Caliphate Journal of Science & Technology (CaJoST)

ISSN: 2705-313X (PRINT); 2705-3121 (ONLINE)

Research Article

Article Info

Received: 22nd March 2021

Revised: 12th July 2021

Accepted: 14th July 2021

Surface Deformation Studies in South of Johor using the Integration of InSAR and Resistivity Methods

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Cite this: *CaJoST,* 2021, 2, 167-172

Over the years, land subsidence has been a serious threat mostly to urban areas. Land subsidence is the sudden sinking or gradual downward settling of the ground's surface with little or no horizontal motion. In most areas, land subsidence is a slow process that covers a large area, therefore it is sometimes left unnoticed. South of Johor is the area of interest for this project because it is going through rapid urbanization. The objective of this research is to evaluate and identify potential deformations in south of Johor using integrated remote sensing and 2D resistivity methods. Synthetic aperture radar interferometry (InSAR) which is a remote sensing technique has the potential to map coherent displacements at centimeter to millimeter resolutions. Persistent Scatterer Interferometry (PSI) stacking technique was applied to Sentinel-1 data to detect the earth deformation in study area. A dipole-dipole configuration resistivity profiling were conducted in three areas to determine the subsurface features in that area. This subsurface features interpreted and then correlated with the remote sensing technique to predict the possible causes of subsidence and uplifts in south of Johor. Based on the results obtained, West Johor Bahru (0.63mm/year) and Ulu Tiram (1.61mm/year) are going through uplift due to possible geological uplift. On the other end, East Johor Bahru (-0.26mm/year) and Senai (-1.16mm/year) undergoes subsidence due to possible fracture and granitic boulders loading. Land subsidence must be taken seriously as it can cause serious damages to infrastructures and human life. Monitoring land subsidence and taking preventive actions must be done to prevent any disasters.

Keywords: Interferometric synthetic aperture radar, Persistent Scatter Minimum Spanning Tree, Resistivity and subsidence

1. Introduction

Precision of Interferometry synthetic aperture radar (InSAR) measurement has been greatly improved in the recent years with the development of new methods for time series analysis such as Persistent Scatterer (PS) (Hooper et al., 2004). Persistent Scatterer deals with both the decorrelation and atmospheric delay error of conventional InSAR and is able to provide a dynamic map of the deformation at millimetre level (Hooper, 2006). A combination of PS technique and geophysical methods could lead to a better evaluation and understanding of subsidence causes. Area of interest for this research is south of Johor where possible subsidence could occur due to its rapid urbanization, ground water extraction and flooding. The most productive acquifers are the alluvial aquifers which are located along the coastal region of Johor where they are deposited in two different environments namely the Quatenary continental deposit and the Quaternary marine deposit and they consist of gravel, sand, silt and clay (Hatta & Rashid, 1999).

Flooding is a main water issue in Johor where historically, there have been six major devastating flood events in Johor that destroyed infrastructure and properties and caused loss of lives (Tan et al., 2015). The most destructive events were the floods which occurred during the period of December 2006 and January 2007. These caused the evacuation of more than 100,000 people and 18 deaths with a total estimated loss of 0.5 billion U.S. dollars (Kia et al., 2012). Various researches on occurrences of subsidence in urban areas will help further in identifying the potential areas of subsidence and creates understanding of the risk to the society so that preventive measures could be taken beforehand. Hassan et al. (2015) employed persistent scatterer InSAR to monitor the level of subsidence in Kelantan Catchment, Malysia. The analysis found that the land subsidence rate at

Pintu Geng, Tanjung Mas and Tumpat is about -1.78 mm/yr, -2.39mm/yr and -1.87mm/yr respectively and suggested the application of PSInSAR to monitor subsidence. Using Time-Lapse Orthometric Leveling Data acquired from 1988 – 2003 Uko et al. (2018), estimated the Land Surface Subsidence induced by Hydrocarbon production in the Niger Delta, Nigeria. The study found out that, the rate of land subsidence at each location of levelling varies from 66.67mm yr-1 to 200.00mm/yr with an average of 86.00mmyr-1. More recently, Sirajo et al. (2020) used remote sensing techniques and resistivity method to detect land subsidence in Seberang Perai Malaysia, the findings suggests that there is an uplift in the Butterworth of an average mean of about 4mm/year. And also suggest the subsidence at Prai, Bukit Mertajam and Juru of about -5mm/year,-2mm/year and -7mm/year respectively. In this research, deformation of Earth surfaces in south of Johor is investigated using integrated remote sensing and geophysical approaches.

2. Experimental

2.1 Location

Johor was known in its early days as ‘Ujong Tanah’ meaning Land’s End and the present name Johor comes from an adaptation of the Arabic word ‘Jauhar’ which means precious stone or jewel. Johor is one of the 13 states found in Malaysia and it is located in the south of the Peninsular Malaysia. Johor has land borders with the Malaysian states of Pahang to the north and Malacca and Negeri Sembilan to the northwest. Johor shares maritime borders with Singapore to the south and Indonesia to both the west and east as shown in Figure 1. The total area of the state is 19,102km2 with a population estimated at 3,700,000.The state has total of 400 km of coastline, with a majority of its coastline, especially on the west coast is covered with mangrove and nipah forests. The east coast is dominated by sand and rocky headlands as shown by geological map of figure 2.

Figure 1: Location map Johor area.

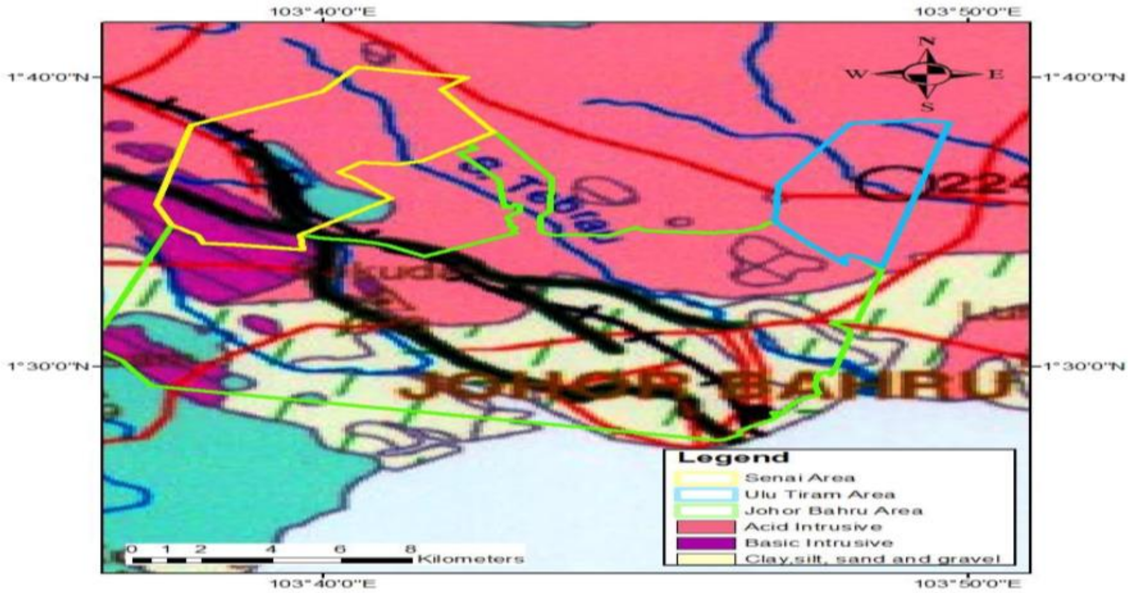

Figure 2: Geological Map of Study Area

About 83% of Johor's terrain is lowland areas while only 17% is higher and steep terrain. Johor is located in a tropical region with an equatorial climate. Both the temperature and humidity are consistently high throughout the year with heavy rainfall. Average monthly temperatures are 26 °C to 28 °C, with the lowest recorded during the rainy seasons. The west coast receives an average of 2,000 millimetres to 2,500 millimetres of rain, while in the east the average rainfall is higher, receiving more than 3,400 millimetres of rain a year (Bakhshipour et al., 2016)

2.2 Data acquisition and analyses

Data used for this research purpose composes of a total of 21 descending Sentinel-1A with 12 days interval data that was downloaded from the Copernicus website which is the European Union's Earth Observation Programme, looking at our planet and its environment. The SENTINEL-1 mission is the European Radar Observatory for the Copernicus joint initiative of the European Commission (EC) and the European Space Agency (ESA). Copernicus, previously known as GMES, is a European initiative for the implementation of information services dealing with environment and security. It is based on observation data received from Earth Observation satellites and ground-based information.

The SENTINEL-1 mission includes C-band imaging operating in four exclusive imaging modes with different resolution (down to 5 m) and coverage (up to 400 km). It provides dual polarization capability, very short revisit times and rapid product delivery. For each observation, precise measurements of spacecraft position and attitude are available. Synthetic Aperture Radar (SAR) has the advantage of operating at wavelengths not impeded by cloud cover or a lack of illumination and can acquire data over a site during day or night time under all weather conditions. SENTINEL-1, with its C-SAR instrument, can offer reliable, repeated wide area monitoring. SENTINEL-1 carries a single C-band synthetic aperture radar instrument operating at a centre frequency of 5.405 GHz.

3. Results and Discussion

Figure 3 shows the persistent scatterer interferometry (PSI) rates in the radar line-of-sight. PSI is mainly used for this research due to its suitability and accuracy for urban areas. From the line of sight and satellite position, it can be said that if the points in PSI moves towards the satellite it can be interpreted as uplift or moving eastward and if the points move away from the satellite it can be interpreted as subsidence or moving westward.

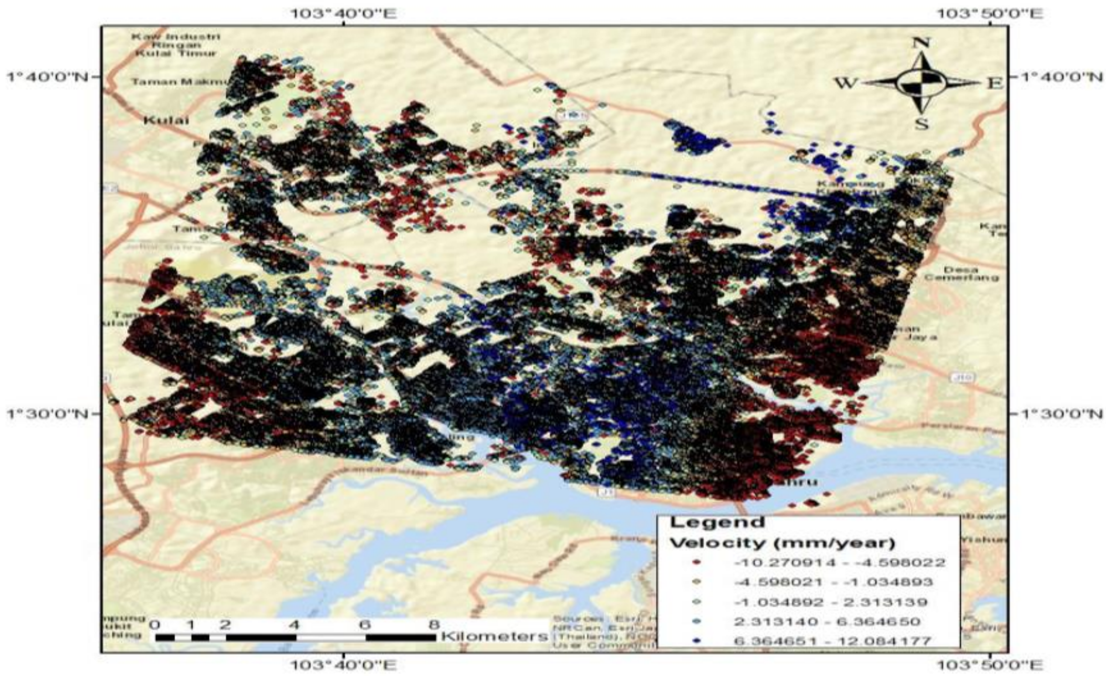

Figure 3: Persistent Scatterer Interferometry Map showing Ground Displacement.

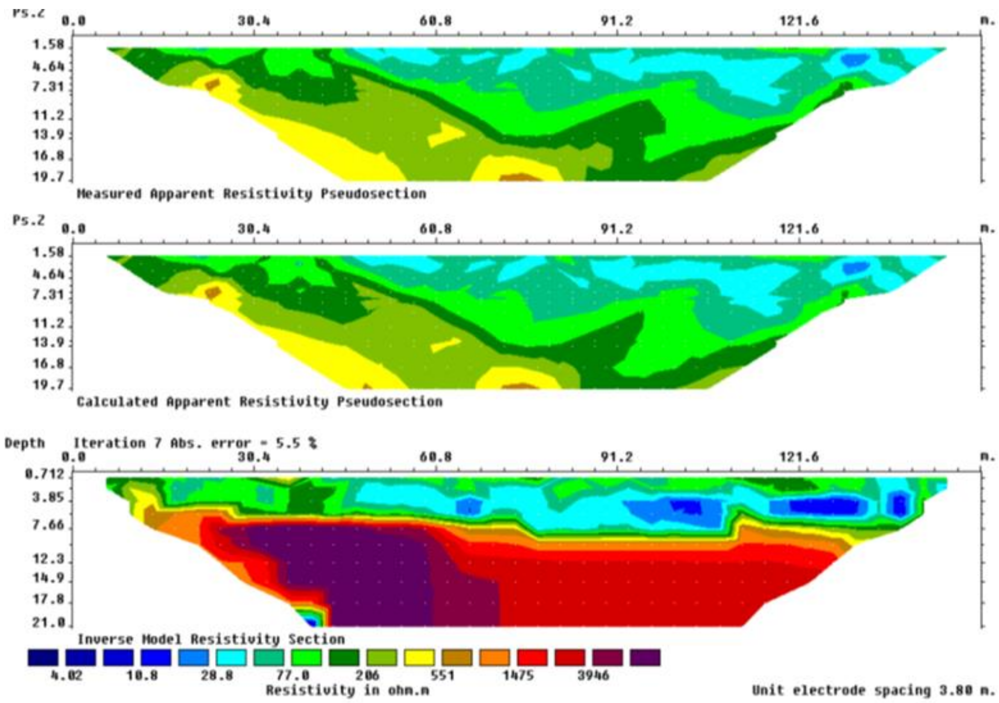

Figure 4: Inverse Model of Resistivity Section

The colder colours indicates uplift while the hotter colours indicates subsidence as shown in Figure 2. In some areas, points are not present as there is no coherence. Central area of south Johor shows mostly uplift and subsidence rates increase towards eastwards and westwards from the central area. High rates of subsidence can be identified in the southeast of Johor Bahru with rates up to -10.270914 mm/year which could be due to possible presence of geological fractures. Uplifts with higher rates about 12.084177 mm/year are predominantly in the westward of Ulu Tiram where the rock type is acid intrusive. This result suggests that there could be a possible intrusive rocks uplift that affects the readings of the PSI. Evidently, the rate of subsidence and uplifts are relatively small as they only range from about -10 mm/year to about 12 mm/year. A study made by Hassan et al. (2015), Uko et al. (2018) and Sirajo et al. (2020)

is a good reference for surface deformation detection.

The persistent scatterer interferometry points obtained were used to generate an IDW interpolation map using ArcGIS software. IDW interpolation is a mathematical deterministic assumption that closer values are more related than further values with its function. IDW interpolation is used for this research as it is a very flexible spatial interpolation method where prediction of any unmeasured values, IDW uses the measured values surrounding the prediction location. IDW assumes that each measured point has a local influence that diminishes with distance. Therefore, the density of subsidence and uplift can be better interpreted compared to the PSI approach. The interpolation map shows that the outskirts of the city area tend to endure subsidence as it is closer to the river bank which could be one of the major contributing factor. In the eastward of Johor Bahru, another possible factor of subsidence could be the presence of thick clay sediment as it is a mangrove swamp area. Uplift in the central of Johor Bahru and the higher rate of uplift in the westward of Ulu Tiram suggests intrusive rocks uplift. Reclamation land nearby straits of Johor could also be another cause of subsidence in the surrounding area.

Resistivity surveying have been widely used to determine the thickness and resistivity of layered media for the purpose of assessing the shallow subsurface. In this research, 2D resistivity surveys were done as shown in figure 4 to provide a more detailed subsurface structure and may assist in identifying the lithology and minerals in the shallow subsurface.

These resistivity results were then used to understand more on the reasons of subsidence and uplift in the south of Johor. Three dipole-dipole configuration resistivity lines were obtained from the research area in Johor Bahru. The resistivity survey areas were selected based on the following reasons:

i. The resistivity survey lines must overlie both the subsidence and uplift areas based on the PSI points.
ii. The survey areas must be easily accessible.
iii. The minimum length of resistivity line that can be deployed is 150m.
iv. Surface soil thickness must be more than 5cm in survey areas to ensure that the electrodes were buried deep enough in to the earth.

4. Conclusion

In this research, deformation of Earth surfaces in south of Johor is investigated using integrated remote sensing and geophysical approaches. A total of 21 descending Sentinel-1A with 12 days interval data from 29 July 2018 to 26 March 2019 were used for this research. To process the InSAR data, SAPROZ tool which is written in Matlab was used. Persistent Scatterer Interferometry (PSI) was the InSAR technique applied in this research as it is a powerful remote sensing technique able to measure and monitor displacements of the Earth's surface over time. This is a cheap and time efficient method as it covers wide area. Based on the results from Persistent Scatterer Interferometry (PSI), some areas mainly the central area shows uplift while the other areas indicates subsidence.

Conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this article.

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