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# Land subsidence analysis in Bandar Lampung City based on InSAR

A Zaenudin<sup>1\*</sup>, I G B Darmawan<sup>1</sup>, Armijon<sup>2</sup>, S Minardi<sup>3</sup> and N Haerudin<sup>1</sup>

<sup>1</sup>Geophysical Engineering, University of Lampung, Bandar Lampung 35145, Indonesia

<sup>2</sup>Geodesy Engineering, University of Lampung, Bandar Lampung 35145, Indonesia

<sup>3</sup>Physics Department, University of Mataram, Indonesia

\*ahmad.zaenudin@eng.unila.ac.id

**Abstract.** Bandar Lampung is one of the cities in Indonesia, which has the potential to land subsidence due to human activities or natural phenomena. However, it is still lack of information and the study of land subsidence that was ever made. This research used 15 SARs data in the intervening years from 2006 to 2011 and was combined to produce the interferogram, and then, it was inverted by using SBAS algorithm. Based on data analysis, SBAS technique was reliable enough to determine the deformation symptoms quickly and accurately. However, some locations had 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 activities and is more likely to occur in the new area suffered by land conversion. Subsidence that occurred implies on damage to the building structure, the occurrence of tidal flooding in coastal areas, and landslides in hilly areas.

## 1. Introduction

Land subsidence is the decline in land surface that is experienced by many cities in Indonesia and in 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 [1]. In western Indonesia, it was analysed for 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 it is due to natural gas extraction and in Sidoarjo due to the discharge of the mud from the soil [2]. Land subsidence in urban areas is usually caused by a combination of excessive extraction of groundwater, the natural consolidation of alluvium soils, construction costs (i.e. high compressibility soil settlement), and sometimes tectonic activity.

The same phenomenon can occur in Bandar Lampung, due to the rapid changes of land use, the increasing exploitation of ground-water and the activity of the Panjang-Lampung Fault that crosses the city. To view the phenomenon, we examine it using DInSAR with the SBAS algorithm.



## 2. DInSAR-SBAS

In the study of land subsidence in an area, 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.

InSAR is a very powerful technique for detecting deformations at a point in the LOS direction occurring between two SAR acquisitions that lead to a phase displacement ( $\delta\phi^{disp}$ ). DInSAR technique has a deficiency that is still having the influence of the atmosphere and still having the influence of phase components due to topography and due to flattening imperfect [3]. 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.

## 3. 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). 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 coherence factor ( $C_{temp}$ ). So by analyzing the value of  $C_{temp}$  (figure 1(a)), it can be known that the pixel has reliable information, which is generally shown in the threshold value (generally  $> 0.7$ ) [3]).

**Table 1.** SAR dataset.

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

Based on figure 1(a), 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  $C_{temp}$  is 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 [3]:

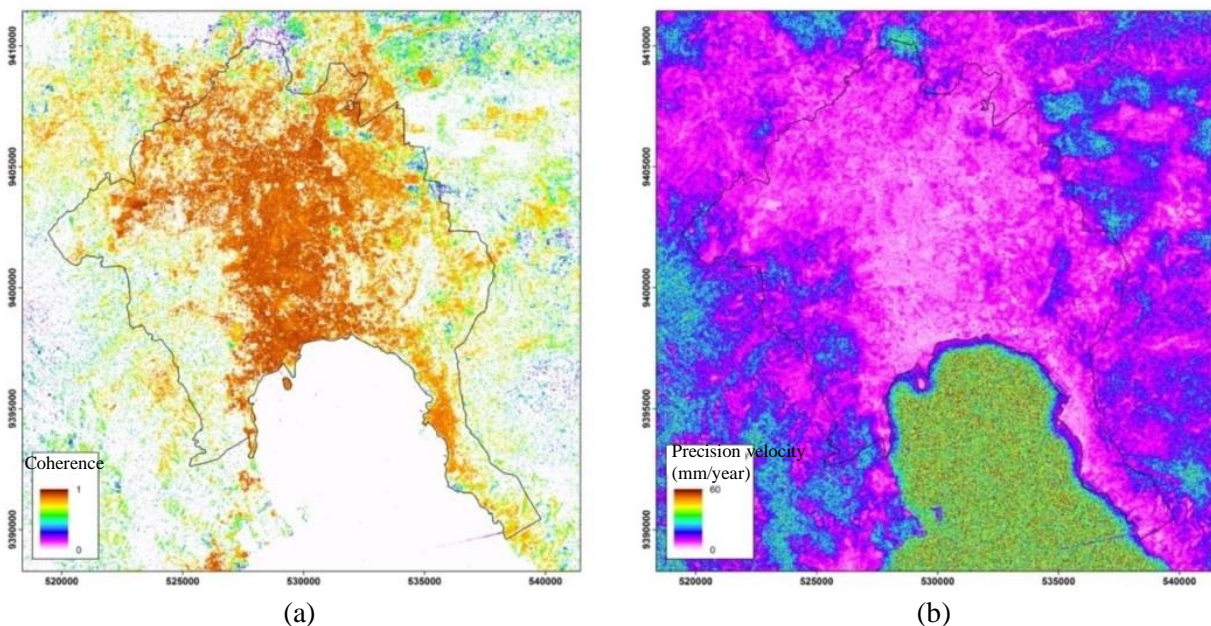
$$\sigma = \sqrt{\frac{1-\gamma^2}{2\gamma^2}} \frac{\lambda}{4\pi} \quad (1)$$

where  $\sigma$  is the measurement accuracy,  $\gamma$  is interferometric coherence, and  $\lambda$  is the wavelength used.

Based on the measurement accuracy estimation ( $\sigma$ ), the value of  $\sigma$  (figure 1(b)) tends to be inversely proportional to the  $C_{temp}$  value (figure 1(a)), since the value of  $\sigma$  is calculated based on the value of  $C_{temp}$ .

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

As for urban areas dominated by buildings and highways, the value of  $\sigma$  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.



**Figure 1.** (a) Temporal coherence map and (b) Precision velocity map.

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 nonparametric 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 2(b)). The result of calculation of Chi Square test on the result of this research is shown in chi square map in figure 2.

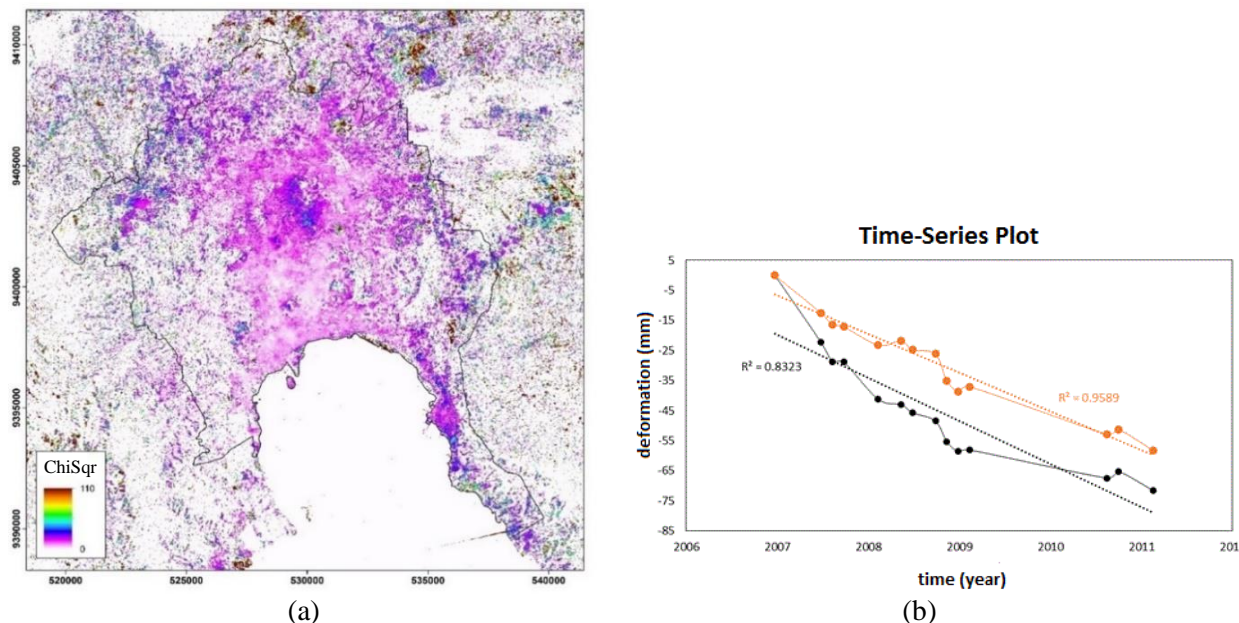
The value of Chi Square of the linear inversion model (figure 2(a)) is quite low in average value indicating that the fitting between the linear regression model chosen in the inversion process with the time-series data is quite good, although in some regions especially the high subsidence rate tends to have a high value of Chi Square because the trend of time-series data in the area tends to be non-linear (parabola). However, since the area with high Chi Square is not very dominant, the linear inversion model is still considered to be relevance enough to represent the deformation velocity in this study.

#### 4. Analysis and Interpretation

The result of SAR data processing using SBAS technique in this research produces information about deformation speed in Line of Sight (LOS) direction in Bandar Lampung City (figure 3) with data resolution of  $20 \times 20$  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 3 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).



The deformation velocity in the LOS direction has a positive value (green colour scale) to represent the relative up end deformation and the negative LOS velocity (red colour 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 ( $<10 \text{ km}^2$ ) in coastal area of Lampung Bay and Kemiling District, and local ( $10 - 100 \text{ km}^2$ ) in Eastern part of Bandar Lampung City, that is in area East Tanjung Karang.

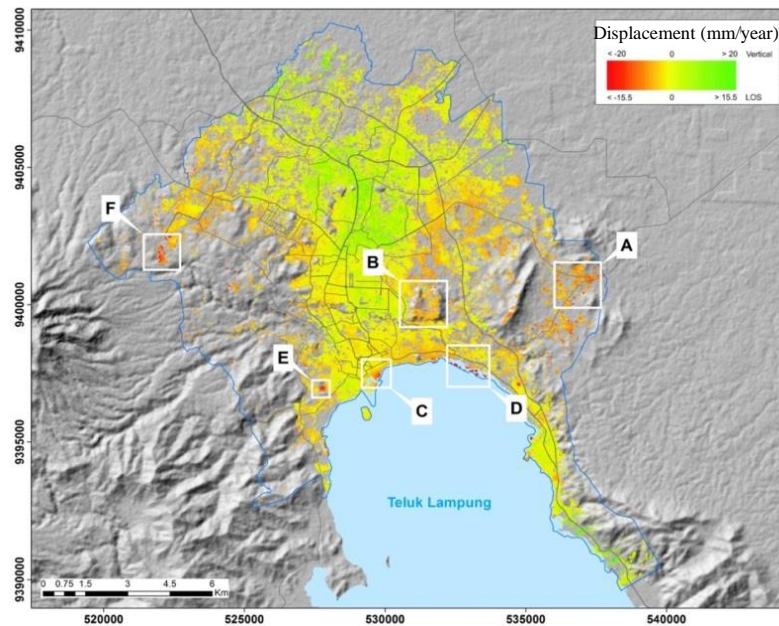


**Figure 2.** Chi Square map (a) Example of time-series data from two point adjacent to identical subsidence rate, but with very different Chi Square values. The black line is a time-series with a large Chi Square value (b).

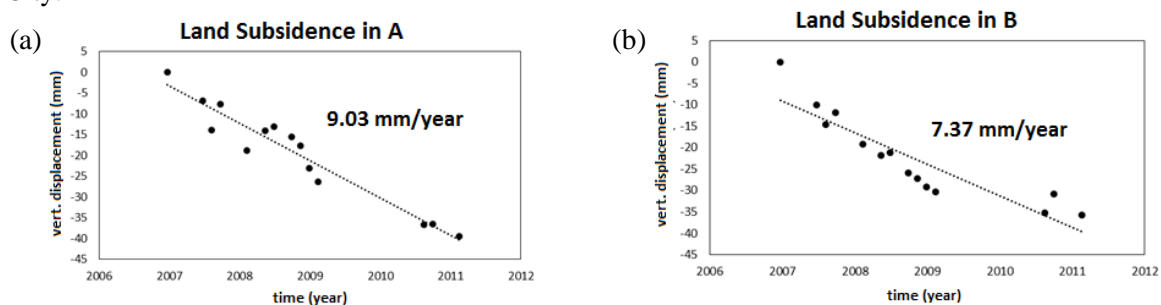
For the analysis process in this study, two approaches are used, the first to investigate the indication of land subsidence on a regional scale, by identifying areas that have high indication of land degradation based on the measurement of SBAS. Further analytics were conducted on a smaller scale (local) 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 were done to indicate land subsidence (mean  $> 5 \text{ mm/year}$  in the area  $200 \times 200$  metres) which is expected to represent the cause factors and the pattern of land subsidence according to Chaussard [2] as depicted in figure 3.

The result of observation in the A area (figure 3) shows the area indicated to land subsidence with an average speed of  $9 \text{ mm/year}$ , in Campang Raya Village. Graph of land subsidence is shown in figure 4(a).

The process of land subsidence in the 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. The process of land subsidence in B area which is the area of Camang Mount (figure 4(b)), which on average undergoes a decrease of  $7.4 \text{ mm/year}$ . In addition to this, there is also intensive land conversion at the peak of Camang Mount into a luxury residential. Decreased ground level is possible although in fact Camang Mount 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 [2].



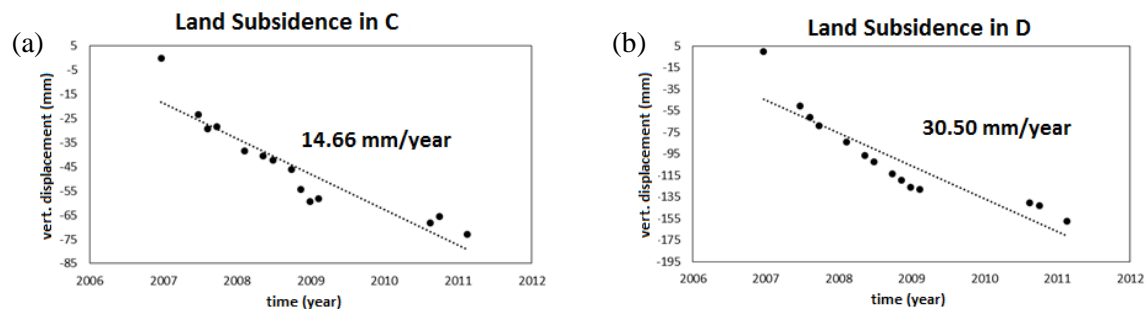
**Figure 3.** The location on the indicated area has subsidence more than 5 mm/year in Bandar Lampung City.



**Figure 4.** The land subsidence in (a) Campang Raya Village (industrial area) and (b) B area (Camang Mount and surrounding area).

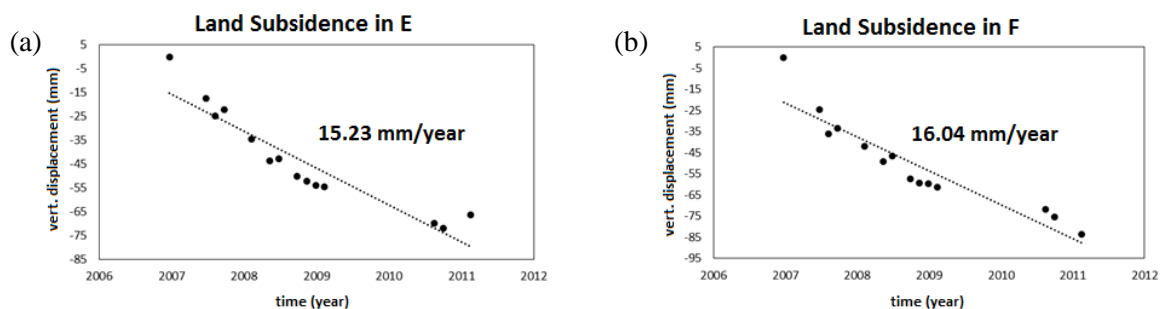
In C area, the land subsidence is detected in densely populated areas in Pasar Kangkung, South of Teluk Betung (figure 5(a)), with a characterized spatial pattern of less than 10 km<sup>2</sup> (patchy). This area indicates a decrease in ground level with an average speed of 14.7 mm/yr. The D area is 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 5(b).

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, it was 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 15.23 mm/year (figure 6(a)). Based on observations in the field, this area has morphology of syncline (valley) which is located between three hills and the northern part is a swamp, while in the south stands a residential area. 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.



**Figure 5.** The land subsidence in (a) C area (Pasar Kangkung, South of Teluk Betung) and (b) D area (Sukaraja reclamation area).

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 16.04 mm/yr which is shown in figure 6(b). 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 expanding when moist/wet, and then shrinking when dries (volumetric change).



**Figure 6.** The land subsidence in (a) E area (Bakung area) and (b) F area (Beringin Raya, Kemiling).

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

Location	Average vert. rate (mm/year)	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 residential	✓	Industrial water extraction and loading structure
Camang Mount (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 services	✓	Water extraction by residence and industry
Reclamation Area, 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

The results of the analytics for the six regions of 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 of lands 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.

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 Tanjung Karang and Kedaton areas with high population densities are not indicated to decrease the land surface. Based on the previous statement and if we look at the pattern in figure 5 then it is suspected that the Central of Tanjung Karang area and Kedaton may have already experienced consolidation as it were 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 [1], which states that land subsidence due to reclamation, construction and agricultural activities is limited to the first twenty years or directly after land conversion.

## 5. Conclusion

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 millimetres. 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 of 0.06 mm/year with trend which tends 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 one is in Sukaraja ( $> 30$  mm/year).
3. Subsidence with a speed of more than 5 mm/year spatially has two patterns, namely patchy ( $< 10$  km<sup>2</sup>) on the coastal area of Lampung Bay and Kemiling District, and local (10 - 100 km<sup>2</sup>) 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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