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Land subsidence estimation using DinSAR method ALOS PALSAR image in Padang City West Sumatra, Indonesia

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ABSTRACT

Land subsidence is a phenomenon that occurs in big cities around the world and in Indonesia. Padang as one of the largest cities in West Sumatera also facing land subsidence due to natural phenomena and human induced. Padang City is located at the west coast of Sumatera Island which is the junction point of three active plates that cause frequent earthquakes. Main goals of this research are to know the distribution of area affected by land subsidence, to know the estimated value of land subsidence and to know the value of the velocity of land subsidence in Padang area using DInSAR method. The data used in this study is ALOS PALSAR Image Level 1.1 of Padang city during 2007 to 2010 was obtained through JMRSL CERES Chiba University, Japan and collected through Alaska Satellite Facility website. Differential Interferometric Synthetic Aperture Radar (DInSAR) is a technique considered to be one of the most efficient technique for detecting land subsidence. The DInSAR method is used in mapping altitude changes developed into a land-subsidence map each year. The mapping results show the distribution of the areas affected by the maximum land subsidence in Padang area of West Sumatera are Padang Utara, Nanggalo, and Padang Barat Subdistricts. The land subsidence insignificant occurred is Padang Selatan and Lubuk Begalung Subdistricts. The estimated value of the land subsidence distribution in Padang area using DInSAR method has decreased significantly after the earthquake of September 30, 2009 in Padang Utara, Nanggalo and West Padang Subdistricts is around 0 - 32.70 cm, and the value of land subsidence velocity is around 0.13 - 12 cm/year. One of the expected effects of land subsidence can be increased in the area susceptible for flooding in Padang city.

Keywords : Land Subsidence; DInSAR; ALOS PALSAR; Padang, Indonesia; Earthquake

I. INTRODUCTION

West Sumatera is one of the provinces located in the Sumatera Island and its capital city is Padang. Padang area is located on the west coast of Sumatera Island which has a varied topography that is a combination of lowland, hills, and river basins. The geographical condition lies between three major fault lines namely the Sumatran Fault, Mentawai Fault, and Subduction Zone that caused the Padang area to be prone to earthquakes. Seismic data from BMG and USGS shows the location of the earthquake center in the shore of Padang spread evenly. Earthquakes

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that have magnitudes more than 6.5 Richter scale on the surface have a great oppurtunity to cause deformation on the land and in the oceans [11]. One of such deformation caused by earthquakes is a land subsidence.

Land subsidence is a serious matter especially if it occurs at the coastal areas or alluvial and big cities such as Jakarta; East Java; Semarang and Bandung [6, 9, 19, 1]. Not only big cities in Indonesia, but there are many other countries in the world suffer from severe land subsidence problems shown in Table 1. The amount of land subsidence of a region varies due to several factors, such as from land or sea, geological condition (natural) [3], and human activities (non-natural) such as over-pumping of groundwater [16]. Several factors cause land subsidence in a region such as the rapid development areas, geological aspects of coastal areas, excessive groundwater extraction [1], geological/ tectonic structure movement [13], and others cause the occurrence of land subsidence variations.

Table 1. Land Subsidence Problems in the several countries

Area	Period	Max subsidence (m)	Refrence
Japan (Tokyo)	1918-2003	4.5	Sato et al., 2006
Taiwan (Taipei)	1950-2007	2.1	Hung and Liu, 2007
China (Taiyuan)	1950-2003	2.9	Ma et al., 2006
China (Shanghai)	1921-2006	3.0	Cong and Yang, 2008
Thailand (Bangkok)	1978-2003	0.8	Noppadol et al., 2006
USA (California)	1916-1969	3.9	Hanson et al., 2005

(Source: Ref [1])

Land subsidence has the potential to cause some problems such as topographic gradient changes, ground surface rupture, and decreased aquifers' ability to store groundwater [15]. Other negative impacts of land subsidence are damage to the urban infrastructure such as buildings and highways, also extend flooding areas. The flood can occur in the areas where the speed of land subsidence is high. The flood can have a negative impact on the affected areas such as economic losses in agriculture, industry, infrastructure, public utilities, and so on. Hence, frequent monitoring of areas facing land subsidence is very crucial. Images acquired through satellite provide a reliable, cost-effective, and accurate coverage over large extent for earth monitoring. During past few decades optical images acquired by satellite are effectively used for several land monitoring applications. However, optical satellite images only provide two-dimensional profile of features on the surface of earth. On the other hand, radar remote sensing which is an emerging field provides the capability to estimate three-dimensional profile of features on earth surface. By using interferometric SAR technique which requires to SAR images of same area acquire at different time; elevation profile of that area can be estimated. Differential Interferometric SAR (DInSAR) utilizes two pairs of SAR images one before and one after subsidence event. By estimating elevation profile before and after the subsidence event, subsidence can be mapped by differencing the the two elevation profiles [2]. The DInSAR method is assessed as an efficient and effective method for monitoring land subsidence continuously in large areas [8]. Furthermore, DInSAR method popular for measuring land displacement due to resultant accuracy [6, 25, 28). In the previous research, the DInSAR method has been successfully used, such as in the Bandung basin area [27], Semarang City [23] and several other research. The results obtained in the form of an interferogram with a good level of coherence and had varying land subsidence value on each region. It's expected DInSAR will perform effectively for land subsidence monitoring for coastal area like Padang.

II. METHOD

A. Study Area

Padang is the capital city of West Sumatra Province, Indonesia, with a total area of 694.96 km², equivalent to 1.65% of the area of West Sumatra. It has tropical climate average annual rainfall about 384,88 mm/month (https://padangkota.bps.go.id). The topography of padang is the combination of sloping land and steep hills. Areas that have relatively flat topography are subdistricts of Padang Utara, Padang Barat, Padang Timur, Nanggalo, and a part of the Kuranji, Pauh, Lubuk Begalung, Lubuk Kilangan, and small part of Padang Selatan. While hilly areas are found in the east of Koto Tangah subdistrict, Pauh, Lubuk Kilangan, and Bungus Teluk Kabung subdistrict [4]. The geological formation is mainly consists of surface deposits, volcanic rocks, intrusions as well as sedimentary and metamorphic rocks. Alluvium (Qal) that spread from north to south throughout the lowlands of the Padang area consists of Silt, Plate, Sand Clay, Plate Chunks of rocks Andesite. The largest type of soil in the Padang area is Latosol which reaches 46.70% and 22.95% of alluvial [11]. Padang region traversed by several major rivers such as Batang Bungus, Batang Arau, Batang Kuranji, and Batang Air Dingin as well as several other small rivers that have a permanent flow throughout the year, often flooded [11]. Padang central city is chosen for this research as shown in Figure 1.

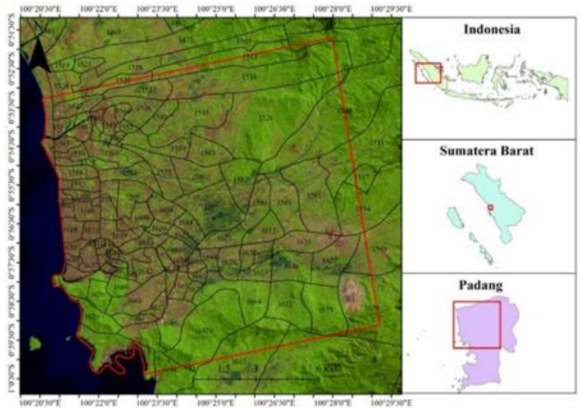


Fig. 1 Study Area Map

B. Data Collection

The data used in this research can be categorized into satellite data and ancillary data. Fine beam dua-polarized (FBD) ALOS PALSAR of five different (December 5, 2007; June 6, 2008; September 9, 2009; October 25, 2009; and October 28, 2010) was acquired. Landsat-8 optical data was acquired from USGS website which is used as the base map for this study. Similarly SRTM based digital elevation model (DEM) was acquired from USGS and administrative boundaries were acquired from DIVA-GIS website. Specifications of data used in this research are summarized in Table 2.

Table 2. Dataset

Data Set	**Specification**	**Source**
Optic Citra	Landsat 8 Multispectral Image	United States Geological Survey (USGS)
SAR Images	Citra ALOS-01 in 2007, 2008, 2009 and 2010	Alaska Satellite Facility (ASF)
Administrative Data	State, Province, District and Subdistrict	DIVA-GIS

C. Methodological Framework

DInSAR analysis is implemented for two radar images obtained at different acquisition times. The phase information contained in each SAR image is examined to derive the topography (InSAR) to determine and estimate the ground displacement that has happened between the two acquisitions (DInSAR) [26]. To measure the interferometric phase term associated with the displacement, the interferometric phase contribution pertinent to the underlying topography has to be removed. The phase difference is explained in Equation 1 [8]. The phase difference is described in Equation (1).

$$\Delta\phi = \Delta\phi_{topo} + \Delta\phi_{flat} + \Delta\phi_{orbit} + \Delta\phi_{displ} + \Delta\phi_{atm} + \Delta\phi_{noise} \quad (1)$$

Where ϕtopo is a topographic phase, ϕflat is phase of the flat earth caused by geometric imaging, ϕdispl is a differential displacement pattern, ϕorbit is a phase caused by error of accuracy or some parameter, ϕatm is atmosphere and ϕnoise refers to the contribution of noise. The phase obtained needs to be converted to vertical displacement value. The vertical displacement value can be obtained by Equation (2).

$$Vertical\ Disp = \frac{\text{Unwrap phase} * \lambda}{4\,\pi\,\cos(\theta_i)} \quad (2)$$

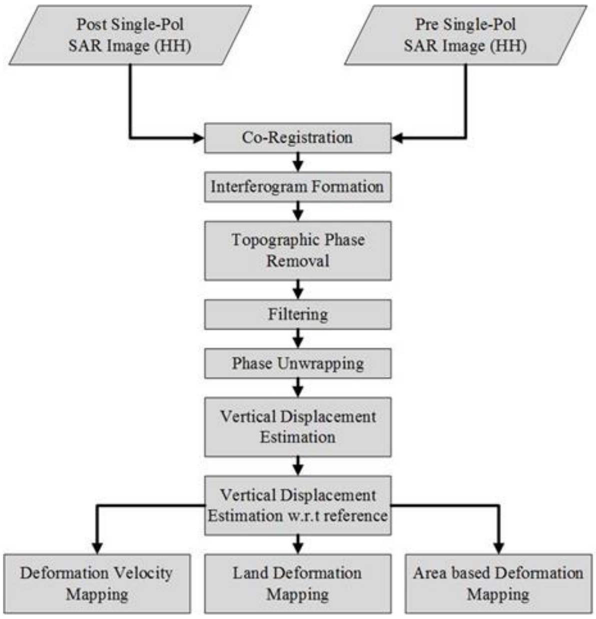


Fig. 2 Methodology of Processing of DInSAR Method

The data processing flow is shown in Figure 2. The result of the phase difference is a new image called an interferogram. The interferogram is a fringe-patterned image containing all the information on relative geometry [21]. The DInSAR method is very effective as a method for observing land subsidence, seismic events, and volcanic activity. The use of SAR for remote sensing is very suitable for tropical countries [10], one of them is Indonesia. ALOS PALSAR satellite was collected through the Alaska Satellite Facility website by forming three pairs of images as in Table 3.

Table 3. Pairs of ALOS PALSAR Processing

Data Pairs	**Time Differences (days)**	**Bper (m)**
05Des2007- 06Jun2008	184	736,96
06Jun2008- 9Sept2009	460	644,4
25Oct2009- 28Oct2010	368	299,55

III. RESULTS AND DISCUSSION

In this study dual-pass DInSAR method is being used. This method requires a pair of images which consists of master and slave. The estimation of land subsidence can be determined by the elevation profile extracted from the two independent SAR pairs. The dual-pass DInSAR requires DEM (Digital Elevation Model) to generate land subsidence maps. The important thing in the processing is checking of the orbital position between the master and slave images that is co-registration. Co-registration ensures that each basic target contributes to the same pixels in both master and slave images. In the checking process, the software automatically determines the value of Baseline Perpendicular (Bper), baseline parameters between two orbits/image pairs, and incidence angle. The terms in InSAR modeling is the baseline distance between the two images should be no more than 1 km [22]. Based on the checking result conducted before doing co-registration of three image pairs from 2007 to 2010 obtained Bper value are 736.96 m, 644.40 m, and 299.55 m as shown in Table 3.

In addition to the Bper value, coherence value is also very important in interferometric coherence processing that is the stage that serves to determine the quality of measurement. The coherence value ranged from 0 to 1 which shows 1 as the most coherent image pairs. The minimum coherence value for DEM formation given by ESA (European Space Agency) is 0.40 [22]. The result of the interferogram has been filtered which shows a relatively reduced noise in areas that previously still have high coherence levels. The type of filtering used in this processing is Goldstein Phase Filtering. The Goldstein Phase Filtering or also called Goldstein-Werner is applied to an interferogram that has noise with an iterative process to remove noise and facilitate interferogram [12]. The coefficient in the filtering process is 0.2. In the case of ALOS PALSAR, the wavelength is 23.6 cm (L band), and each cycle of the interferogram represents 11.8 cm of ground displacement [6]. Interferogram after filtering shows increased sharpness of areas that still have high coherence. Figure 3 shows the interferogram of filtering process results.

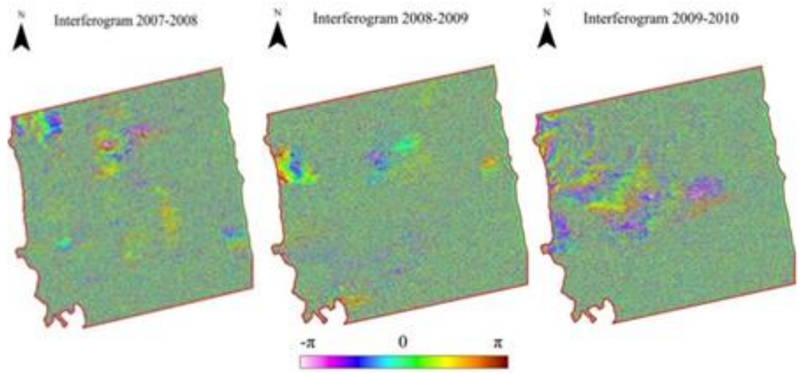


Fig. 3 Interferogram

The results of filtering will be unwrapped and converted to displacement value. The vertical displacement value is obtained by Equation 2. The purpose of the vertical displacement step is to convert the phase obtained during the unwrapping step into the elevation values. The villages which suffered significant changes are Sungai Sapih, Gunung Sarik, Gurun Lawas, Kampung Olo, Rimbo Kaluang, Kalumbuk, Kurao Pagang, Kampung Lapai, Surau Gadang, Air Tawar Timur, Tabing, Lolong Belanti, Air Tawar Barat, Alai Parak K, Ulak Karang Selatan, Gunung Pangilun, Ujung Gurun, Plamboyan Barat., Korong Gadang, and Purus. Figure 4 represents the 5 villages in Padang area that have suffered changes during 2007 to 2010.

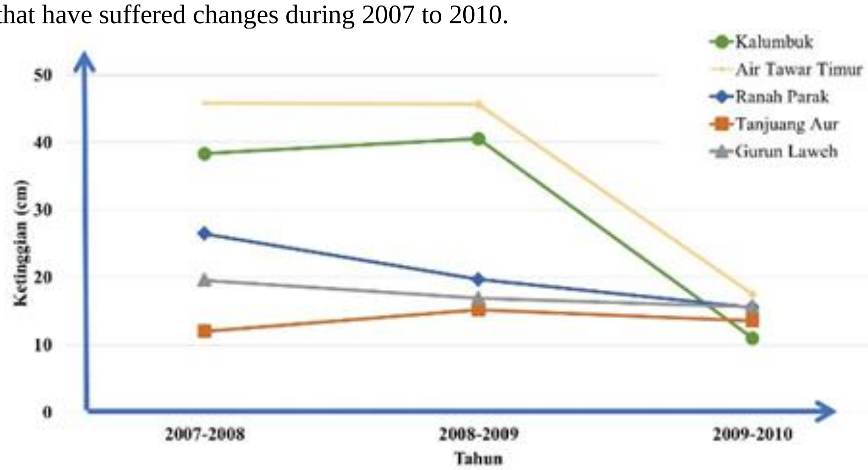
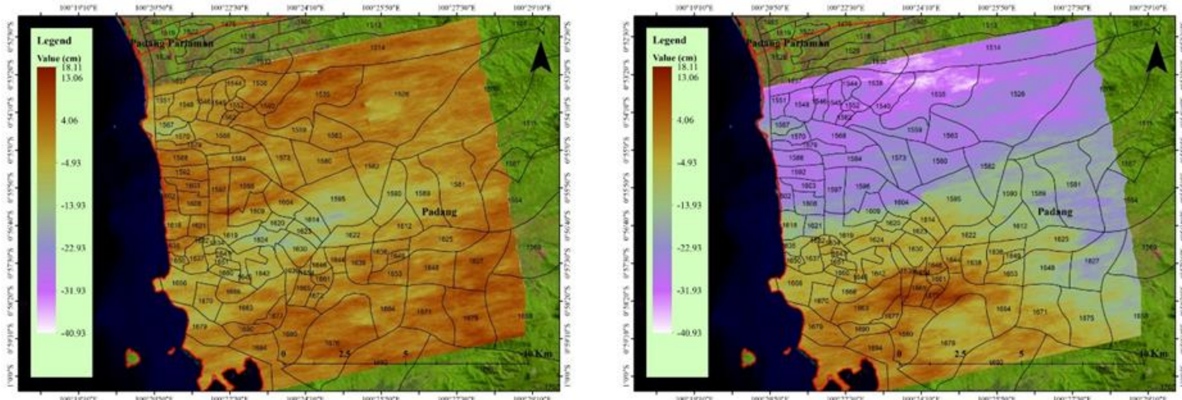


Fig. 4 The Elevation Profile of 5 Villages in Padang City

The green and yellow graphs show the villages that suffered significant changes that are found in Kuranji, Padang Utara, and Padang Barat subdistrict. As well as blue, gray, and red graphs are the villages that suffered no significant elevation changes that are found in Padang Selatan and Lubuk Begalung subdistrict. The resulting map of land subsidence or uplift distributions is shown in Figure 6. The changes of a color to another color show the changes of land subsidence or uplift values with a certain range of values.



(a) (b)

Fig.5. Land Subsidence Distribution During 2007 to 2010 (a) 2007-2009 Pair and (b) 2008-2010 Pair

Figure 5 is the overlay result of two elevation maps which aims to see the value of elevation changes from 2007 to 2010. Estimation graph of land subsidence value shown in Figure 6. This graph shows significant land subsidence between the image pair before the big earthquake of September 26, 2009 (2007-2009), and after the earthquake (2008-2010) at the point of a certain area. Areas that experienced very significant subsidence are located on the left side of the graph which is lowland close to the beach or sea area.

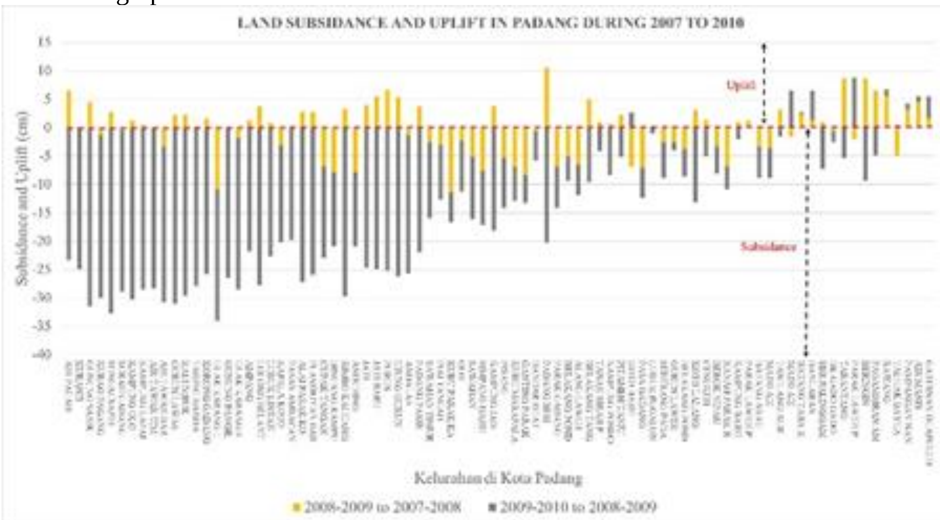


Fig. 6 Estimated Value of Land Subsidence from 2007 to 2010

The yellow graph is a pair of images which is at that time there was no seismic activity/earthquake with a high scale (before earthquake on September 30, 2009). Such small changes occur due to other several factors of land subsidence such as human activities, development, and so on. So, the change in land subsidence is very small (close to zero). The gray graph is a pair of images with data acquisition after the big earthquake with the strength of 7.6 SR. The biggest value of land subsidence is -32.70 cm. The results obtained that the subdistrict of Padang Utara, Nanggalo, and Padang Barat have very significant subsidence compared to other subdistricts. According to the Agriculture Agency of Padang about the elevation of the mainland of Padang areas that is the subdistrict of Padang Utara, Nanggalo and Padang Barat are a lowland area with the elevation around 0-25 m, 3-8 m, and 0-8 m. Based on the geological map of Padang City where the subdistrict of Padang Utara, Nanggalo, and Padang Barat have types of soil that are Qal (Alluvium), Qf (Fan Deposits). While the subdistricts have a little change (not significant) that are subdistrict of Lubuk Begalung and Padang Selatan. According to the Agriculture Agency of Padang about subdistrict of Lubuk Begalung and Padang Selatan have a relatively flat topography with the elevation around 8-400 m and 0-322 m. The type of soil is the red-yellow component of pedsolic latosol and latosol. Based on the results of the processing that has been done on three image pairs, there is coherence between the influence of the movement of the geological structures (such as the earthquake of September 30, 2009) and the type of soil in Padang areas especially subdistrict of Padang Utara, Nanggalo and Padang Barat that Alluvial as a type of its soil. The type of soil is easy to cause land subsidence. The value of maximum and minimum land subsidence velocity is shown in Table 4.

Table 4. the Value of Land Subsidence Velocity from 2007 to 2010

Codes	**Villages**	**Max Velocity (cm/year)**
1535	Gunung sarik	12.03
1540	Sungai Sapih	11.80
1552	Gurun Lawas	11.04
Codes	**Villages**	**Min Velocity (cm/year)**
1644	Lubuk Begalung	0.35
1647	Belakang Pondok	0.35
1630	Parak Gadang	0.13

Figure 7 shows a graph of the land subsidence velocity in Padang areas from 2007 to 2010 in each village.

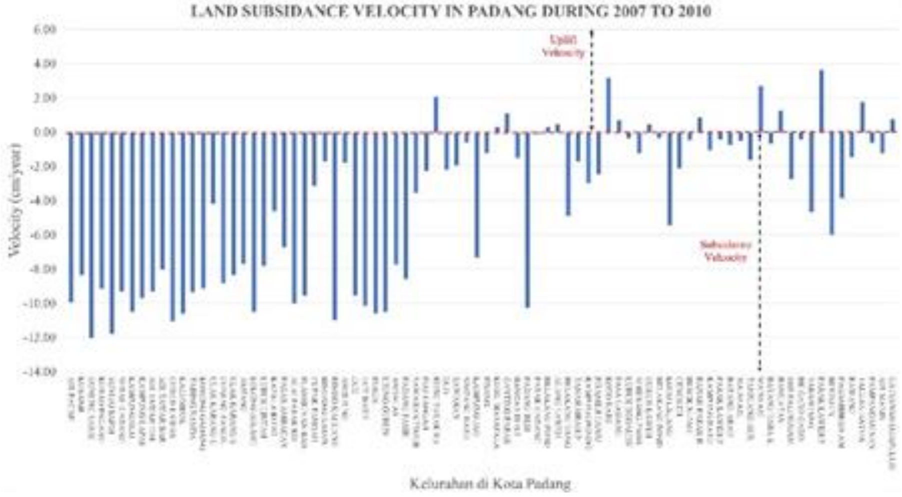


Fig. 7 Graph of the Land Subsidence Velocity in Padang Areas from 2007 to 2010

According to the theory about factors of land subsidence [7] that one of the factors is tectonics energy such as earthquakes and Earth's crust. The results obtained through processing that the earthquake on September 30, 2009, had an impact on land subsidence in Padang city. In this research, not reviewed yet which factors are the most influential on land subsidence every year in Padang city because there are several factors in an area that influence it.

IV. CONCLUSION

The research presents distribution of areas affected by land subsidence in Padang city based on analysis of DInSAR method. The results obtained indicate that are Sungai Sapih, Gunung Sarik, Gurun Lawas, Kampung Olo, Rimbo Kaluang, Kalumbuk, Kurao Pagang, Kampung Lapai, Surau Gadang Air Tawar Timur, Tabing, Lolong Belanti, Air awar Barat, Ulak Karang Selatan, and several other areas are the affected areas of land subsidence due to the earthquake on September 30, 2009. The most significant distribution of land subsidence occurred in subdistrict of Padang Utara, Nanggalo and Padang Barat which causes the frequent occurrence of floods. The estimated amount of subsidence in Padang city from 2007 to 2010 range from -32.70 cm (max) to -0.18 cm (min) and subsidence velocity is found to be 0.13 ~ 12.03 cm / year. This research can be useful in the further development of land subsidence maps which can act as the reference for further study, especially in Padang City. Further analysis is required to get in depth understanding about land subsidence causes; for this it is recommended to incorporate data collected from global navigation satellite stations or data collected using differential GPS to validate the acquired results. The limitation of this research is the unavailability of ground data in Padang city, West Sumatra as based data to clarify the result of this research. However, it is necessary to have the ground data as a confirmation of the result.

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REFERENCES

[1] Abidin, H.Z., Andreas, H., Gamal, M., and Darmawan, D, "Land Subsidence Characteristic of Bandung Basin (Indonesia) Between 2000 and 2005 as Estimated from GPS Survey*", XXIII FIG Congress, Munich*, p.1-14, 2006.

[2] Abidin, H. Z., R. Djaja, D. Darmawan, S. Hadi, A. Akbar, H. Rajiyowiryono, C. Subarya, "Land Subsidence of Jakarta (Indonesia) and its Geodetic Monitoring System, Natural Hazards 23", pp. 365–387, 2001.

[3] Akbar, Tengku Oki. 2015. *Analisis Dampak Penurunan Muka Tanah Terhadap Tingkat Ekonomi Menggunakan Kombinasi Metode Dinsar Dan Sig (Studi Kasus: Kota Semarang)*. Jurnal Geodesi UNDIP.

[4] Bappeda (Badan Perencanaan Pembangunan Daerah). 2012. *Lampiran Peraturan Daerah Kota Padang Nomor 6 Tahun 2014 Tentang Rencana Pembangunan Jangka Menengah Daerah Tahun 2014-2019: Padang.*

[5] Bappeda (Badan Perencanaan Pembangunan Daerah). 2009. *Geographical Location and Regional Administration of Padang: Padang.*

[6] Bayuaji, L., J.t. Sri Sumantyo, and H. Kuze, "ALOS PALSAR D-InSAR for Land Subsidence Mapping in Jakarta, Indonesia," *Can. J. Remote Sensing*, vol. 36, no.1, pp. 1-8, 2010.

[7] Chang C. P., Wang C.T., Chang. T. Y., Chen. K. S., Liang. L.S., Pathier. E., et al. "Application of SAR Interferometry to a large thrust deformation: the 1999 Mw=7.6 Chichi earthquake in Central Taiwan," *Geophysical Journal International,159, 9-16,* 2005.

[8] Chatterje RS, Benedicte F., et al. "Subsidence of Kolkata (Calcutta) City, India during the 1990s as Observed from Space by Differential Synthetic Aperture Radar Interferometry (D-InSAR) Technique," *Remote Sensing of Environment 102:176-185,* 2006.

[9] Deguchi, T., Maruyama, Y., Kato, M., and Kobayashi, C., *Surface Displacement Around Mud Volcano, East Java Captured by InSAR Using Palsar Data.* Earth Remote Sensing Data Analysist Centre (ERSDAC), Tokyo, 1-6, 2008.

[10] ESA, *InSAR Principles, Guidelines for SAR Interferometry Processing, and Interpretation (TM-19, February 2007).* Frascati, Italy, 2007.

[11] Fauzi, A., Sutarman K., Hamdi, dkk., *Penyelidikan Karakteristik Batuan di Kota Padang Menggunakan Metode Geofisika dan Geomorfologi untuk Memetakan Daerah Rawan Bencana.* Laporan Penelitian Hibah Kompetitif Sesuai Prioritas Nasional Batch 1, Bidang Mitigasi dan Managemen Bencana, 2009.

[12] Goldstein R.M. and C.L. Werner," Radar Interferogram Phase Filtering for Geophysical Applications." *Geophysical Research Letters,* 25, 4035-4038, 1998.

[13] Gumilar, I., H.Z. Abidin and L.M. Hutasoit, *Pemetaan karakteristik Penurunan Muka Tanah Berdasarkan Metode Geodetik Serta Dampaknya Terhadap Perluasan Banjir di Cekungan Bandung*. ITB: Bandung, 2012.

[14] Hanson, R. T., Zhen, L., & Faunt, C., "Simulation of subsidence for the regional aquifer system in the Santa Clara Valley, California," *Proc., 7th International Symposium on Land Subsidence, Shanghai (CN),* 2005.

[15] Holzer, T.L. & Galloway, D.L., *Impacts of Land Subsidence caused by withdrawal of underground fluids in the United States*. Engineering Geology. 16,87-99, 2005.

[16] Hou CS, Hu JC, Shen LC, Wang JS, Chen CL, Lai TC, Huang C, Yang YR, Chen RF, Chen YG, Angelier J, "Estimation of subsidence using GPS measurements, and related hazard: the Pingtung Plain, southwestern Taiwan," *Comptes Rendus Geosci 337(13):*1184–1193, 2005.

[17] Hung, W. C., & Liu, C. S., *Taiwan land subsidence monitoring and surveying analysis.* Report of Industrial Technology Research Institute (ITRI), Hsinchu 335 pp. (in Chinese), 2007.

[18] Geografis Kota Padang [Online]. Available: (https://padangkota.bps.go.id/statictable/2015/04/26/2/letak-geografis-kota-padang.html)

[19] Marfai, R., "GIS Modelling of River and Tidal Flood Hazards in A Waterfront City (Case Study: Semarang City, Central Java, Indonesia)," *ITC, The Netherlands*, p.1-123, 2003.

[20] Noppadol, P. W., Giao, P. H., & Nutalaya, P., *Land subsidence in Bangkok, Thailand.* Engineering Geology, 82, 187−201, 2006.

[21] Potter, Yudo. (2009) Faktor-Faktor Penyebab Penurunan Muka Tanah (Land Subsidence). [Online]. Available: https://yudopotter.wordpress.com/2009/05/06/faktor-faktor-penyebab-penurunan-muka-tanah-land-subsidence/

[22] Prasetyo,Y dan Janisa,A., *Penerapan Teknik Differential Interferometric Synthetic Aperture Radar (DInSAR) Untuk Kajian Pemantauan dan Pengukuran Penurunan Muka Tanah (Studi Kasus: Lembang Bandung).* Forum Ilmiah Ikatan Surveyor Indonesia, Pekanbaru 10-11 November 2010.

[23] Saputro, Eko Andik, *Deteksi Penurunan Muka Tanah Kota Semarang Dengan Teknik Differential Interferometric Aperture Radar (DInSAR) Menggunakan Software ROI_PAC Berbasis Open Source.* Teknik Geodesi FT Universitas Diponegoro, 2012.

[24] Sato, C., Haga, M., & Nishino, J. *Land subsidence and groundwater management in Tokyo.* International Review for Environmental Strategies, 6(2), 403−424, 2006.

[25] Stramondo, S., Bignami, C., Chini, M., Pierdicca, N. & Tertulliani, A., “Satellite radar and optical remote sensing for earthquake damage detection: results from different case studies,” *International Journal of Remote Sensing.* 27(20): 4433–4447, 2006.

[26] Raucoules, D., Colesanti, C. and Carnec, C., “Use of SAR interferometry for detecting and assessing ground subsidence,” *Comptes Rendus Geosciences,* 339, 2007, pp. 289-302.

[27] Syafiudin, M. Fifik and R.S. Chatterjee, “Potensi Pemanfaatan Teknologi Diferential Interferometric Syinthetic Aperture Radar (D-INSAR) Berbasis Satelit Untuk Pemanfaatan Penurunan Muka Tanah di Cekungan Bandung” *Jurnal Ilmiah Geomatika Vol. 15 No. 1, Agustus* 2009.

[28] Tralli, D.M. Blom, R. G., Zlotnicki, V., Donnellan A. & Evans, D. L., “Satellite remote sensing of earthquake, volcano, flood, landslide, and coastal inundation hazards” *ISPRS Journal of Photogrammetry and Remote Sensing*. 59(4), 185-198, 2005.