The Southeast Asian Journal of Advance Engineering and Technology
Vol. 2, No. 3, September 2025, pp.88-94

ISSN 3032-1230
Original Research

Land Subsidence Analysis Using PS-InSAR Method in Duri Hoou Oil Exploration Area, Mandau District, Riau Province

Ryan Eka Putra[1], Fajrin[1], Dwi Arini[1], Dwi Marsiska Driptufany[1]
[1]Teknik Geodesi, Institut Teknologi Padang, Indonesia

Corresponding Author:

Ryan Eka Putra

Teknik Geodesi
Institut Teknologi Padang
Aie Pacah, Koto Tangah, Padang City, West Sumatra

E-mail:
2023510034.ryan@itp.ac.id

ABSTRACT

Duri City is the largest national petroleum producing area located in Mandau District and part of Bengkalis Regency in Riau Province. Land subsidence occurs due to continuous groundwater extraction, this has the potential to cause land subsidence and can trigger other problems such as damage to infrastructure, oil and gas production facilities. This will disrupt operations and require large repair costs. The method used is PS-InSAR, this method can calculate the value of land movement using scin 23 imagery so that movement can be obtained in a time series. The accuracy of the land movement value was tested by conducting geodetic GPS observations so that values were obtained at several points in the study area. To determine whether there was an influence on the value of PS-InSAR processing and geodetic GPS observations, a parametric t-test was conducted. The range of movement values obtained after the results of PS-InSAR processing was a range of 17.5 mm to -27.5 mm per year, with the distribution of land movement in the northern and southern parts of the Duri HO area. The results of the paired sample T-Test calculation with 25 samples produced a test value of 0.754, so the initial hypothesis was accepted (H0) with the conclusion that there was no significant difference between the data from the sarproz processing results and the GPS coordinate value data in the HO Duri area.

Keywords: Ps-InSAR, GPS Geodetik, Paired Sample T-Test.

Article history:

Received Aug 24, 2025
Revised Sep 2, 2025
Accepted Sep 3, 2025

1. Introduction

Duri City is one of the largest contributors to national petroleum production, located in Mandau District and part of Bengkalis Regency in Riau Province. This exploration activity can create jobs and boost the regional economy. Negative impacts arising from this exploration activity include environmental impacts. Land subsidence is very likely to occur due to continuous groundwater extraction, which has the potential to cause land subsidence and trigger several other problems, such as damage to infrastructure and damage to oil and gas production facilities such as platforms, pipes, wells, and other supporting buildings. This will certainly disrupt operations and require significant repair costs [4]. Significant land subsidence can increase the risk of flooding and land degradation. Furthermore, secondary disasters can arise from frequent land subsidence, such as the emergence of low-lying areas, which can lead to the unexpected formation of artificial lakes, which can cause the soil layer to change from hard ground to mud or swamps in the coming years [5]. Landslide monitoring has been conducted in several areas, such as in the Cepu oil well area located in Blora Regency (Central Java), Bojonegoro Regency, and Tuban Regency (East Java). [6] This study discusses land subsidence monitoring in the Liaohe lowland area of China. This area was chosen due to the presence of oil and gas exploration, aquaculture, and salt production activities covering an area of 12,620 square kilometers. [7] Research related to landslides was conducted on Sipora Island using the PS-InSAR method. This study aimed to measure the effect of the amplitude stability index (ASI) value on the landslide measurement process. [8] The use of ERS-1 and ERS-2 imagery in this study was carried out to observe subsidence in the California oil field area, San Joaquin Valley, Lost Hills, and Belridge [9].

Land subsidence monitoring in an area can be analyzed using conventional engineering methods such as terrestrial methods using leveling surveys, Total Station and GPS (Global Positioning System), or the latest extraterrestrial technologies such as lidar and radar. The frequency range of electromagnetic waves in SAR is 0.3 – 40 GHz with a wavelength of 0.7 cm – 100 cm [3], one method that can be used to observe land movement over a long period of time and does not require large costs is by using the ps-insar method which this method can measure how much land movement in an area in a time series, this method allows mapping of land movement widely, which is sufficient for a general description of movement in the area, this is because the correction obtained is quite large by using 30 meter SRTM DEM data. To determine the accuracy of the PS-InSAR method obtained, a parametric t-test was carried out, where the value of the test results resulted in the decision to select the hypothesis to be used, where the hypothesis itself consists of points generated by PS-InSAR measurements that do not have significant changes with GPS observation data or vice versa.

2. Research method

2.1 Research Location

The research area itself is located in the Pertamina Hulu Rokan area, specifically in the Hoou Duri oil refinery area, which has an area of 10160.24 Ha, this area contains an oil drilling location often called a well, which is one of the largest oil drilling areas in the Mandau and Bathin Solapan districts. Which stretches from latitude 101◦11'38.688", and longitude 1◦23'58.641" to 101◦15'9.829", and longitude 1◦15'45.280", and from latitude 101◦13'12.294", and longitude 1◦15'34.095" to latitude 101◦13'21.480", and longitude 1◦24'14.167"Provide sufficient detail to allow the work to be reproduced. Methods already published should be indicated by a reference: only relevant modifications should be described.

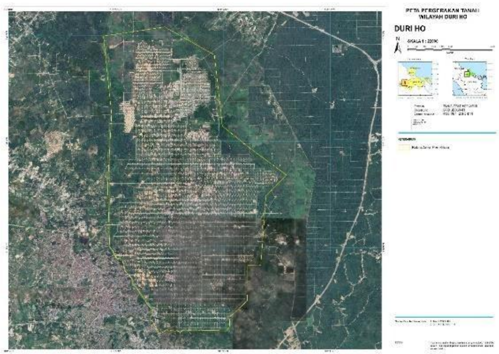


Figure 1. Duri HO in map

2.2 Data Collcetion

Sentinel 1 imagery of 23 sin images with IW (SLC) specifications recorded from March 2020 to December 2024 with ascending VV (vertical sensor of vertical objects) polarization on path 69 with frame 1182 of 23 sin images. With digital elevation model (DEM) data from the shuttle radar topography mission (SRTM) for 1 second with a resolution of 30 m, the following are the results of selecting master data and slave data used in this study.

Table 1. Master and slave image data

Master Data	Slave data	Bperm (M)	Btemp (days)	Master Data	Slave Data	Bperm (M)	Btemp (days)
01/05/2022	3/24/202	-768	-44	01/05/2022	8/17/2022	108	-44
01/05/2022	6/16/2020	-684	-24	01/05/2022	12/15/2022	228	49

Master Data	Slave data	Bperm (M)	Btemp (days)	Master Data	Slave Data	Bperm (M)	Btemp (days)
01/05/2022	8/27/2020	-612	-95	01/05/2022	3/9/2023	312	78
01/05/2022	12/25/2020	-492	48	01/05/2022	6/1/2023	396	-99
01/05/2022	1/18/2021	-468	14	01/05/2022	9/5/2023	492	-93
01/05/2022	3/19/2021	-408	81	01/05/2022	10/23/2023	540	-87
01/05/2022	5/6/2021	-360	10	01/05/2022	12/10/2023	588	-49

The master data is on the image dated May 5, 2022. The pendicular distance itself is the value of the difference in the range of image capture with the master image used in meters, and the temporal distance is the distance or time difference in image capture where the zero point is on the master image.

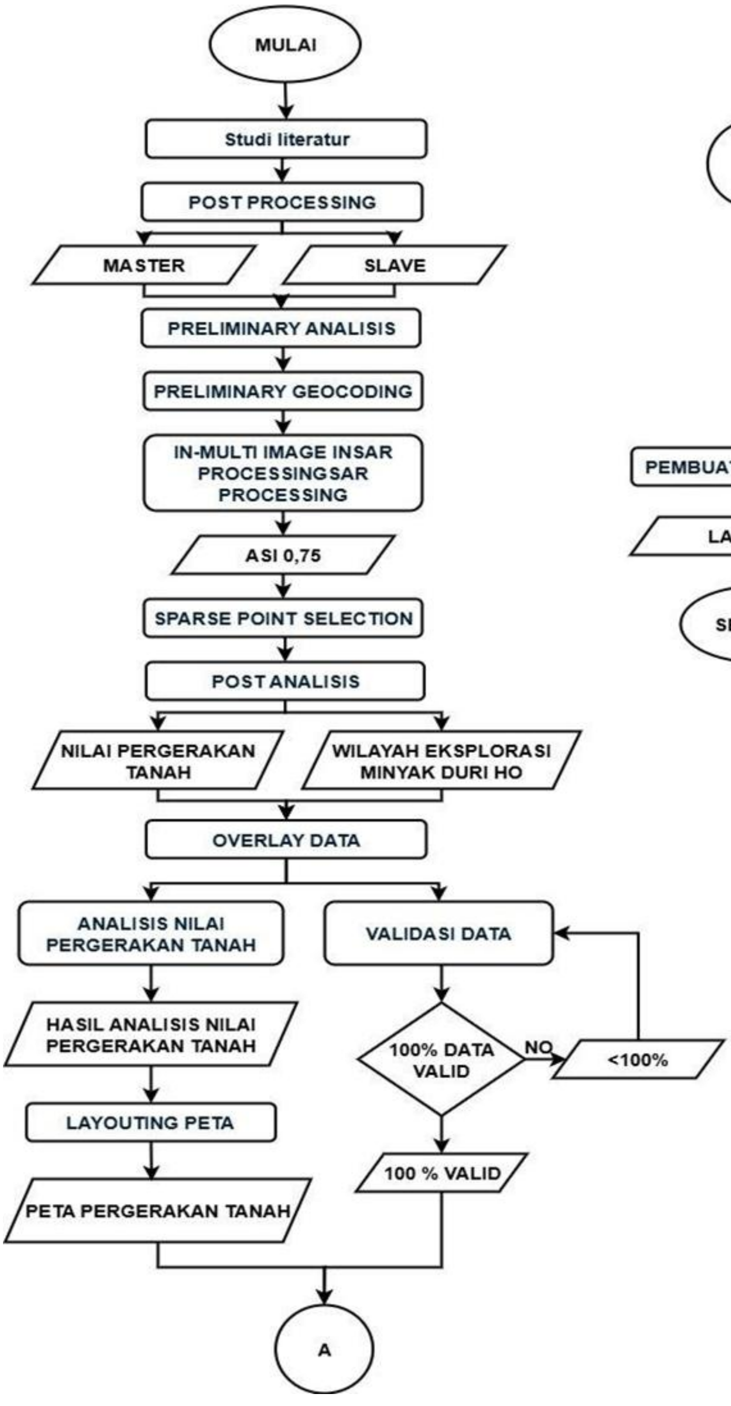


Figure 2. Research flow chart

2.3 Calculation of Ground Movement Using the PS-InSAR Method

In mid-1999 at the International Geoscience and Remote Sensing Symposium in Hamburg, Germany. Ferreti et al. released a journal entitled Permanent Scatterers in SAR Interferometry with the research concept of single coherent pixels. This can be defined as Permanent Scatterers (PS), using SAR image pairs to obtain millimeter-level accuracy. The value of surface area movement on a pixel-by-pixel basis. In-SAR PS technology is considered a development of InSAR and Din-SAR. With this aim, it is able to overcome the problems that occur in In-SAR and Din-SAR technology related to temporal and geometric decorrelation [2].

The equation for determining height difference in the PS-InSAR processing technique is based on the following mathematical model:

$$dzi,j = \frac{1}{\cos\theta'}\{\frac{z'B\perp}{rm\sin\alpha} + \frac{\lambda\phi}{4\pi} - Bd\}; \tag{1}$$

$$dzi,j = \begin{cases} tanda\ (dzi,j) = +(Kenaikan\ Muka\ Tanah) \\ tanda\ (dzi,j) = -(penurunan\ Muka\ Tanah) \end{cases} \tag{2}$$

The following is an explanation of the above equation where dzi,j is Deformation value at two observation epochs i and j, θ' is Incident angle, Z' is Phase difference indicating topographic information, rm is Range, ϕ is Incidence angle of the primary and secondary images, α is Microwave wavelength used, Bd is Horizontal base distance, and B⊥ is Perpendicular base distance. It has the advantage of eliminating contributions from atmospheric phases that cannot be eliminated using the In-SAR or Din-SAR methods. Permanent Scatterer Synthetic Aperture Radar (PS-InSAR) can analyze the level of surface deformation over a coverage area (~100 x 100km) [1].

2.4 Paired Sample T-Test

The Paired t-test is a parametric statistical method used to determine whether there is a significant difference in means between two sets of paired (dependent) or related data.

Paired (Dependent)

a. Both measurements come from the same individual or unit under two different conditions or times (e.g., "before" and "after" an intervention). A classic example: measuring a person's blood pressure before and after taking medication.
b. Both measurements come from matched pairs based on certain characteristics. For example, comparing the performance of two teaching methods on students who have been matched based on their initial abilities.

Mean Difference

The primary objective is to test whether the mean difference between the two sets of measurements is statistically different from zero. If the mean difference is significantly different from zero, it indicates a real effect or difference between the conditions or methods being compared.

As a parametric test

The Paired t-test has several assumptions that must be met for its results to be valid, particularly the normality of the distribution of differences between the pairs of data. If these assumptions are not met, non-parametric alternatives such as the Wilcoxon Signed-Rank Test.

3. Results and discussion

Based on the results of calculations carried out using the PS-InSAR method, the results of scatter plots and time series modules are obtained, where at this stage the ground movement points will be seen based on the amplitude stability index value parameters used, the distribution of points at the scatter plots stage, seen in Figure 3 A where the distribution of scatter points is evenly distributed throughout the SAR image used, points that are very close or overlapping indicate that there is a lot of ground movement in the area, and points that are spaced out or areas that are white are areas that do not have ground movement values, this area does not mean that there is no ground movement but the data in the area does not meet the requirements to enter the threshold value of the amplitude stability index of 0,75 that has been previously determined. The number of scatter points produced with a processing radius of 20 km is 10.424 points, which are spread throughout the image area with a radius of 20 km.

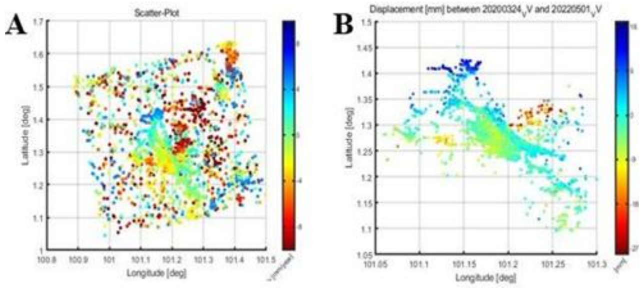


Figure 3. Scatter plots and time series module results

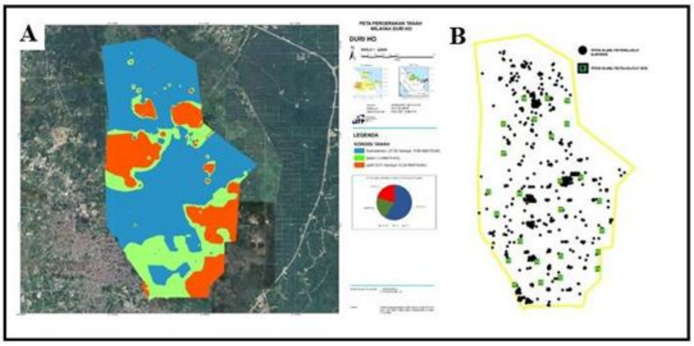


Figure 4. Landslide results map and sample point distribution data

At this stage, the results of the land movement trend from the image pair that has been converted to the coordinates of the earth's surface so that the distribution of points has the value of the earth's coordinates as seen in Figure 3 B if the value of land movement from March 2020 to May 2022 where the comparison image is the master data of 2022, which can be seen if there is land movement in the research area shown in the area marked with a black square, with the highest land movement value at a decrease of -27 mm per year and a land increase of 18 mm per year. If observed carefully, the movement in red tends to be in the research area, this indicates that significant land movement occurs in the area, while the value of land movement that tends to be small occurs in the middle of the image which shows urban areas which are mostly permanent buildings, such as houses, hospitals, offices, and so on, where this area experiences little or no land movement.

Figure 4 A is a map of landslides that occurred in the Pertamina Hulu Rokan oil exploration area in the Duri HO section. Landslides that experienced land increases were spread in the northern and western parts to the center of Duri HO, and areas that experienced high land subsidence occurred in parts of the northern and eastern regions. The range of landslide values produced when processing data using SARPROZ software was 17,5 mm to -27,5 mm per year, with an average value of -4,02 mm per year, this shows that in the research area land subsidence is more dominant than land increase, this is reinforced by the area experiencing land subsidence which is 5.992.929 (M) and the area of land experiencing land increase which is 2.066.402 (M) and the area that did not experience land movement is 2.100.912 (M). The points produced in this research area with a total of 1.104 points. The study was dominated by 917 subsidence points (83,06%) and 185 (16,76%) land subsidence points. Two points (0,18%) did not experience land movement. The distribution of these points creates a pattern that indicates the distribution of land movement. The closer the points are located, the smaller the area occupied by them, due to overlapping points. Furthermore, points that are further apart or spaced apart will have a larger area. Figure 4 B shows the distribution of the sample points used: 25 sample points, with a distance of less than 200 meters between the GPS observation points and the SARPROZ data processing results.

A

One-Sample Kolmogorov-Smirnov Test

		Unstandardized Residual
N		25
Normal Parameters[a,b]	Mean	.0000000
	Std. Deviation	2.48259571
Most Extreme Differences	Absolute	.079
	Positive	.079
	Negative	-.063
Kolmogorov-Smirnov Z		.395
Asymp. Sig. (2-tailed)		.998

a. Test distribution is Normal.

b. Calculated from data.

B

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1 GPS - SARPROZ	.164	2.586	.517	-.903	1.232	.317	24	.754

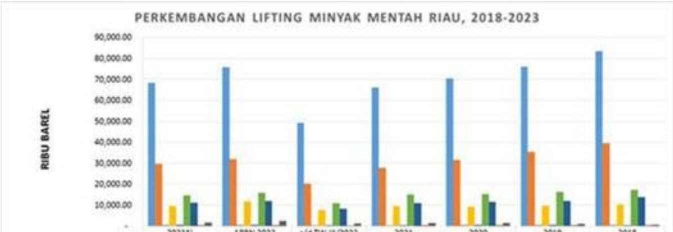
Figure 5. Normality test results and t-test results

Figure 5A shows the results of the data normality test, indicated by an asymptomatic value of 0.998, which exceeds the threshold of 0.05, indicating normality. A paired-sample t-test was then performed by comparing the GPS data and the SARPROZ processed data. Decision-making in a paired-sample t-test is generally based on comparing the significance value (Sig. or p-value) with a predetermined significance level (α) (usually 0.05 or 5%). The following is a frequently used basis for decision-making, based on the significance value (Sig. / p-p-value):

1. If the 2-tailed significance value (Sig.) is <α (e.g., <0.05), then H0 is rejected and Ha is accepted. This indicates a significant difference between the SARPROZ and GPS processed data.
2. If the 2-tailed significance value (Sig.) is >α (e.g., <0.05), then H0 is accepted and Ha is rejected. This means there is no significant difference between the SARPROZ and GPS data processing results.

Figure 5.B shows the results of the Paired Samples T-Test for significance (2-tailed), which is 0.754, which exceeds the test threshold.

The amount of oil obtained in the Duri Ho field has increased since 1985, which has increased oil production and is in line with the fact that new wells have been made to be able to produce stored oil [10], as well as repairs or developments to old wells. This can cause land movement in the area due to changes in land cover from forests and hills to flat empty land, and the pressure on the earth's interior contributes to land movement. This can be seen from the latest data. The peak of total production of the Duri Field is estimated to reach 300,000 BOPD in 1994, although it has decreased to 165,057 BOPD in the following years, thus strengthening that the part of the land that stores oil has begun to empty and that is one of the causes of land movement. The development of Indonesian crude oil lifting during 2018-2022 and the projection for 2023 tends to decrease [11].



	2023*)	APBN 2022	s/d TW.III/2022	2021	2020	2019	2018
	PROGNOSA LIFTING*)			REALISASI LIFTING			
R I A U	68,274.70	75,783.76	49,284.55	66,157.53	70,446.24	76,019.55	83,305.79
1 KAB. BENGKALIS	29,618.62	31,909.85	20,245.56	27,721.39	31,520.30	35,356.12	39,598.50
2 KAB. INDRAGIRI HULU	630.59	662.09	379.08	531.33	579.11	580.03	584.32
3 KAB. KAMPAR	9,513.78	11,795.33	7,574.43	9,462.84	9,345.47	9,686.56	10,388.37
4 KAB. ROKAN HULU	610.72	572.73	410.54	509.20	553.62	696.91	506.55
5 KAB. ROKAN HILIR	14,700.09	15,934.13	11,019.39	15,008.33	15,161.61	16,223.44	17,235.05
6 KAB. S I A K	11,116.58	11,995.50	8,215.67	11,039.48	11,511.19	11,972.27	13,843.49
7 KAB. PELALAWAN	432.64	424.42	259.98	354.06	392.17	413.90	414.39
8 KAB. KEPULAUAN MERANTI	1,651.68	2,489.71	1,179.90	1,530.91	1,382.78	1,090.32	735.12

Figure 6. Riau crude oil lifting in 2018-2022 and projections for 2023

The development of Riau crude oil lifting in 2018-2022 and the projection for 2023 is shown in the Figure 6 above. Seeing various challenges and obstacles in the field, the optimistic achievement of Riau crude oil lifting until the end of December 2022 is around 90.09% of the prediction of Riau crude oil lifting in 2022, which is 68,274.70 thousand barrels, the same as the prediction of Riau oil lifting in 2021. So in conducting the simulation of calculating the allocation of Oil and Gas DBH in 2023 using the prediction data of oil and gas lifting in 2021. With this low oil production, several possibilities can be taken, namely oil resources that are starting to decrease or run out or the development of oil production is still low so that oil extraction is not optimal, apart from that, the lack of oil reserves will trigger changes in the soil structure so that the soil above will fill the empty space below it so that the phenomenon of land movement occurs in the area.

4. Conclusions

Based on the identification of the study area, land movement tends to be in the southern and northern regions of the research area, with values ranging from 17.5 mm to -27.5 mm per year, with an average value of -4.02 mm per year. This is indicated by the even distribution of points in the northern and southern regions. The total number of land movement points is 1,104, dominated by land subsidence points of 917 points with an area of 5,992,929 square meters (M2) and land increase points of 185 points of 2,066,402 square meters (M2), while points that do not experience land movement are 2 points of 2,100,912 square meters (M2). Based on the results of the Paired Sample T-Test calculation with testing 25 samples spread across the research area, the resulting test limit value is 0.165. This value exceeds the minimum test threshold of 0.05, so the initial hypothesis is accepted (H0) and it is concluded that there is no significant difference between the sarproz processing data and the BM coordinate value data in the Duri HO area.

Declaration of competing interest

The author is very grateful to the Padang Institute of Technology campus which has facilitated this research and various parties that the author cannot mention one by one.

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