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LAND SURFACE CHANGES AT BUKITTINGGI CITY DUE TO EARTHQUAKE USING DInSAR METHOD

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Abstract

Bukittinggi city is in the sink segmentation "semangko" fault line, which causes Bukittinggi City to frequently experience earthquakes. From 2019 to 2020, there have been at least 9 earthquakes above 5 on the Richter scale. DInSAR is a radar imaging method that utilizes phase, amplitude, and wavelength in its processing to obtain topography and land surface changes. This study has three aims. This research shows that the earthquake from 2019 to 2020 uses 18 pairs of sentinel-1 image scans recorded in 2019-2020 and uses DEM SRTM 30, namely the earthquake that happened on February 2, 2019, in the sub-district of Guguak Panjang with a range of 1 – 45 mm. In comparison, the smallest increase occurred in the sub-district of Guguak Panjang and Mandiangin Koto Selayan, with a length of 1 mm on November 11, 2019. The most significant reduction happened in the sub-district of Aur Birugo with -22 mm. In contrast, the less substantial reduction occurred in the sub-district of Guguak Panjang with -5 mm on October 8, 2019. The Modified Mercalli intensity scale for earthquakes in 2019-2020 uses the measure of Donovan's parameters demonstrated by numbers 2, 3, and 4. Number 2 indicates that resting people feel the earthquake's strength, especially hanging, shaking, and vibrating on the second floor. Number 3 represents the vibrations of passing trucks, windows, doors, and glassware clashing and making noises.

Keywords: *DInSAR, Earthquake, Sentinel-1A, Subsidence, Uplift*

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INTRODUCTION

Sumatera accommodates the collision of the Indo-Australian Plate, which subducts the Eurasian Plate at a speed of 5-6 cm/year [1]. This collision causes Sumatera to be prone to tectonic earthquakes caused by the movement of this plate. Bukittinggi City, one of the cities located in West Sumatera Province and on the broken "semangko" route, has active segments such as "The sianok segment". This city has an area of 25,239 km2 with a population in 2016 of 122,621 people, a population density of 4,858,394 people/km2 and an annual population growth rate of 1.77. % and is also an area. This tourist area which tourists densely visit, is very vulnerable and in danger of an earthquake. In essence, an earthquake is a vibration or a series of pulses from the earth's crust that are not eternal/temporary and then spread in all directions [2]. Earthquakes are natural vibrations from within the earth, originating within the world, propagating to the earth's surface due to the earth's fractures breaking and shifting violently [3]. The earthquake is a factor in deformation or changes in the ground surface.

Deformation indicates a decrease in the ground surface or movement of the ground surface. Deformation must be related to spatial variations of displacement gradients. Therefore, the deformation consists of a displacement gradient tensor [4]. In the general case of deformable bodies moving relative to one another, distance, time, and temporal variation are the basis of all deformation theories. Deformation is obtained based on the temporal variation of the metric or from the coordinates [5]. The author uses the Synthetic Aperture Radar (SAR) method in this study. This method is one of the remote sensing methods in which this study only uses satellite image data, which means this research has no direct contact with the object observed. The accuracy of the SAR method has not been able to achieve more precise level of accuracy than using the GPS method in getting the value of land surface changes. Still, in research with a wide coverage area, the SAR method can minimize resources making it easier to monitor deformation on a large scale [6].

Efforts to monitor land subsidence are essential. Donovan said that the maximum acceleration of the ground surface and the amount of damage caused by the earthquake. Modified Mercalli (MM) explained that the scale could calculate one of the steps for mitigating and investigating unexpected natural disasters. This study has three aims in showing the research novelty. First, this study aims to determine changes in the land surface in Bukittinggi City from 2019 to 2020. Second, this study aims to assess the magnitude changes in the land surface after the earthquake in Bukittinggi City from 2019 to 2020. Third, this study seeks to find the scale of the earthquake's intensity value that occurred in the 2019-2020 period on the Donovan parameter.

DATA AND METHOD

Location

This research conducts Bukittinggi as the city observed, located in West Sumatera Province. Geographically, the coordinates of the location are between 100° 20'-100°25' East Longitude and 00°16'-00°20' South Latitude. Bukittinggi City is in the Bukit Barisan

Mountains chain or about 90 km north of Padang City with 25.24 km2 (9.75 sq mi). The location of the research can be seen more clearly in Figure 1.

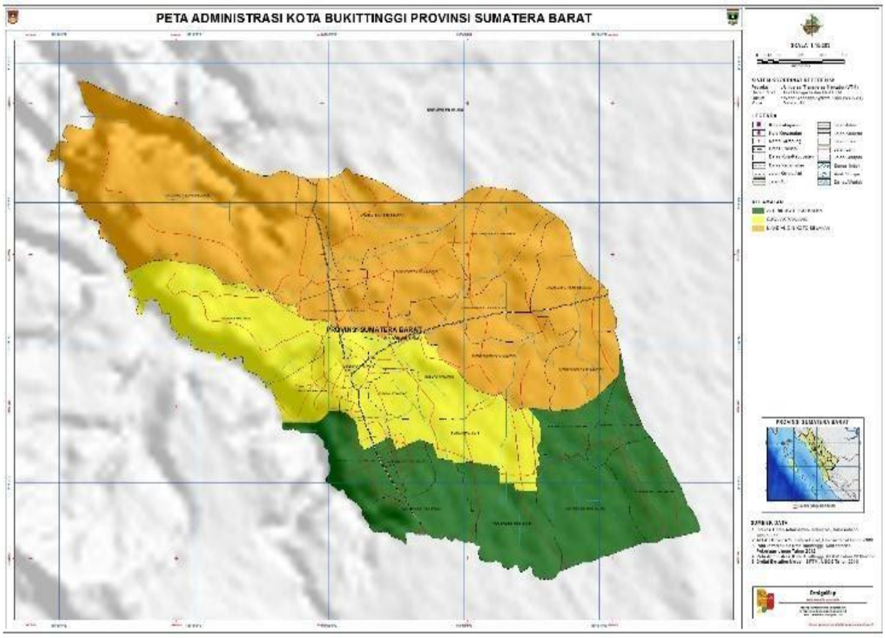


Figure 1. Research location

Data

Sentinel 1 (SLC) images in the 2019—2020 recording years with VV polarization (transmission from vertical sensors, backscatter from vertical objects) and descending flight direction (Table 2.1). The Sentinel data is selected based on earthquakes in the 2019—2020 range with a magnitude greater than 5 on the Richter scale (Table 1).

Table 1 Data Sentinel Image Based on Earthquake Event

Earthquake	Before	After	Direction
2019-02-04	03/02/2019	15/02/2019	Descending
2019-02-27	15/02/2019	11/03/2019	Descending
2019-06-17	15/06/2019	27/06/2019	Descending
2019-08-10	02/08/2019	14/08/2019	Descending
2019-11-14	06/11/2019	18/11/2019	Descending
2019-11-24	18/11/2019	30/11/2019	Descending
2020-08-04	28/07/2020	09/08/2020	Descending
2020-09-08	28/08/2020	09/09/2020	Descending
2020-11-18	08/11/2020	20/11/2020	Descending

Table 2 Earthquake Data

Time	Latitude	Longitude	depth	mag
2019-02-04T19:29:54.350Z	-0.4203	98.0357	19	5.6
2019-02-27T23:27:04.240Z	-1.3226	101.5784	10	5.4
2019-06-17T11:04:04.235Z	-0.3042	99.0252	59.2	5
2019-08-10T21:11:09.688Z	-0.7389	99.391	36.69	5.2
2019-11-14T08:04:04.145Z	-1.8917	100.2621	63.9	5
2019-11-24T01:08:26.452Z	-0.9072	97.9212	10	5
2020-08-04T23:51:11.030Z	-1.7797	100.1815	48.42	5.1
2020-09-08T04:37:02.589Z	-1.14	98.4985	10	5
2020-11-18T04:41:56.604Z	-1.8052	100.4248	13.66	5.2

DinSAR Process

Differential Interferometric Synthetic Aperture Radar (DInSAR) is a sideways radar imaging method that utilizes the phase difference of two or more SAR images with different acquisitions in processing to obtain deformation. The main goal of DInSAR is to extract the total phase caused only by deformation by removing or minimizing other contributing factors. A topographic surface module functions as a reference for three or more radar images. The changes are determined through differential InSAR. The phase information possessed by the interferogram from the observations of 2 SAR at different times has topography, orbital shift, surface deformation, and atmospheric effects [7]. At this time, both spacecraft systems and airborne radar systems are used to form interferograms. Spacecraft resources have advantages such as global coverage with less turbulence impact and easier trajectory control [8]. The basis of the DInSAR method is the SAR image pair analysis technique to identify surface changes to sub-centimetres along the sensor-to-target line of sight or Line of Sight (LoS).

From the DInSAR procedure, after smoothing the interferogram, the dominant phase component of DInSAR consisting of topographic impacts and deformations is shown in the following equation [9]:

$$\phi(p) = 4\pi B \perp, p\lambda Rp\ [\Delta R(p)] \quad \text{...(1)}$$

Where (p) is the topographic phase calculated on the DEM grid, is the perpendicular baseline, is the microwave wavelength emitted by the satellite, R (p) is the oblique distance between the sensor targets. Implementation of phase information from two complex data, such as DInSAR, to retrieve volume changes caused by successive long-term ground surface deformations, especially land subsidence or elevation. Parameters in the DinSAR processing use a coherence threshold of 0.5 [10].

RESULTS

The earthquake with a magnitude of 5.6 M occurred on February 4, 2019, was centred in Sikabaluan, 259 km from Bukittinggi City, with a depth of 19 km. This earthquake resulted in changes in the land surface in Bukittinggi City by subsidence and uplift. This land surface change is a form of deformation pattern after an earthquake. Based on Figure 2, the following results are obtained:

a). There has been a decline in almost all areas of Bukittinggi City due to the earthquake that occurred on February 4, 2019. In identifying the processing results, land subsidence marks a value range of 0 – (-40) mm, then the increase in ground-level marks a value range of 0—40 mm.

b). Almost all areas have an uplift, only in the sub-district of Aur Birugo Tigobaleh that experienced a decline due to the earthquake on February 27, 2019. In identifying the processing results, land subsidence marks a value range of 0 – (-40) mm, then land level rise marks a value range of 0—40 mm.

c). In the sub-district of Mandiangin Koto Selayan, some areas such as Guguak Panjang and Aur Birugo Tigobaleh uplift and have subsidence. Consequently, these areas evenly increased due to the Earthquake on October 08, 2019. In identifying the processing results, land subsidence marks a value range of 0 – (-60) mm, then land level rise marks a value range of 0—60 mm.

d). Almost all sub-districts in Bukittinggi City partially experienced changes in the ground surface due to the earthquake on September 14, 2019. In the sub-district of Mandiangian, such as Guguak Panjang, Aur Birugo Tigobaleh experienced subsidence. In identifying the processing results, land subsidence marks a value range of 0 – (-40) mm, and land level rise marks a value range of 0 – 40 mm.

e). The earthquake that occurred on June 17, 2019, did not result in significant changes in the ground surface. It is just that the sub-district of Mandiangin Koto Selayan has subsidence and uplift. In identifying the processing results, land subsidence marks a value range of 0 – (-140) mm, and land level rise marks a value range of 0—140 mm.

f). On November 24, 2019, the earthquake occurred in the uplift range of 0-80 mm, which occurred throughout Bukittinggi City. It causes subsidence in the 0-80 mm field in a small part of Bukittinggi City.

g). As a result of the earthquake on August 4, 2020, Mandarin Koto Selayan experienced uplift. Some other areas experienced subsidence in the sub-district of Guguak Panjang, which is also part of the area experiencing uplift and subsidence. For the sub-district of Aur Birugo Tigobaleh, almost all areas experienced subsidence. In identifying the processing results, land subsidence marks a value range of 0 – (-60) mm, and land level rise marks a value range of 0—20 mm.

h). Due to the earthquake on September 8, 2020, the sub-district of Mandiangin Koto Selayan was almost evenly distributed in all areas. District of Guguak Panjang also experienced an uplift evenly in all areas, and for the sub-district of Aur Birugo Tigobaleh, practically all areas experienced subsidence. In identifying the processing results, land subsidence marks a value range of 0 – (-40) mm, and land level rise marks a value range of 0—60 mm.

i). Due to the earthquake on November 18, 2020, Mandiangin Koto Selayan experienced uplift, then some other areas also experienced subsidence. The Sub-District of Guguak Panjang also experienced an uplift evenly in all areas, then the sub-district of Aur Birugo Tigobaleh also experienced an uplift. In identifying the processing results, land subsidence marks a value range of 0 – (-40) mm and land level rise marks a value range of 0—40 mm.

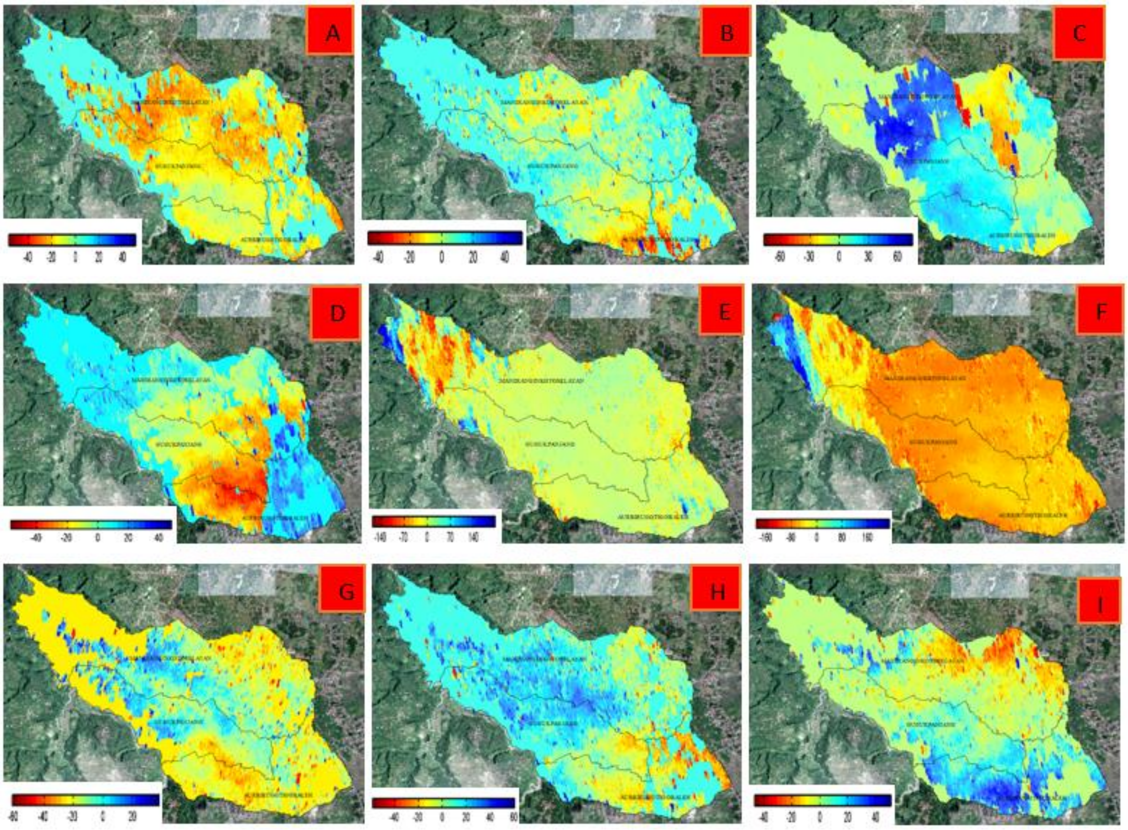
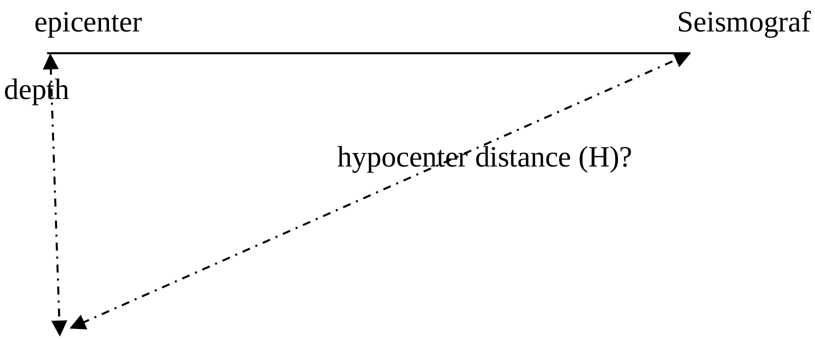


Figure 2. (A) Earthquake 04/02/19, (B) Earthquake 27/02/19, (C) Earthquake 08/10/19, (D) Earthquake 14/11/19, (E) Earthquake 17/06/19, (F) Earthquake 24/11/19, (G) Earthquake 04/08/20, (H) Earthquake 08/09/20, (I) Earthquake 18/11/20

In this study, the author uses Donovan parameters with the Modified Mercalli method in equations (II, III, and IV) to see the potential for earthquakes felt in Bukittinggi City from the earthquake's epicentre during the 2019 – 2020 period. The steps are including:

1) Determine the hypocenter distance



$$H = \sqrt{earthquake\ depth^2 + epicenter^2}$$

2) Determine acceleration

$$a = 1080.e^{0,5R}.(H+25)^{-1,32} \quad (2)$$

A is the earthquake acceleration value, E is the exponential value, R is the earthquake Richter scale, and H is the distance from the earthquake's hypocenter

3) Determine the amount / level of damage (MM) based on acceleration

$$\text{Log } a = \frac{1}{3}.I - \frac{1}{2} \quad (3)$$

Table 3 Modified Mercalli

No	Earthquake Date	SR	Distance (Km)	MM	Uplift (m)			Subsidence (m)		
					District Mandiangin	District Guguak	District Aur Birugo	District Mandiangin	District Guguak	District Aur Birugo
1	04/02/2019	5,6	259	2	10 mm	45 mm	-	-15 mm	-20 mm	-15 mm
2	27/02/2019	5,4	179	4	10 mm	-	6 mm	-15 mm	-12 mm	-12 mm
3	17/06/2019	5,4	150	4	4 mm	-	9 mm	-15 mm	-21 mm	-
4	08/10/2019	5,2	122	4	30 mm	-	10 mm	-15 mm	-12,5 mm	-20 mm
5	14/11/2019	5	180	3	-	1 mm	-	-6 mm	-8 mm	-8 mm
6	24/11/2019	5	281	3	15 mm	6 mm	2 mm	-8 mm	-8 mm	-8 mm
7	04/08/2020	5,1	167	4	-	8 mm	-	-10 mm	-8 mm	- 12 mm
8	08/09/2020	5	227	3	15 mm	3 mm	2 mm	-10 mm	-5 mm	-12 mm
9	18/11/2020	5,2	168	4	1 mm	-	1	-8 mm	-6 mm	-14 mm

Based on Donovan's parameters, namely 2, 3, and 4, which means that at number 2, people who were resting felt the strength of the earthquake, especially on the second floor, hanging objects shook, vibrated lightly (3), and the vibrations of passing trucks, windows, doors, and crockery collided and rattled (4).

CONCLUSSION

Land surface changes in Bukittinggi City based on earthquakes from 2019-2020 with a strength of more than 5 M show the subsidence and uplift of the ground surface caused after the quake. The magnitude changes in the land surface that occurred in the sub-district of Guguak Panjang on February 4, 2019, shows a range of 1 – 45 mm, while the smallest increase in the sub-district of Mandiangin Koto Selayan reaches 1 mm (uplift) based on earthquake happened on November 8, 2020. The most extensive subsidence in the earthquake on October 8, 2020, is the sub-district of Aur Birugo Tigobaleh show -22 mm, while the smallest subsidence is in the sub-district Guguak Panjang, that is -5 mm. The Modified Mercalli intensity scale for earthquakes in 2019-2020 uses the measure of Donovan's parameters demonstrated by numbers 2, 3, and 4. Number 2 indicates that resting people feel the earthquake's strength, especially hanging, shaking, and vibrating on the second floor. Number 3 represents the vibrations of passing trucks, windows, doors, and glassware clashing and making noises. Number 4 illustrates the results of the DinSAR processing are still in the form of Line of Sight (LoS), so it is necessary to have GPS observations to obtain vertical changes in the ground surface.

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