surface deformations and hence, deformation variations. In this paper, a review of the recent Izmir Earthquake Master Plan using the InSAR method is presented based on data from the October 30, 2020, Samos Earthquake. Sentinel-1 images before and after the

[1] Student Worker, Siemens Gamesa RE, ahmetkaanbrnc@gmail.com (Sorumlu Yazar)
[2] Geotechnical Engineer, Siemens Gamesa RE, begum.kaya@siemensgamesa.com

earthquake were utilized to create interferometric images of the area. Various processes and filtering are applied to the Sentinel-1 data to remove the noise from the image. After processing the radar data, the deformation due to the Samos earthquake on all ground surfaces of Izmir was obtained. According to ground types, zonings were classified based on 500 boreholes conducted at 98 different fields and previous site investigation reports within the mapped area in the Izmir Earthquake Scenario and Master Plan. The results show that the interferometric images obtained by InSAR and the zoning maps presented in the Izmir Earthquake Scenario and Master Plan are coherent in certain regions. One of the main goals of this paper is to support the results of the maps of master plan with the InSAR results and to discover whether deformation and zonings according to ground amplification are related or not. This study's result contributes to the geological/geotechnical mapping process using remote sensing technology (InSAR) for the general purpose of investigation.
Keywords: Remote Sensing, InSAR, Earthquake, Geotechnical Mapping, Deformation, Ground Type

1. INTRODUCTION

Various research disciplines, particularly geosciences, have seen the growing importance of remote sensing technology in providing helpful information for monitoring surface deformation. Interferometric Synthetic Aperture Radar (InSAR) is one of the several technologies used in remote sensing. It has become an effective method for detecting and analyzing ground movement/replacement on the surface due to seismic activities. This paper assesses the InSAR applications for ground movements due to the Samos Earthquake on October 30, 2020, using Sentinel-1 satellite data. The research objective is to understand the linkages between seismic deformation and underlying geological zones by investigating the relationship between InSAR-measured deformations and zonal classifications based on ground amplification proposed in the Izmir Earthquake Scenario and Master Plan.

2. LITERATURE REVIEW

2.1. Interferometric Synthetic Aperture Radar

Interferometric Synthetic Aperture Radar is a valuable tool in the study of ground deformation and more so in the event of natural disasters like earthquakes or landslides. This literature review explores the application of InSAR to the study of earthquake-induced ground displacement, focusing on the influence of ground type on the observed displacements.

Remote sensing with Synthetic Aperture Radar Interferometry has been widely used to study ground deformation. Creating accurate Digital Elevation Maps requires unwrapping the interferometric phase, which can be affected by noise from sources like atmospheric factors. Accurate phase filtering and coherence estimation are essential for reliable displacement measurements. To improve this process, deep learning models like DeepInSAR have been developed, enhancing the usability and scalability of InSAR for applications such as wide-area ground displacement monitoring and prediction (Sun et al., 2020).

InSAR has been widely used for natural hazard detection, such as landslides, effectively identifying land deformation through Quasi-Permanent Scatterers, which is crucial for monitoring hazards in smart cities (Jefriza et al., 2020). Additionally, InSAR has been applied to urban detection, with studies comparing image classification techniques to extract urban areas from L-band Synthetic Aperture Radar imagery (Pradhan et al., 2016). Ground amplification plays a critical role in earthquake-induced displacement, as soil and geological conditions significantly affect the magnitude and pattern of ground movement. Understanding these factors is vital for assessing infrastructure impact and developing mitigation strategies (Mukherjee et al., 2018).

Overall, the literature highlights the growing importance of InSAR as a tool for monitoring and analyzing ground deformation, particularly in the context of natural hazards such as earthquakes. Incorporating deep learning techniques and considering ground type are emerging as critical areas of focus in this field of research (Kim et al., 2020).

2.2. İzmir Earthquake Scenario and Master Plan

In the scope of the protocol signed between İzmir Metropolitan Municipality and Boğaziçi University, a project titled the İzmir Earthquake Scenarios and Earthquake Master Plan has been presented.

During an earthquake, cyclic loading on soft soil areas can lead to an increase in pore water pressure, deformations, and a reduction in soil shear strength, which can cause settlements/replacement. Altınsu et al (2024) highlight that the significant increase in seismic acceleration and duration as seismic waves transition from bedrock to softer soils is a well-documented phenomenon observed in analyses of past earthquakes. For example, the severe damage in Hatay's Iskenderun district and along the Asi River in Antakya after the Kahramanmaraş Earthquake, in areas with sandy and clayey soft soils, closely aligns with the specific geological and soil conditions of those regions. On October 30, 2020, an earthquake with a magnitude of Mw 6.9 struck north of Samos Island. The nearest location to the epicentre in Turkey is Seferihisar, which is 27 km away. However, Bayraklı and Bornova in İzmir were the most affected areas, despite being 70 km from the earthquake's epicentre, due to the predominance of soft and loose soils in these regions compared to other areas. The soft areas and the damaged/collapse buildings are shown in Figure 1.

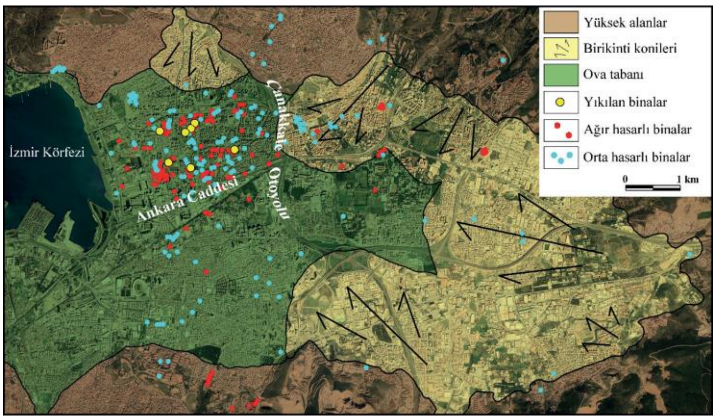

Figure 1. Damaged/collapse building on soft soil areas (Karadaş and Öner, 2021)

In the scope of the Master Plan, various micro-zonation maps were obtained by analyzing historical seismic events and geological/ geotechnical data. Site investigation reports have been compiled to map and classify the local soil conditions within the İzmir's residential areas. Around 500 boreholes and CPT results from 98 sites were evaluated and classified with data assessed alongside the İzmir Geological Map. The equivalent shear wave velocities from the compiled boreholes were used to calculate the corresponding equivalent amplification curves based on Borchert et al. (1991) and presented in Figure 2.

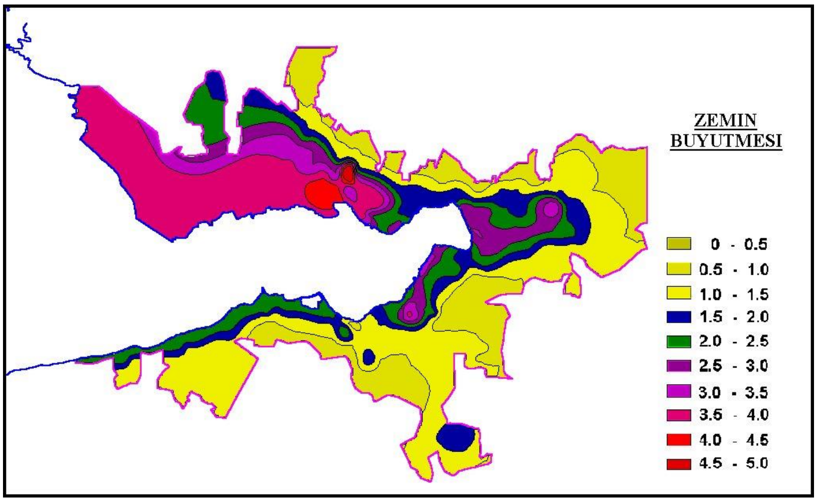

Figure 2. Equivalent curves of ground amplificaition in İzmir Province

3. METHODOLOGY

The chapter describes the method used to study ground deformation due to the Samos Earthquake that occurred on October 30, 2020, using InSAR. The analysis was performed using the Sentinel-1 data of the ascending orbit; SLC data were obtained from the Copernicus Open Access Hub. The processing was performed using the SNAP (Sentinel Application Platform) software, with standard interferometric steps. The following are the steps that are followed in the processing of the material.

3.1. Data Acquisition and Data Preparation

The Sentinel-1 SLC data were downloaded from the Copernicus Open Access Hub before and after the earthquake. Ascending orbit data were selected for this study to maintain consistency in the observation geometry. The descending orbit data were not utilized because they showed poor alignment with the soil amplification map, leading to less reliable results. The acquired Sentinel-1 data then underwent the following preprocessing steps in SNAP:

- Split: The SLC data were divided to choose the study area's subswath and bursts of interest.
- Apply Orbit File: The precise orbit files were incorporated into the data to enhance the accuracy of the process.

3.2. Coregistration and Interferogram

Coregistration is a critical step in InSAR processing to align the master (post-earthquake) and slave (pre-earthquake) images accurately.

- Back-Geocoding: This was done to merge the master and slave images using a DEM(Digital Elevation Model). Back-geocoding is crucial in mapping radar measurements to ground coordinates since it helps identify the correct geographical location.
- Interferogram Formation: Interferometry was then performed to generate an interferogram representing the phase difference between the two images. This phase difference is directly related to ground displacement.

3.3. Interferogram Filtering and Phase Unwrapping

After interferogram generation, noise reduction and phase unwrapping are essential steps:

- Goldstein Phase Filtering: The Goldstein filter was applied to reduce noise and enhance the quality of the interferogram. This filtering helps improve the signal-to-noise ratio, making the phase information more interpretable.
- SNAPHU Export: The filtered interferogram was exported to SNAPHU (Statistical-Cost Network-Flow Algorithm for Phase Unwrapping) for unwrapping, a crucial step in converting the wrapped phase into a continuous phase map.
- Phase Unwrapping (SNAPHU): SNAPHU was used to unwrap the phase, removing the 2π phase ambiguities to generate a continuous phase map accurately representing the ground displacement.
- SNAPHU Import: The unwrapped phase data were then imported back into SNAP for further processing and analysis.
- Phase to Displacement Conversion: The unwrapped phase values were converted into displacement measurements using the standard SNAP workflow. This step involves applying the radar wavelength and other relevant parameters to calculate the displacement in the line-of-sight direction of the satellite. The resulting displacement map indicates the amount of ground movement caused by the earthquake.

3.4. Post-Processing and Analysis

After generating the final displacement map, the compatibility of the ground amplification maps outlined in the Izmir Earthquake Scenario and Master Plan with the displacement map obtained in InSAR was analyzed. This analysis assessed the correlation between the observed deformation and the geological conditions. Using standard InSAR processing techniques in SNAP, this methodological approach enabled the detailed analysis of surface deformation caused by the Samos Earthquake, contributing to a better understanding of the earthquake's impact on the region's ground stability.

3.5 Possible Errors

In Synthetic Aperture Radar (SAR) processing, several sources of error can affect the accuracy and reliability of the deformation measurements derived through Interferometric Synthetic Aperture Radar (InSAR) techniques. Understanding these potential errors is crucial for accurately interpreting the results, especially in studies like the Samos Earthquake analysis, where precise ground deformation data is essential.

- Orbital Error: Orbital inaccuracies in the satellite's position can lead to errors in the interferogram, resulting in phase distortions that may affect the accuracy of the deformation measurements. Although precise orbit files are applied during preprocessing to correct these errors, residual inaccuracies can persist. These errors typically manifest as long-wavelength phase trends across the interferogram, which can be misinterpreted as ground displacement.
- Atmospheric Delays: Atmospheric conditions, mainly water vapour and temperature variations, can introduce phase delays that affect the SAR signal as it travels through the atmosphere. These delays can cause apparent phase shifts in the interferogram that do not correspond to actual ground deformation, leading to erroneous displacement measurements.
- Temporal Decorrelation: Temporal decorrelation occurs when changes on the ground surface between the acquisition of the master and slave images reduce the coherence of the SAR signal. This issue is particularly prevalent in areas with vegetation, water bodies, or urban development, where surface conditions can change rapidly. Temporal decorrelation reduces the accuracy of phase measurements and can lead to unreliable deformation results.
- Spatial Decorrelation: Spatial decorrelation arises due to the difference in viewing geometry between the two SAR acquisitions, leading to reduced coherence. This can occur in areas with complex topography or rough surfaces, where the radar signals from the master and slave images interact differently with the terrain.
- Phase Unwrapping Errors: Phase unwrapping is a critical step in InSAR processing, where the wrapped phase values are converted into a continuous phase map. Errors in this process, particularly in areas with low coherence, can lead to significant inaccuracies in the final displacement map. Unwrapping errors can result in incorrect displacement measurements, especially in regions with steep topography or high deformation gradients.
- Geometric Distortions: Due to the side-looking radar geometry, SAR data is susceptible to geometric distortions, such as layover, shadowing, and foreshortening. These distortions can affect the accuracy of the interferometric measurements, particularly in mountainous or steep terrain.
- Instrumental Noise: Instrumental noise inherent to the SAR system can introduce random phase errors into the interferogram. While typically low, this noise can still affect the accuracy of the displacement measurements, particularly in areas with low signal strength or high complexity.
- Mapping Error in İzmir Earthquake and Master Plan: A limited number of data has been used to create the maps in İzmir Earthquake Scenario and Master Plan. It was mentioned in the Master Plan that the accuracy of the study would increase with more data, and due to the limited data, there may be changes in the mapping in future stages.

The accuracy of InSAR-derived ground deformation measurements is influenced by various sources of error, including orbital inaccuracies, atmospheric conditions, temporal and spatial decorrelation, phase unwrapping challenges, geometric distortions, and instrumental noise. Additionally, using a limited amount of SAR data, relying only on the pre and post-earthquake images, can impact the accuracy and reliability of the results. Without time series analysis, it is difficult to identify between actual seismic deformation and other ground movements or noise. To improve the accuracy of the results, it is recommended to use data spanning longer periods before and after the earthquake.

4. COMPARISON

In this chapter, a comparison of the map showing relatively ground movement after the earthquake obtained from InSAR results with the map of ground amplification presented in the İzmir Scenario and Earthquake Master Plan is focused. The regions of Bayraklı/Bornova, Konak, Karşıyaka/Çiğli, and Balçova/Narlıdere/Güzelbahçe are of particular interest due to their varying geological characteristics and urban densities.

4.1. Bayraklı and Bornova Region

The InSAR results (left) in Figure 3 depict significant ground movement due to the Izmir earthquake, with purple and magenta areas indicating the most ground movement in central and southern Bayraklı, extending into Bornova. A promising correlation exists between the InSAR data and the high amplification zones. Central of Bayraklı, where the greatest ground movement is observed, also corresponds with areas of high soil amplification, indicating these regions are particularly vulnerable to seismic events. Conversely, areas with minimal movement generally align with lower amplification zones, suggesting greater stability. Additionally, the collapse buildings in Figure 4 – also shown in Figure 1 in detail – are predominantly located within these high-movement and high-amplification zones. This strong correlation suggests that significant ground movement and high soil amplification contributed to the structural damage observed in these areas.

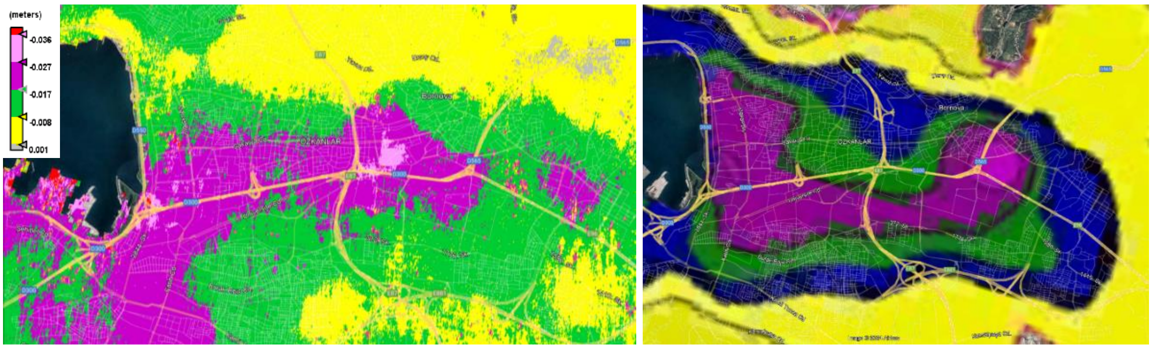

Figure 3. InSAR Results(left) and Soil Amplification Map (right) of Bayraklı and Bornova

Figure 4. Collapse Buildings locations with InSAR Result

4.2. Konak Region

The InSAR results (Figure 5) show significant ground movement in the Konak region, particularly along the coastline and central urban areas. The soil amplification map aligns with these findings, identifying the same areas that have high amplification potential.

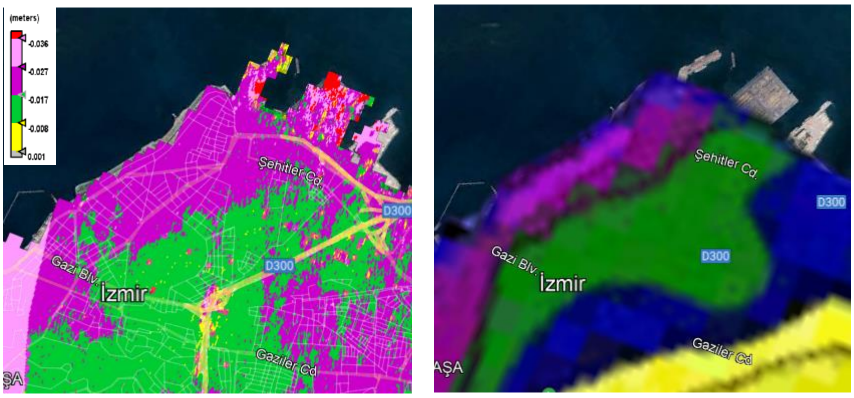

Figure 5.InSAR Results(left) and Soil Amplification Map (right) of Konak

4.3. Karşıyaka and Cigli Region

There is some alignment in coastal zones where both maps suggest higher vulnerability as shown in Figure 6. When focusing on the Alaybey section, more consistent results were obtained compared to other sections. However, discrepancies exist in other regions where significant movement in the InSAR results does not match with lower-risk areas on the soil map.

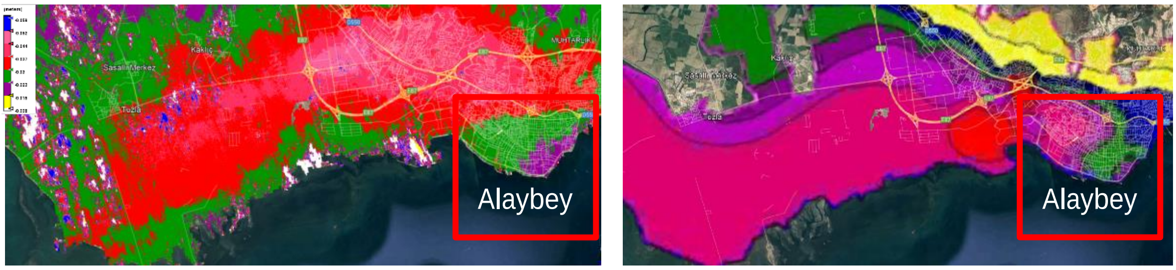

Figure 6. InSAR Results(left) and Soil Amplification Map (right) of Karşıyaka and Cigli

4.4. Balcova, Narlidere and Güzelbahçe Region

The InSAR results show significant ground deformation in the Balçova, Narlıdere, and Güzelbahçe regions (Figure 7), but these do not align well with the soil amplification map. InSAR-specific errors may also influence the discrepancies between the InSAR results and the ground amplification map.

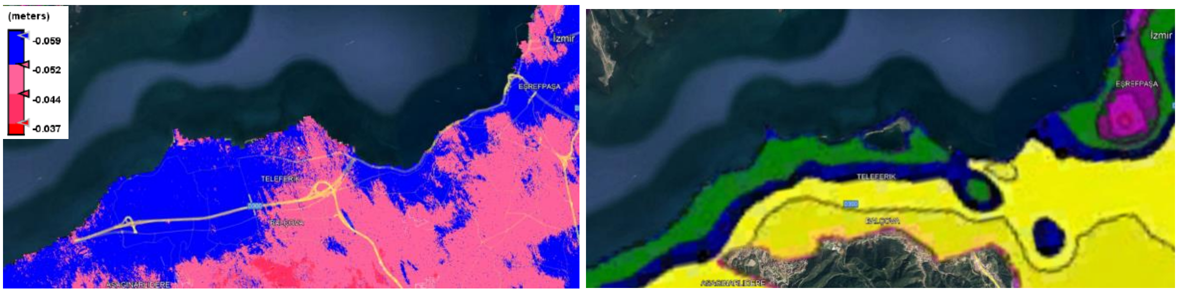

Figure 7. InSAR Results(left) and Soil Amplification Map (right) of Balcova, Narlıdere and Guzelbahce

5. DISCUSSION AND CONCLUSION

This study utilized InSAR data to analyze ground movement across various regions of Izmir. Despite the study's limitations, including a limited dataset and data from only one orbit (Ascending), the results provide significant insights into the areas most affected by the October 30th, 2020 Samos Earthquake, particularly in the Bayraklı and Bornova regions. Additionally, there is a good match between the InSAR results and the ground amplification map for the coastal side of the Konak region. However, while there are some similarities in the Karşıyaka and Çiğli regions, particularly in Alaybey, the areas with more stable soil conditions could not be effectively detected by the InSAR results. For the Balçova, Güzelbahçe, and Narlıdere regions, the results show poor alignment with the expected soil behaviour. The reasons behind these misalignments vary. In this study, only ascending orbit data was used. Ideally, data from both ascending and descending orbits should be employed to offer a more comprehensive view of ground deformation. Additionally, the InSAR results are presented in the LOS (Line of Sight) format, which may introduce additional errors. As mentioned before, this study has various possible sources of error, with topographical errors being a significant factor. As illustrated in Figure 8, regions like Narlıdere and Güzelbahçe are mountainous, which likely contributes to the misalignment observed in the SAR results.

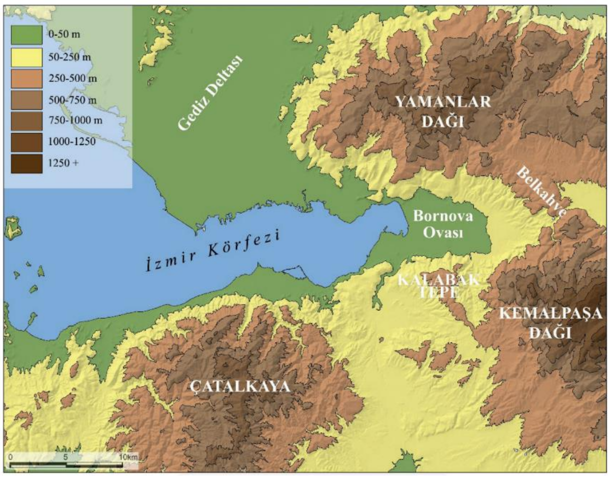

Figure 8. Elevation Plan of the Investigated Area (Karadaş and Öner, 2021)

InSAR methods are beneficial for detecting ground movement, especially in landslides, and can work well with shoring systems and excavation works in vast areas. However, independent datasets such as GNSS (Global Navigation Satellite System) are necessary to validate and calibrate SAR data. As a recommendation for further study, increasing the amount of data used would likely improve the accuracy of InSAR results.

A limited number of data has been used to create the maps in the İzmir Earthquake Scenario and Master Plan. The area studied covers the entire surface area of Izmir; however, in a more specific, relatively smaller area, where the soil stratification and surface effects are examined with more detailed and abundant data, the results will be obtained with higher accuracy.

Moreover, more sophisticated InSAR methods, such as Persistent Scatterer Interferometry (PSI), could be employed to obtain time-series deformation data for specific areas. If possible, these results should be compared with independent data to enhance the reliability and accuracy of the findings.

In conclusion, despite the limited data and some discrepancies in the results, the areas most affected by the earthquake were identified with sufficient accuracy. This has pointed to the way for more accurate results to be obtained through more detailed studies.

ACKNOWLEDGMENTS

We would like to express our sincere gratitude to Onur Güneş and Müge Kuleli for their invaluable support and insightful feedback during the preparation of this work.

REFERENCES

Altunsu, E., Güneş, O., Öztürk, S., Sorosh, S., Sarı, A., Beeson, T. (2024, March), "Investigating the Structural Damage in Hatay Province after Kahramanmaraş-Türkiye Earthquake Sequences."

Erdik, M., Ansal, A., Aydınoğlu, N., Barka, A., Işıkara, A., Yüzügüllü, Ö., Avcı, J., Özel, O., Biro, Y., Birgören, G. (2018), "İzmir Deprem Senaryosu ve Deprem Master Planı," *İzmir Büyükşehir Belediyesi.* Available at: https://www.izmir.bel.tr/izmirdeprem/#t561

Jefriza, Yusoff, I. M., Abir, I. A., Syahreza, S., Rusdi, M., Razi, P., Lateh, H. (2020, June 1), "The Applications of InSAR Technique for Natural Hazard Detection in Smart Society," *IOP Publishing,* Vol 1572(1).

Karadaş, A., Öner, E. (2021), "Effects of the Alluvial Geomorphology on the Damage of the Samos Earthquake in the Bornova Plain."

Kim, J., Dorjsuren, M., Choi, Y., Purevjav, G. (2020, November 11), "Reconstructed Aeolian Surface Erosion in Southern Mongolia by Multi-Temporal InSAR Phase Coherence Analyses," *Frontiers Media,* Vol 8.

Mukherjee, S., Zimmer, A., Kottayil, N. K., Sun, X., Ghuman, P., Cheng, I. (2018, October 1), "CNN-Based InSAR Denoising and Coherence Metric."

Pradhan, B., Abdullahi, S., Seddighi, Y. (2016, September 26), "Detection of Urban Environments Using Advanced Land Observing Satellite Phased Array Type L-Band Synthetic Aperture Radar Data Through Different Classification Techniques," *SPIE,* Vol 10(3), 036029-036029.

Sun, X., Zimmer, A., Mukherjee, S., Kottayil, N. K., Ghuman, P., Cheng, I. (2020, July 21), "DeepInSAR—A Deep Learning Framework for SAR Interferometric Phase Restoration and Coherence Estimation," *Multidisciplinary Digital Publishing Institute,* Vol 12(14), 2340–2340.