Land Subsidence Analysis in Bandar Lampung City based on InSAR

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Abstract. Bandar Lampung is one of the cities in Indonesia, which has the potential to land subsidence due to human activity or natural phenomena. However it is still lack of information and the study of land subsidence that ever made. This research used 15 SARs data in the intervening years from 2006 to 2011 were combined to produce the interferogram and then inverted by using SBAS algorithm. Based on data analysis, SBAS technique reliable enough to determine the deformation symptoms quick and accurately. However, some locations have indications of subsidence more than 5 mm/year, even the highest reaches more than 30 mm/year which is identified in the Campang Raya, Camang, Kangkung, Sukaraja, Bakung, and Beringin Raya. Subsidence that occurred is suspected caused by tectonic and human activity and is more likely to occur in the new area suffered by land conversion. Subsidence that occurred implications on damage to the building structure, the occurrence of tidal flooding in coastal areas, and landslides in hilly areas.

Keywords: DInSAR, SBAS, subsidence, Bandar Lampung

INTRODUCTION

Land subsidence is a phenomenon that many experienced big cities in Indonesia and the world. This phenomenon is the decrease of the soil surface due to several reasons: excessive groundwater exploitation, ground surface loading by construction and infrastructure, natural consolidation of alluvium, and tectonic activity. Land subsidence is reported to occur in Mississippi of 2 cm/year due to natural compaction [1], in Mexico and Las Vegas about 10 cm / year due to groundwater exploitation [2]. And in western Indonesia, analyzed several cities experiencing an average subsidence above 22.5 cm/year. In Medan, Jakarta, Bandung and Semarang are caused by groundwater extraction for industry. In Arun, Lhoksumawe due to natural gas extraction, and in Sidoarjo due to the discharge of the mud from the soil [3].

Bandar Lampung is a rapidly growing city, as Serambi City of Sumatera, the first major city traversing the Sumatra Highway connecting P. Java with P. Sumatra. The total population of Bandar Lampung city in 2010 reached 757,000 inhabitants. Population Growth Rate (LPP) Bandar Lampung reached 1.61 since 2000-2010 and jumped to 2.04 in the year 2010-2015 [4]. Since 2010, Bandar Lampung City has grown as a tourist destination in Sumatera, it can be seen from the growth rate of the hotel. Until 2014, Bandar Lampung City Tourism Office noted there were 59 non-star hotels (~ 1500 rooms) and 9 starred hotels (~ 800 rooms). From this growth, there must have been an enormous increase in groundwater exploitation. Bandar Lampung also grows as a Student City, until 2015 there are 4 State Universities and 14 Private Colleges. The growth of the number of students also increased the density of Bandar Lampung City.

Land use in Bandar Lampung is very fast. In 1992, the highest percentage of land was dryland agriculture (60%) but 14 years later the land shrank to 13.4% or shrunk to more than 8900 ha. Land use in Bandar Lampung City is dominated by settlement that is 31,24%. This happens because of high population growth rate and urbanization flows to Bandar Lampung City. Water needs for residents of Bandar Lampung City is fulfilled through PDAM and shallow groundwater capture through dug wells. At present PDAM is only able to meet 27% of the total citizens of Bandar Lampung, while the remaining 73% still have to utilize the water wells dig. The depth of the dug well is about 30 to 50 meters from the local soil surface. Bandar Lampung is passed by Fault Panjang-Lampung. Fault of Length-Lampung has been identified regionally as in Geological Map of Tanjung Karang-Lampung [5].

Land subsidence caused many problems for the city that experienced it, including: cracks in buildings and infrastructure, widespread puddles / rob for coastal cities, and malfunctioning drainage system. The next consequence is the change of water flow in the canals and rivers, the increasing cost of maintenence of buildings and infrastructure and also the declining quality of the environment, such as health and sanitation conditions. This research will develop subsidence mapping method in Bandar Lampung City, to delineate and analyze the impact of subsidence in relation to population growth, groundwater extraction, construction and infrastructure loading, and Panjang-Lampung fault activity.

POTENTIAL FOR LAND SUBSIDENCE IN INDONESIA

Natural and anthrogenic processes can cause subsidence. Natural land subsidence results either from isostatic sediment loading and natural compaction of Holocene deposits or from tectonic and volcanic activities. Anthropogenic subsidence results from processes such as fluid withdrawal, solid withdrawal (tunnel construction or mining), changes in surface water drainage, and sediment loading. Land subsidence resulting from each of these processes is characterized by specific rates and spatial patterns and the spatial patterns as follows: large-scale: >100 km2, local: 10–100 km2, and patchy: <10 km2 [3].

In urban areas of Indonesia, ongoing land subsidence has been observed in Jakarta [6,7] Bandung [8,9], and Semarang [10,11]. Land subsidence in urban areas is usually caused by a combination of excessive extraction of ground water, the natural consolidation of alluvium soils, construction costs (ie high compressibility soil settlement), and sometimes tectonic activity.

INSAR-DINSAR-SBAS

In the study of land subsidence in an area, there are various methods to find out the information of ground level reduction that is by flat ploting method and GPS observation, but due to the limitations of spatial coverage in both methods, the spatial pattern of land subsidence and factors which causes a decrease in the face of the land remains unknown. Therefore, the DInSAR - SBAS method can be selected to study the symptoms of ground subsidence because it has a wide range of spatially and temporally and has high accuracy.

DInSAR (Diffrential Interferometric Synthetic Aperture Radar) is one technique that utilizes phase difference between two SAR data that has different acquisition time in the same area. This technique can generate spatial information about deformations with high accuracy (sub-centimeters). But the DInSAR technique has a deficiency where its accuracy can be reduced due to atmospheric propagation, topographic field interference, and temporal decoration. Therefore, it is used the technique of SBAS (Small Baseline Subset) which is the development of DInSAR technique that is able to reduce the disorder, where this technique has been tested its accuracy to GPS measurement and leveling which one is done in Chiba, Japan [12] and Napoli Bay [13].

SAR technology was developed to overcome the limitations of spatial resolution on real-radar (RAR) real images, by making short antennas that functioned like long antennae (synthetic aperture). By moving forward, the actual short-sized sensor that electronically forms parts of the long antenna. This is made possible by the Doppler effect which results in the pseudo motion of the object on each radar pulse jet [14].

Interferometric SAR itself is a technique of merging two SAR images. In both images recorded the amplitude and phase values of the reflection of radar waves from the earth's surface. The phase information contained in the image is used to determine the location of points on the surface of the earth. The geometry of SAR data acquisition in slant ranges in single-pass and two-passs modes is illustrated in **Figure 1.**

In the InSAR configuration of **Figure 1.a** there is a point (z) that is perpendicular to the orbit of the satellite. The distance between the two antennas and point z is r and r + δr. The two antennas are separated by a distance referred to as baseline (b), which can be decomposed into normal baseline (bn) and parpendicular baseline (b⊥) which can be seen in **Figure 1.b** [15].

The image of the result of the phase difference between the two acquisitions is known as the interferogram. Each pixel on an interferogram shows the corresponding phase difference in the pixels of the two SAR images. This technique is known as SAR interferometry [16]. Each color gradation cycle (fringe) represents a phase change in 2π or a full wave [3].

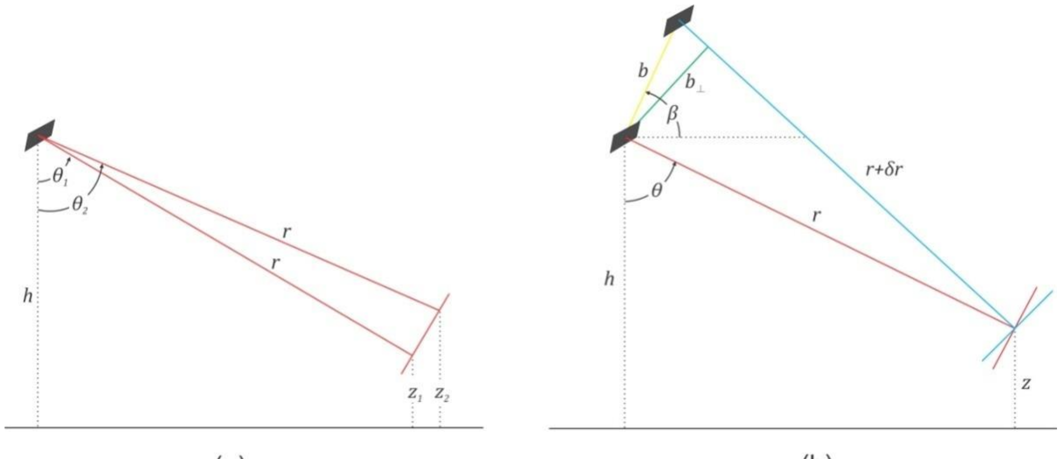


Figure 1. SAR imaging geometry; (a) single-pass. (b) two-pass (modified from Goel, 2013)

InSAR is a very powerful technique for detecting deformations at a point in the LOS direction (**Figure 2**) occurring between two SAR acquisitions that lead to a displacement phase ($\delta\phi^{disp}$). Different phases that occur due to deformation can be written:

$$\delta\phi^{disp} \approx \frac{4\pi}{\lambda}\delta r_s \qquad (1)$$

To avoid decorelation, surface deformation (δr_S) is assumed to be smaller than the resolution of the cell. The common equations are:

$$\delta\phi = \delta\phi^{flat} + \delta\phi^{topo} + \delta\phi^{disp} \qquad (2)$$

by combining Equations 11 and 17 it will give you a total interferometric phase, that is:

$$\delta\phi = -\frac{4\pi}{\lambda} b \sin(\theta_0 - \beta) - \frac{4\pi}{\lambda} b \frac{z}{r' \sin\theta_0} \cos(\theta_0 - \beta) + \frac{4\pi}{\lambda}\delta r_s \qquad (16)$$

(3)

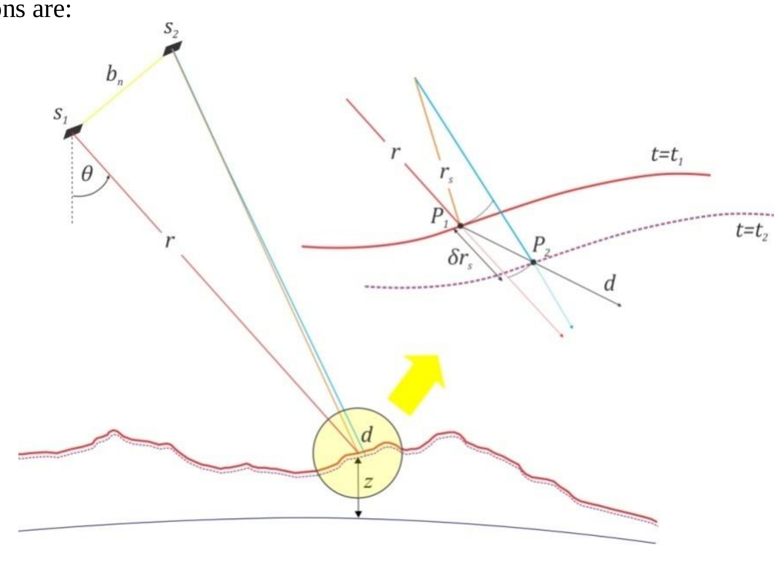


Figure 2. Detection of surface deformation with InSAR

DInSAR technique has a deficiency that is still the influence of the atmosphere and still the influence of phase components due to topography due to flattening imperfect [13]. To eliminate the influence of atmospheric propagation and topographic phase components, several algorithms have been developed, one of which is the Small Baseline Subset (SBAS) technique.

The SBAS technique was developed by P. Berardino, G. Fornaro, R. Lanari and E. Sansosti in 2002 to produce time series deformation, focusing on non-urban areas (Berardino et al., 2002 quoted from [17]. basic processing on SBAS is as follows:

a. There is a stack of N + 1 CAR image that has been calibrated and in-coregistration obtained at time tn where n = 0, ..., N; and M is a multi-look differential interferogram with a small baseline (spatial and spatial). DEM reference is used to compensate for the topographic field phase. The use of a small baseline is done to reduce the effects of temporal decorelation and uncompensated spatial decoration.

b. Each pixel is identified to know the spatial coherence greater than a certain limit and the SBAS is applied only to the pixel.
c. The unwrapping process is done on the interferogram differential. All coherent pixels are then referenced on one pixel that is not deformed and has a high coherence value.
d. The low-pass component of the deformation signal and topographic error is estimated in each coherent pixel with the least square (LS) equation. Each interferogram is subtracted with residual topographic and low-pass components which will result in a decrease in fringe rate on the interferogram.
e. Linear modeling is performed of each coherent pixel of the interferogram.
f. A low-pass filter in the spatial domain is used to estimate the atmospheric propagation effect. This is followed by a high-pass filter in time domain, since the atmospheric phase components show high spatial correlation but low temporal correlation [17].

DATA AND PROCESSING

The research data used in the implementation of this research are: (a) ALOS-PALSAR dataset in horizontal aligned polarization (HH) in descending acquisition mode in Bandar Lampung City region obtained from ASF ALASKA (**Table 1. a** and **b**). Digital Elevation Model DEM) SRTM 1-Arc Second area of Bandar Lampung and surrounding areas obtained from Earth Explorer - USGS.

Errors in the unwrapping process, the noise on the interferogram, as well as errors in data processing can lead to inconsistent deformation patterns. The quality index of the deformation data is also called the temporal coherencefactor (Ctemp). So by analyzing the value of Ctemp (**Figure 3a**), it can be known that pixelmana has reliable information, which is generally shown in the threshold value (generally > 0.7) [13]. 2009).

Table 1. SAR *dataset*

No.	Acquisition Date	Acquisition Type
1	21-12-2006	FBS
2	23-06-2007	FBD
3	08-08-2007	FBD
4	23-09-2007	FBD
5	08-02-2008	FBS
6	10-05-2008	FBD
7	25-06-2008	FBD
8	25-09-2008	FBD
9	10-11-2008	FBS
10	26-12-2008	FBS
11	10-02-2009	FBS
12	01-07-2010	FBD
13	16-08-2010	FBD
14	01-10-2010	FBD
15	16-02-2011	FBS

Based on **Figure 3a**, the C_{temp} value is strongly influenced by the type of land cover in the study area, where in the dynamic areas (agricultural and forest) tend to have low C_{temp} values, whereas in statutory population areas the C_{temp} high.

Accuracy of the result of deformation measurement in study area is obtained from several parameters such as coherence and wavelength which then calculated so that will get estimation of measurement accuracy (standard deviation), where the bigger value will be lower accuracy of measurement and vice versa. Estimation of measurement accuracy is calculated by the following equation:

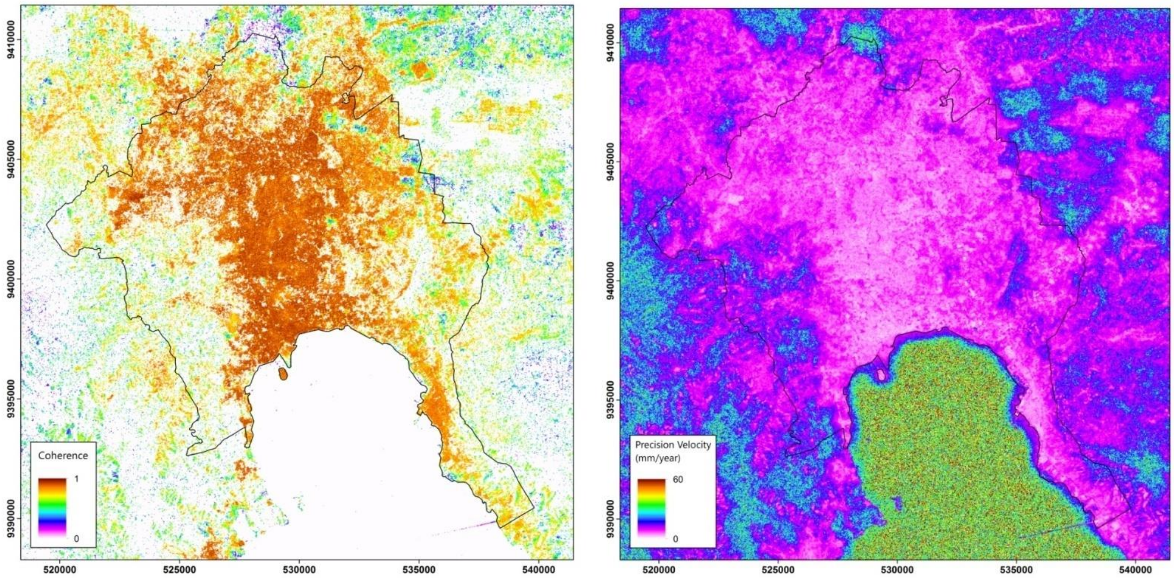
$$\sigma = \sqrt{\frac{1-\gamma^2}{2\gamma^2}\frac{\lambda}{4\pi}} \qquad (4)$$

where σ is the measurement accuracy, γ is interferomatric coherence, and λ is the wavelength used.

Based on the measurement accuracy estimation (σ), the value of σ (**Figure 3b**) tends to be inversely proportional to the C_{temp} value (**Figure 3a**), since the value of σ is calculated based on the value of C_{temp}.

The measurement accuracy (σ) is quite high (20-50 mm/year) in a dynamic area (high-vegetation area). Since the value of σ is not sufficiently reliable in terms of measurements of ground subsidence in the millimeter order, no relevant that can be obtained in these areas.

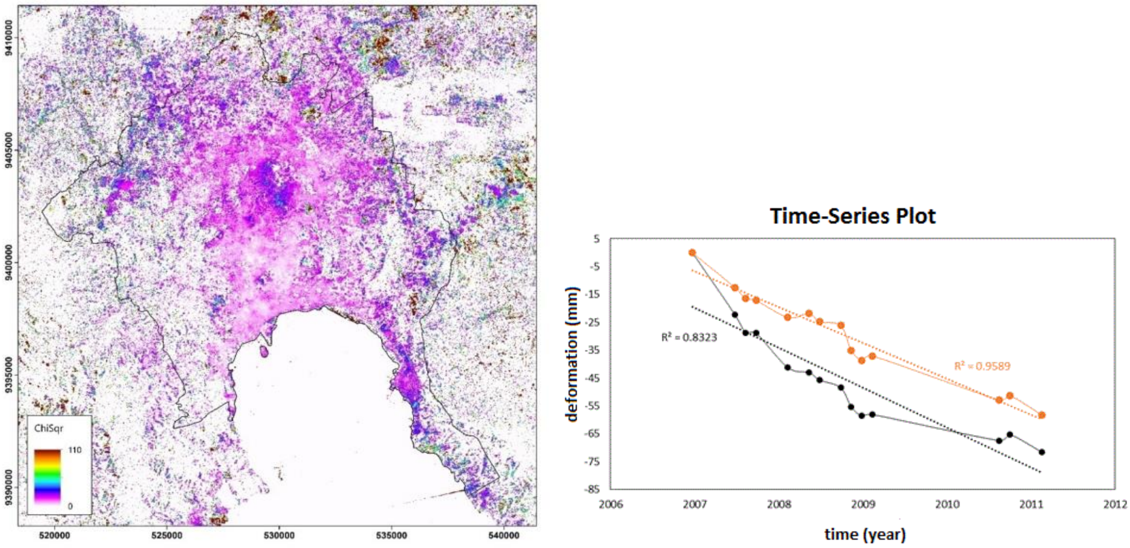
As for urban areas dominated by buildings and highways, the value of σ ranges from 0 to 0.7 mm / year. Accuracy is quite high considering the urban areas tend to be static (not experiencing significant changes) from time to time. Therefore, the result of SBAS measurement having high reliability is mostly obtained in urban area.



(a) (b)

Figure 3. *Temporal* coherence *map* (a), *Precision velocity map* (b)

In the inversion process to get the value that represents the deformation velocity model in the research area, linear regression is done by using Least Square method on time-series deformation data. To know the quality of the fitting of the inversion model used for the time-series data, then a non parametric comparative test using Chi Square method (kai square) is used. The low value of Chi Square shows good fitting to the regression line, and vice versa (**Figure 4b**). The result of calculation of Chi Square test on the result of this research is shown in chi squre map in **Figure 4**.



(a) (b)

Figure 4. *Chi Square map(a),* Example of time-series data from two points adjacent to identical subsidence rate, but with very different Chi Square values. The black line is a time-series with a large Chi Square value (b)

The value of Chi Square of the linear inversion model (**Figure 4a**) is quite low in average value indicating that the fitting between the linear regression model chosen in the inversion process with the time-series data is quite good, although in some regions especially the subsidence rate high tend to have a high value of Chi Square because the trend of time-series data in the area tend to be non-linear (parabola). However, since the area with high Chi Square is not very dominant, the linear inversion model is still considered relevant enough to represent the deformation velocity in this study.

ANALYSIS AND INTERPRETATION

The result of SAR data processing using SBAS technique in this research produce information about deformation speed in Line of Sight (LOS) direction in Bandar Lampung City (**Figure 5**) with data resolution of 20 × 20 meter. The deformation velocity data in this study was limited to areas with an accuracy of <7 mm / year and temporal coherence> 0.7. The deformation speed in **Figure 5** refers to the direction of LOS (Line of Sight) and in the vertical direction (z-axis) referenced at a reference point which is a stable region (not deformed in 2006-2011), represented by an asterisk .

The deformation velocity in the LOS direction has a positive value (green color scale) to represent the relative up end deformation and the negative LOS velocity (red color scale) to represent relative deformation away from the satellite direction (subsidence).

Indication of land subsidence in Bandar Lampung City spatially has two main patterns, namely patchy (<10 km2) in coastal area of Lampung Bay and Kemiling District, and local (10 - 100 km2) in Eastern part of Bandar Lampung City, that is in area East Tanjungkarang.

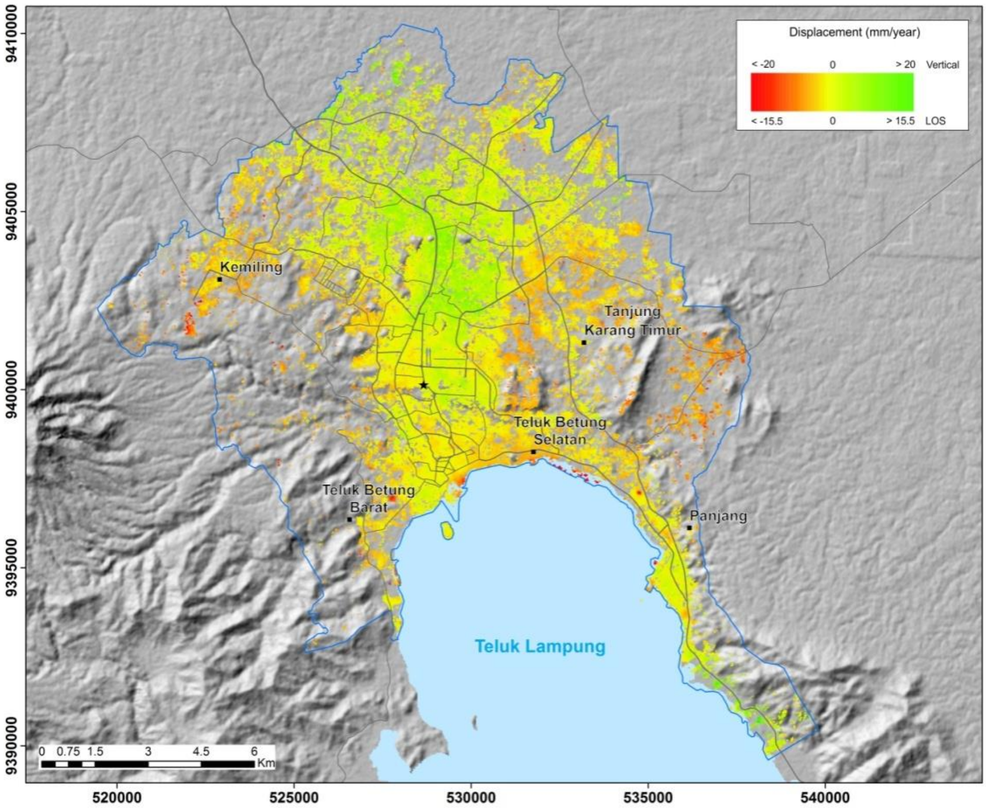


Figure 5. Deformation velocity (mm / yr) of measurement results by SBAS technique in Bandar Lampung City

For the analysis process in this study, two approaches are used, the first to investigate the indication of land subsidence on a regional scale, by identifying areas that have high indication of land degradation based on the measurement of SBAS. Later analyzes were conducted on a smaller scale (local) aimed at limiting the discussion to only certain areas to reduce the complexity of the subsurface geological conditions as well as the varied causes of ground subsidence.

Therefore, in this study, only six observations observed indicated land subsidence (mean> 5 mm / year in the area 200 × 200 meters) which is expected to represent the factors causing and the pattern of land subsidence according to Chaussard (2013) as depicted in **Figure 6**.

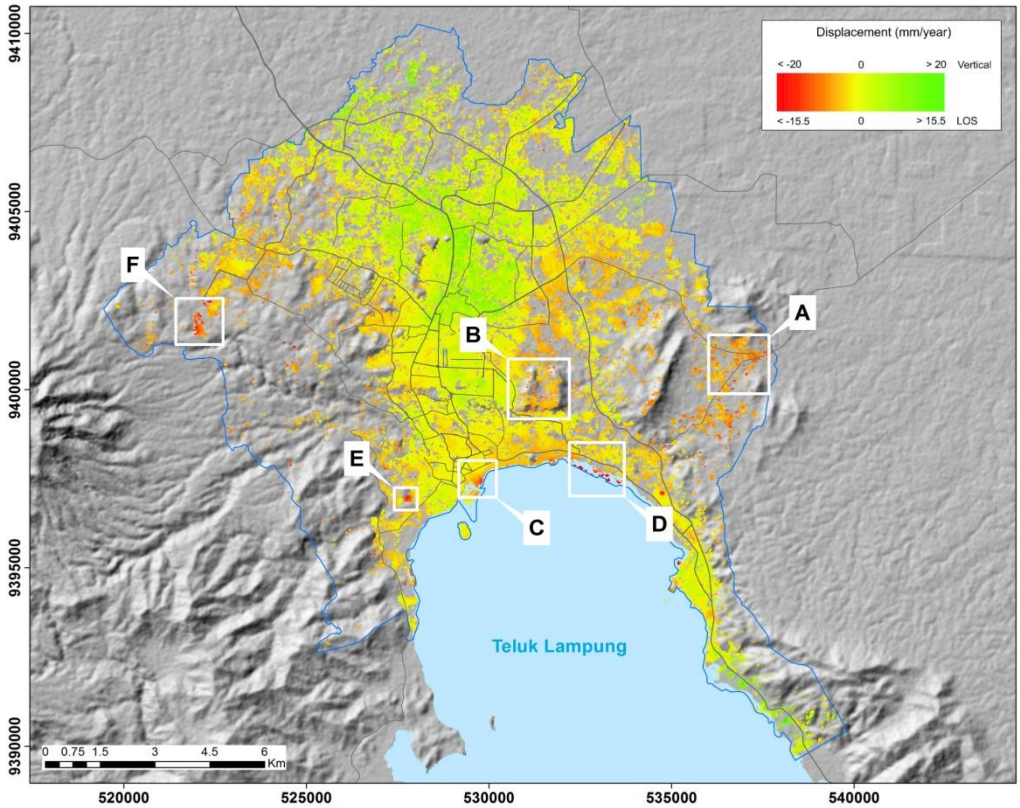


Figure 6. The location on the indicated area has subsidence more than 5 mm/year in Bandar Lampung City.

The result of observation in A area (**Figure 6**) shows the area indicated to land subsidence with an average speed of 9 mm / year, in Campang Raya Village. Graph of land subsidence is shown in **Figure 7**.

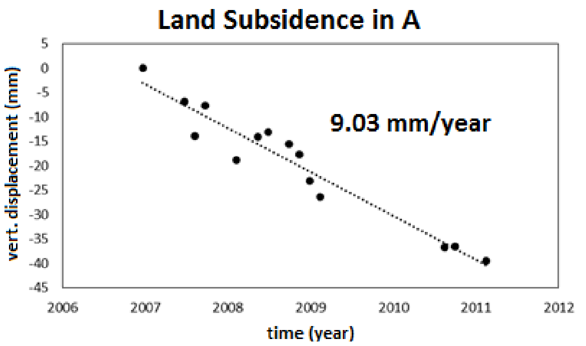


Figure 7. The land subsidence in Campang Raya Village (industrial area)

The process of land subsidence in A area correlates to land use in this area, where in this area it is an industrial area and densely populated residential. The pattern of soil surface decline velocity tends to be higher in the South, that is, around the industrial estate). The development of industrial estate and settlements in this area caused additional load to the soil layer and also increased groundwater exploitation (assuming the increase of population and industry is directly proportional to groundwater consumption).

The process of land subsidence in B area which is the area of Mount Camang, which on average undergoes a decrease of 7.4 mm/year. Graph of land subsidence of Mount Camang in the period 2006 - 2012 is presented in **Figure 8.**

In addition to this, there is also intensive land conversion at the peak of Mount Camang into a luxury residential. Decreased ground level is possible although in fact Mount Camang is composed of tuff-tuffit, because the decrease of land surface due to mining activities and land conversion can intensively affect all kinds of rocks (Chaussard, 2013).

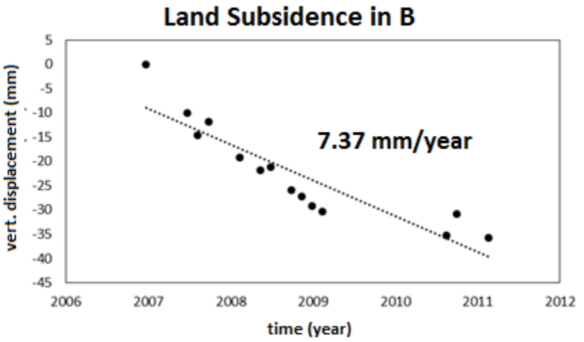


Figure 8. The land subsidence in B area (Mount Camang and surrounding area)

In C area, the land subsidence is detected in densely populated areas in Pasar Kangkung, South of Teluk Betung, with a characterized spatial pattern of less than 10 km2 (patchy). Graphs and patterns of dispersal of land subsidence in this area are represented in **Figure 9**.

This area indicates a decrease in ground level with an average speed of 14.7 mm / yr. The density of the population (9,251 inhabitants / km2) is certainly proportional to groundwater consumption in this area, where for groundwater needs, the community uses dug wells with a depth of 8-12 meters [18] as well as some drilling wells with average discharge 150 liters / minute [19].

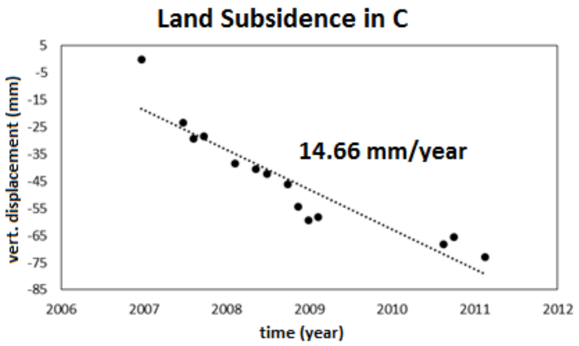


Figure 9. The land subsidence in C area (Pasar Kangkung, South of Teluk Betung)

The D area is one of the beach reclamation projects on Sukaraja, South of Teluk Betung. In the west the reclaimed area is currently used as a coal deposit site, but the East is still an untapped land. The land of reclaimed land is still largely unconsolidated and well-compacted, so that the physical properties and mechanics of the embankment material may potentially subsided, and based on the results of SBAS measurements, the land subsidence in this area averaged 30.5 mm/yr, as shown in **Figure 10**.

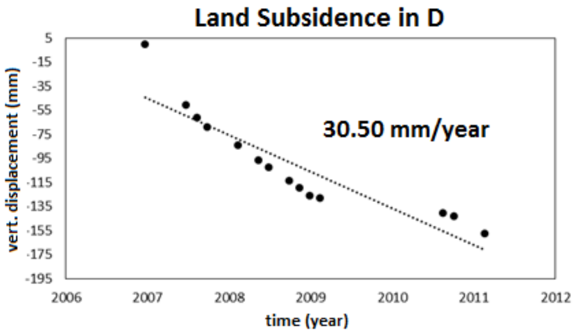


Figure 10. The land subsidence in D area (Sukaraja reclamation area)

Indication of land subsidence in the southwest of Bandar Lampung City shows an interesting pattern of land subsidence in a residential area in Bakung Village, West Teluk Betung District. In this area found anomalous land subsidence that is very contrast with the surrounding area that tends to be stable. This area has decreased ground level with an average speed of 15.3 mm/year, which is shown in **Figure 11**.

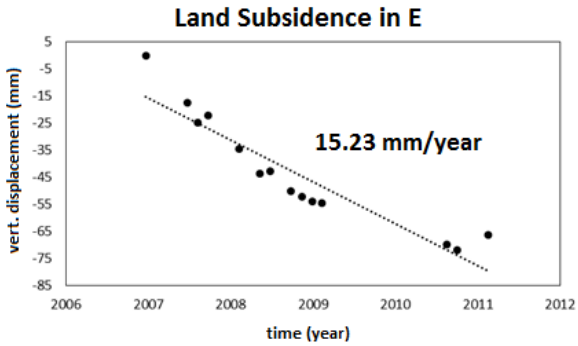


Figure 11. The land subsidence in E area (Bakung area)

Based on observations in the field, this area has a morphology of sinklin (valley) which is located between three hills and the northern part is a swamp, while in the south stands a residential area. The estimation of the causes of land subsidence in this area is allegedly caused because this region was originally a former swamp area, which was later converted into residential areas. This then leads to the occurrence of underground layer compaction in the form of organic materials that can experience decomposition and also compression due to building loads on it.

Decreased ground level is indicated in Kelurahan Beringin Raya, Kemiling Sub-district (F area), which is dominated by clay-rich layer. The average decrease in this area based on the SBAS measurement is 16 mm/yr which is shown in **Figure 12**).

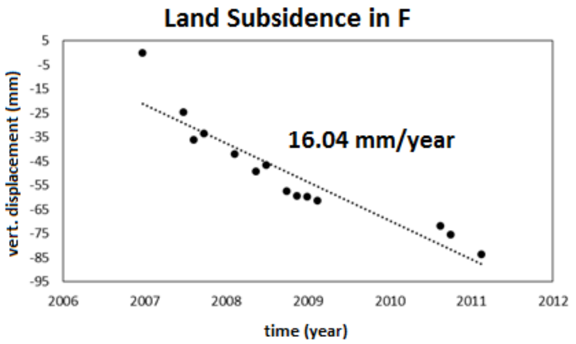


Figure 12. The land subsidence in F area (Beringin Raya, Kemiling)

Due to the area dominated by the clay-rich layer, so the mechanics of the soil is what is suspected as the cause of the decrease of ground level in this area. Land that is cohesive (clay-rich soil) is very likely to decrease the face of the soil, because this layer is very sensitive to changes in water content (soil moisture). This makes it expand when moist / wet, and then shrinks when dry (volumetric change).

The results of the analyzes of the six regions indicated land subsidence are summarized in this section which are then represented in **Table 2**. The observed area is correlated to the characteristics and factors lans subsidence in **Table 2**, so as to obtain a provisional estimate of the factors causing land subsidence in Bandar Lampung City based on spatial patterns, land use, and geological conditions.

Table 2. Compilation of the observations made in the six locations experiencing subsidence

Location	Average vert. rate (mm/tahun)	Spatial pattern	Surface geology	Correl. with surface geology	Land use	Correl. with land use	Interpreted cause of rapid subsidence
Campang Raya (A)	9	local	Surficial deposits	×	Industrial and resisdential	√	Industrial water extraction and loading structure
Gunung Camang (B)	7,4	patchy	Surficial deposits (tuff – tuffit)	×	Residential and mining	√	Water extraction and mining
Pasar Gudang Lelang (C)	14,6	patchy	Surficial deposits (sandstone)	√	Residential and trade and sevices	√	Water extraction by residence and industry
Area reklamasi, Sukaraja (D)	30,5	patchy	Surficial deposits (alluvial)	√	Industrial and stockpiling of coal	√	consolidation of embankment material
Bakung (E)	15,5	patchy	Surficial deposits and peat	√	Residential and swamp	√	decomposition of organic matter and loading structure
Beringin Raya (F)	16	patchy	Surficial deposits (clay)	√	Residential and vacant land	×	volume shrinkage in the clay layer

Land subsidence is likely to occur in areas of alteration or land conversion that occurred less than 20 years earlier. This is why the Central Tanjungkarang and Kedaton areas with high population densities (10,953 persons/km2 and 8,205 persons/km2 respectively) are not indicated to decrease the land surface.

Based on the previous statement and if you look at the pattern in **Figure 5** then it is suspected that the Central of Tanjungkarang area and Kedaton may have already experienced consolidation as it developed earlier than other regions, and in the past 10 years has tended to be stagnant in terms of development and conversion of land, this is certainly similar to the statement Sestini (1996) in [3], which states that land subsidence due to reclamation, construction and agricultural activities is limited to the first twenty years or directly after land conversion.

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CONCLUTION

1. The type of land use greatly affects the reliability of the data, the more dynamic the area, the measured deformation speed information by InSAR-SBAS method becomes less precise for the measurement of deformation symptoms in millimeters. SBAS technique is reliable enough to know the symptoms of deformation in Bandar Lampung City quickly and accurately.
2. Indication of land subsidence is not evenly distributed in all places, but on average Bandar Lampung city decreased the average 0.06 mm / year with trend which tend to linear. In some areas in Campang Raya, Camang, Kangkung, Sukaraja, Bakung, and Beringin Raya have subsidence more than 5 mm / year, where the highest is in Sukaraja (> 30 mm / year).
3. Subsidence with a speed of more than 5 mm / year spatially has two patterns, namely patchy (<10 km2) on the coastal area of Lampung Bay and Kemiling District, and local (10 - 100 km2) in the East Bandar Lampung , that is in East Tanjung Karang area.
4. Land subsidence in Bandar Lampung City occurred due to tectonic activity and also due to human activities (industry, loading, mining, ground water extraction, and land conversion). The above factors affect the speed of land subsidence individually or simultaneously.
5. Subsidence is not highly correlated to population density and rock lithology, but tends to occur in areas where land conversion is less than 20 years ago.

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