LAND SUBSIDENCE ANALYSIS OBSERVED BY PS-INSAR METHOD IN SOUTHERN PART OF BALI, INDONESIA (A CASE STUDY OF DENPASAR AND BADUNG AREA)

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ABSTRACT

The utilization of groundwater unwise leads to problems for the life of sentient beings. The majority of environmental damage, mainly by groundwater utilization, is done or caused by human activities. The land subsidence, drought, seawater intrusion are some examples of damage caused by groundwater utilization unwise. This research aims to estimate land subsidence in southern Bali and analyze groundwater level reduction with land subsidence. The PS-InSAR technique to monitor land subsidence has been carried out in several regions in Indonesia and other countries. In this study, 38 images of Sentine1-1 taken from February 2015 to December 2018 are used to analyze the PS-InSAR technique. Land subsidence is found in Denpasar Utara district and Kerobokan district with deformation in -8 mm to -19 mm and velocity up to -5 mm/year. The utilization of groundwater causing land subsidence in Southern Bali is no significant relationship with coefficient correlation 0,16 and influenced only 2,7%. Limited groundwater data also influences the correlation between groundwater utilization and the occurrence of land subsidence.

Keywords: Land Subsidence; Sentinel-1A; PS-InSAR; Southern Bali.

1. INTRODUCTION

The utilization of groundwater unwise leads to problems for the life of sentient beings. The majority of environmental damage, mainly by groundwater utilization, is done or caused by human activities. The land subsidence, drought, seawater intrusion are some examples of damage caused by groundwater utilization unwise. Subsidence areas are usually located where population and urban activity are developed (Suprabadevi, 2012a).

Southern Bali is the area where the majority of tourism activities are located in the area. With the development of tourism activities in Southern Bali, tourism accommodation in the area such as hotels and restaurants also proliferate. The regions included in the southern Bali area Denpasar, Kuta, Seminyak, Canggu, Kedonganan, Jimbaran, Ungasan, Uluwatu, and Nusa Dua. With the abundance of groundwater utilization in southern Southern Bali, the enormous potential of environmental damage can occur, especially land subsidence.

Sentinel-1 is an image product released by the European Space Agency (ESA), which can be accessed free of charge. The advantage of this image is that it has several spatial resolution options according to research needs. In this study, the spatial resolution used is the Interferometric Wide Swath (I.W.) mode with a size of 5x 20 m.

The temporal resolution of this image every 12 days. The PS-InSAR technique to monitor land subsidence has been carried out in several regions in Indonesia and other countries. This technique is the development of D-InSAR, which can also calculate an area's deformation. However, this D-InSAR technique's drawback is the large amount of ambiguity generated by the atmosphere due to temporal and geometrical decoration. PS-InSAR uses multitemporal data that can produce outstanding coherence values so that atmospheric noise can be eliminated. This technique can measure deformations up to millimeters (Ferreti, 2000b).

This research aims to estimate the land subsidence in Southern Bali and analyze groundwater reduction with land subsidence. Thirty-eight images of Sentinel-1 were used and processed using the PS-InSAR technique. Finally, the occurrence of land subsidence can be detected.

2. METHODOLOGY

2.1 Research Location

The research locations are located in Southern Bali, covering Denpasar and Badung Regency (Figure 1) located at 8^o 15'28"-8^o 50'19" S and 115^o 05'38"-115^o 17'06" E with an area of 547,87 km^2. Denpasar City and some of the Badung Regency areas are included in the Southern Bali area. Denpasar City and some area in Badung Regency like Kuta, Nusa Dua, Jimbaran, and Kedonganan is lowland area with a height of 0-5 meters from sea level. The few areas in Southern Badung Regency are higher areas with altitudes of up to 750 meters above sea level.

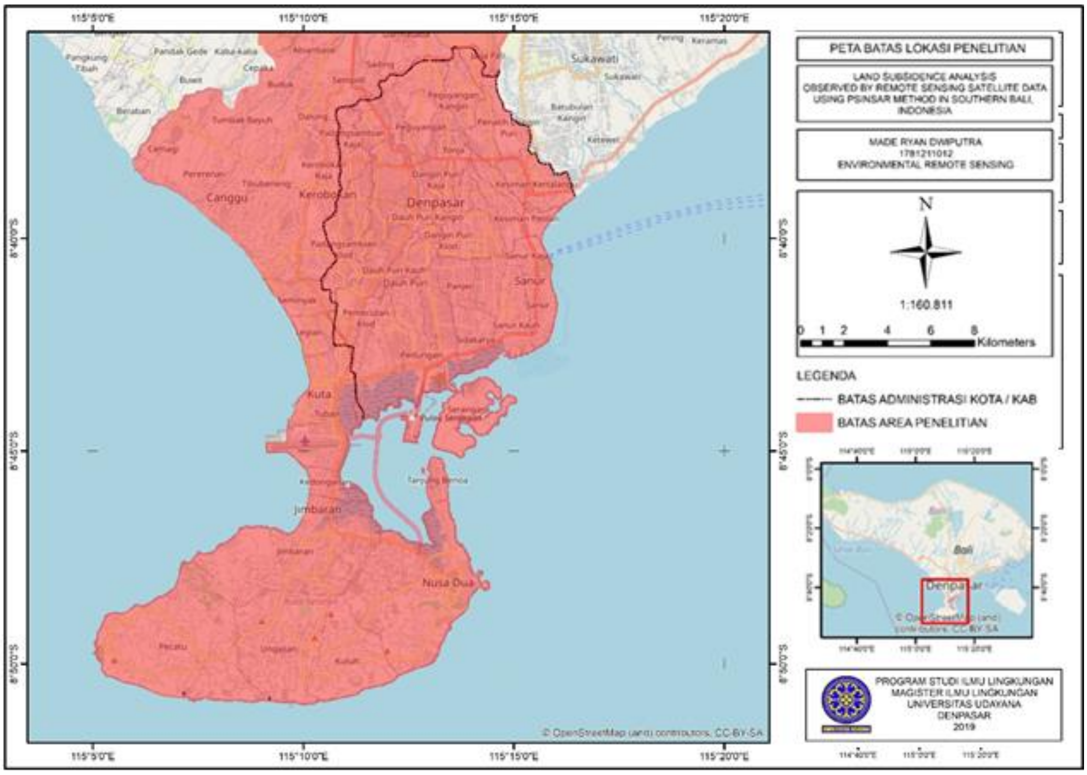

Figure 1.
Research Location

2.2 Outline PS-InSAR

Persistent Scatterer Interferometry (PSI) is one technique representing a specific class of Differential Interferometry Synthetic Aperture Radar (D-InSAR). This technique is a time series analysis and use for detecting the slow and long-term surface deformation. At the interferogram stage in D-InSAR, there are many shortcomings in the decorrelation of spatial, temporal, and atmospheric phases. Moreover, this PS-InSAR technique can slightly overcome problems. PS-InSAR directly influences the interferogram and time series analysis. For analytical purposes, this method uses coherent radar targets that can be distinguished clearly in all images and do not vary in their properties (Ferreti, 2001c). The total phase (ϕ_x^k) equation is a general equation that used in interferometry techniques. The P.S. algorithm is made to reduce the limitation of the D-InSAR technique. This algorithm separates the different phase contributions (deformation, topographic error, APS (Atmospheric Phase Screen), and decorrelation noise).

$$\phi_x^k = W\{\phi_{x,topo}^k + \phi_{x,defo}^k + \phi_{x,atmo}^k + \phi_{x,noise}^k\} \quad (1)$$

$W\{*\}$ is the wrapping operator. Where $\phi_{x,topo}^k$ is the phase due to inaccuracy and error of the reference DEM or the high of the reflection object above the surface, as in the case object like a building or rock. $\phi_{x,defo}^k$ is the phase component due to the displacement of the point in time. $\phi_{x,atmo}^k$ is the phase due to the atmospheric medium at the time of the acquisition. The error or phase noise is $\phi_{x,noise}^k$.

2.3 Data Collection and Data Processing

This research used 38 Sentinel-1 images to conduct PS-InSAR analysis, Sentinel-1A level 1 Single Look Complex (SLC) data Bali area has taken on 38 different acquisition dates, i.e., 28 February 2015 and 27 December 2018 with specification I.W. mode beam, path: 32, frame: 620, and flight direction is descending.

Table 1. Specification of Sentinel-1 Satellite Imagery

Satellite Name	Sentinel-1
Sensor Name	SAR-C SAR
Operation Mode	I.W.
Observation Date	28 February 2015- 27 December 2018
Flight Direction	Descending
Path	32
Frame	620
Number of Images	38
Polarization	VV+VH

2.4 Data Analysis

There are several steps in the data analysis, namely Pre-Processing, Preliminary Analysis, Preliminary Geocoding, and Data Processing (Figure 2). In the pe-processing step, master data was chosen by minimum normal baseline and shorter temporal baseline. Only one image can be master data, and the other images become slave data. All the slave's data must be co-registered to the master data. Preliminary analysis is used to generate the reflectivity map, and preliminary geocoding is used for correcting the initial orbit offset. After the reflectivity map and correcting orbit generated, data processing is carried out to produce the interferogram. With the amount of interferogram data used, there will be an atmospheric disturbance. In multi-image InSAR processing, there is an Atmosphere Phase Screen (APS) estimation process. This is a process to reduce the effects of atmospheric interference. In the PS-InSAR technique, this atmospheric phase is removed so that the deformation values obtained are more accurate and even reach sub-millimeters. A multi-temporal analysis is carried out, beginning with determining the parameters of the sparse point. This parameter determination uses the range of results from integrated velocity and integrated residual height. After the parameters are determined, then sparse point processing is performed. This processing will produce velocity and cumulative displacement after the effects of the atmosphere are removed. This result is the actual cumulative displacement and velocity.

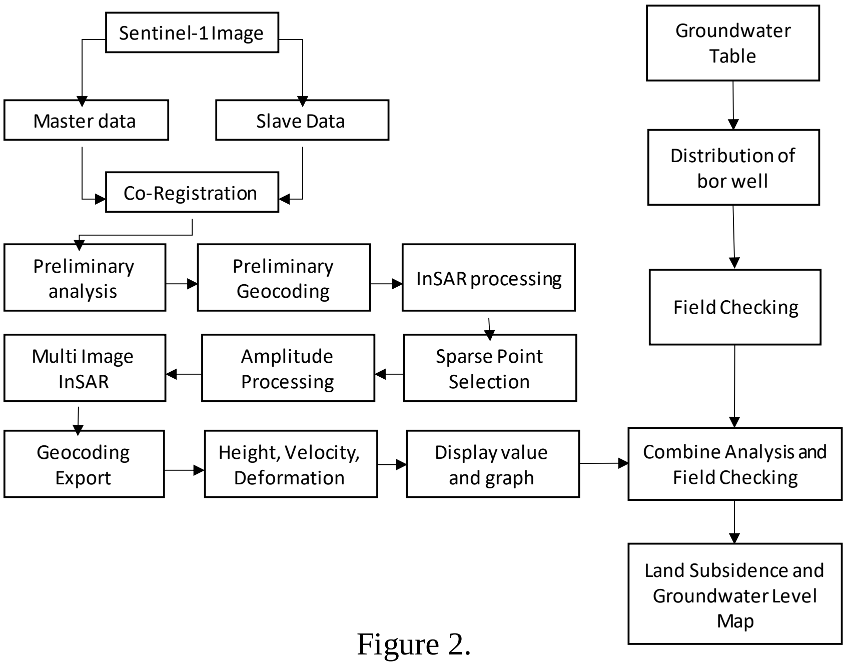

Figure 2.
Analysis of Procedure

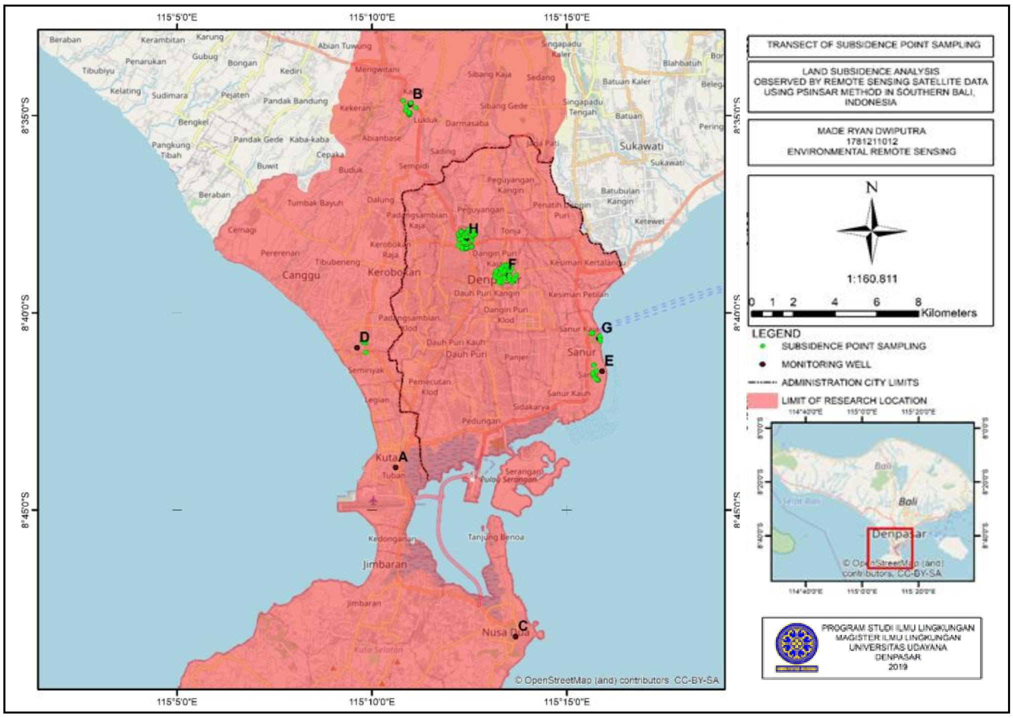

Figure 3.
Subsidence Point Sampling in around monitoring well

After obtaining the value of land subsidence from software calculations, a correlation is made to groundwater subsidence value at the monitoring well location. The obstacle faced is that we cannot control the position of the P.S. point so that it is precisely at the monitoring well point. A transect is made to determine the value of land subsidence at the monitoring well from land subsidence value around the monitoring well area. Buffers can be made as needed. The narrower the buffer distance, the more detailed data obtained will be. After making a buffer, the subsidence point sampling and the value of land subsidence around the monitoring well location are obtained (Figure 3).

The value is then extracted, and the correlation coefficient is calculated for the groundwater subsidence value using the Pearson equation. If there is a decrease in the groundwater level at the drill point and followed by land subsidence, the resulting correlation is positive. The next step is calculating the groundwater level decrease on the land subsidence by squaring the correlation coefficient's value. The last step is calculating the relationship's significance by doing a T-test to know probability (P) value.

3. RESULT AND DISCUSSION

3.1 Groundwater Condition on South Bali

Monitoring wells in the Regency of Badung and the Municipality of Denpasar each amounted to 4 units. Location monitoring wells for Badung Regency are in Wisma Bima Cottages Kuta with code A, Kapal Mengwi Hospital with code B, BTDC Nusa Dua with code C and B-Villas Kerobokan with code D. Whereas for Denpasar Municipality, monitoring wells are in Werdha Pura Hotel with code E, Gor Ngurah Rai with code F, Bali Beach Hotel Sanur with code G and UPT Ubung Public Service Equipment with code H. the monitoring well location on Table 2.

Table 2**.** Coordinate the location map of the well-monitored the province of Bali.

Longitude	Latitude	CODE	Location
299430.36	9034292	A	Bima Cottages, Kuta
300028.2	9051251	B	R.S. Kapal, Mengwi
305113.02	9026416	C	BTDC Nusa Dua
297585.24	9039870	D	B-Villas Kerobokan
309122.36	9038827	E	Hotel Werdha Pura
304554.57	9043304	F	Gor Ngurah Rai
308968.04	9040367	G	Bali Beach Hotel Sanur
302631.23	9044870	H	UPT Peralatan Ubung

The monitoring well data used in this study began in 2008 until 2018. However, there were several data constraints in 2014, 2016, and 2017 due to management changes so that the data in that year was not recorded properly. Based on the monitoring well data above, it is known that the groundwater level (from the ground) at each point varies greatly, as can be seen in Figure 5.

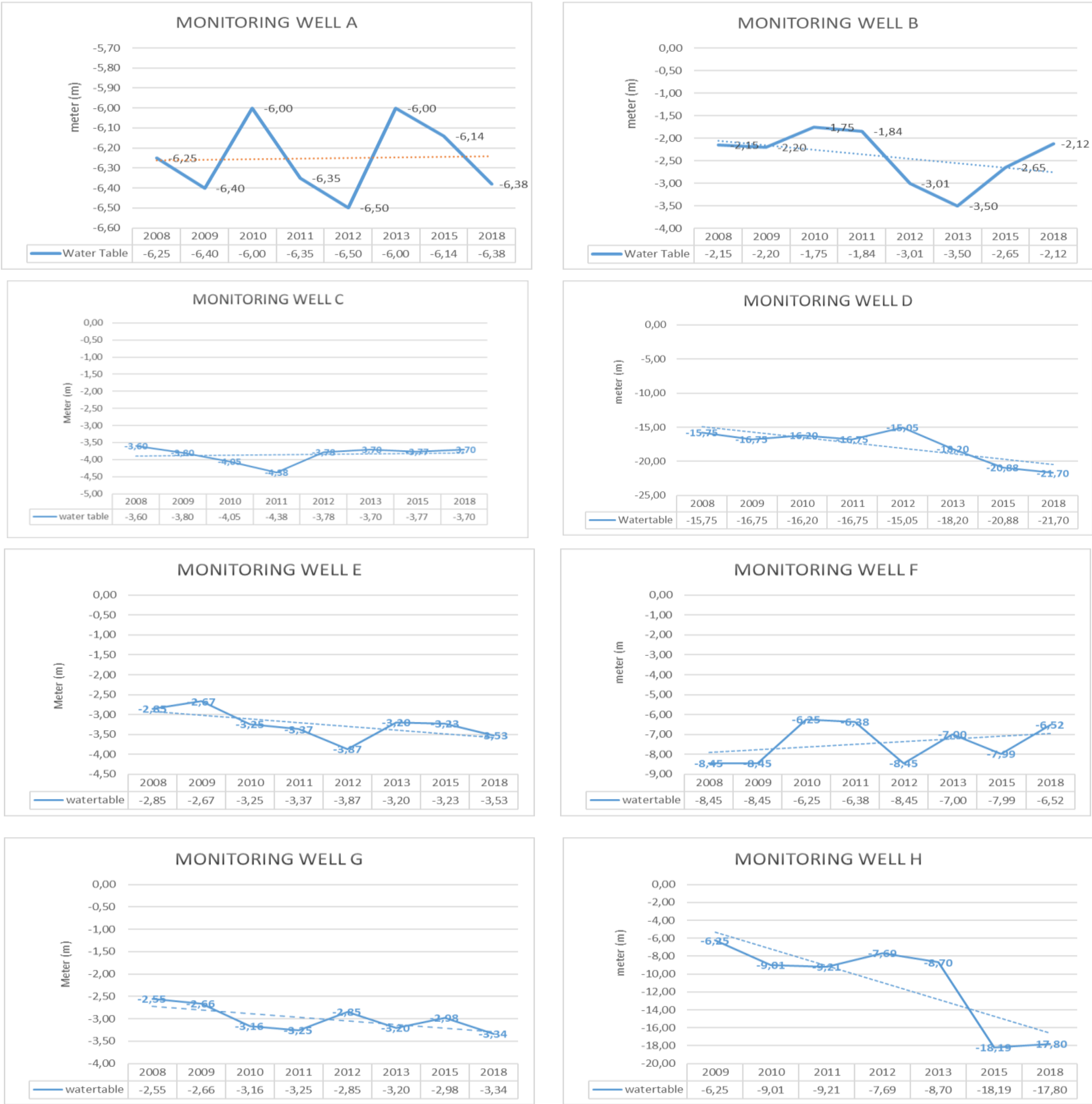

Figure 5.
Groundwater conditions in 8 locations

3.2 Land Subsidence

After all the processing in data analysis has been done, the resulting data is the value of cumulative displacement and velocity. Cumulative displacement is the value of the total displacement that has occurred from 2015 to 2018. In contrast, velocity is the speed of movement of the displacement. Cumulative displacement and velocity in this research are separated by five-category (Table 3).

Table 3. Categorized by Subsidence

Category	Range of Displacement (mm)	Range of Velocity (mm/year)
I	-19.14 - -12.82	-5 - -3.34
II	-12.82 - -8.6	-3.34 - -2.24
III	-8.6 - -5.11	-2.24 - -1.33
IV	-5.11 - -1.38	-1.33 - -0.36
V	-1.37 - +17.87	-0.36 - +4.67

Cumulative displacement Category I is symbolized with red color, Category II symbolizes yellow color, and the majority found in Denpasar Utara district (Ubung, Peguyangan). Some of this Category also found in Kerobokan district, Badung Regency. Category III symbolized with green color, Category IV symbolized with light blue color, and Category V symbolized with blue color (Figure 7). This Category was found in Denpasar Barat district (Dauh puri, Padangsambian) and also in Kerobokan district. Figure 6 shows the effect of land subsidence in Kerobokan and Ubung district.

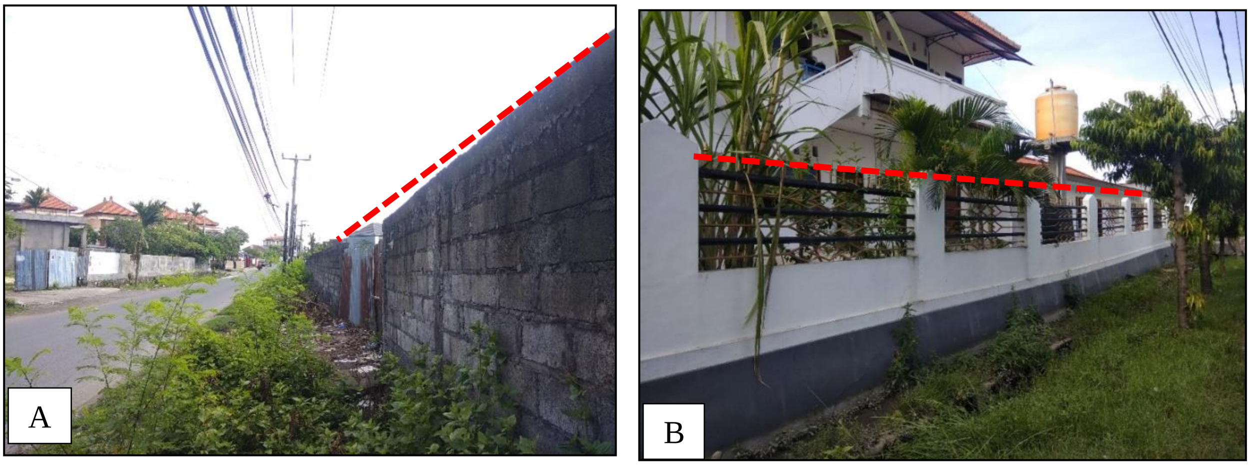

Figure 6.
Subsidence indication in Kerobokan district category IV, (B) Subsidence indication in Ubung district category I

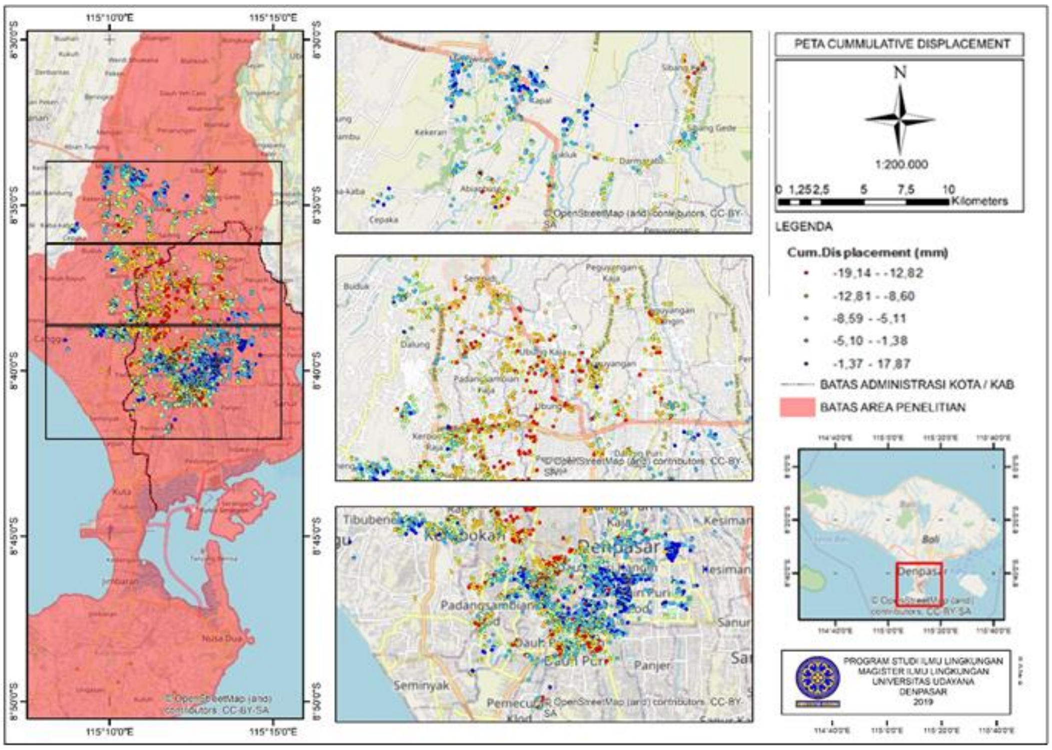

Figure 7.

Cumulative Displacement Map

Velocity category I and category II majority found in Denpasar Utara district (Ubung and Peguyangan), Category III, Category IV, and Category V majority found in Denpasar Barat district (Dauh Puri and Padangsambian) and also spread to Tibubeneng and Kerobokan in north Badung, Badung Regency Figure 8.

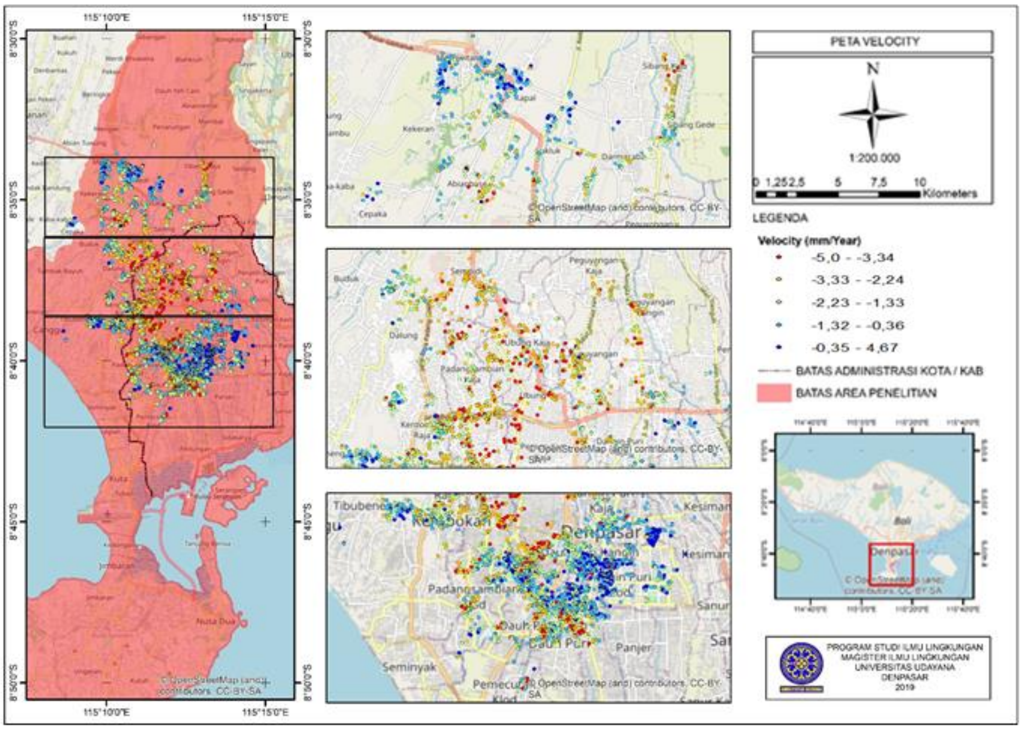

Figure 8.
Velocity Map Southern Bali, Indonesia

3.3 Relationship between groundwater level and land subsidence

Based on the calculation of the correlation coefficient using the Pearson equation, it is known that the correlation coefficient of the decrease in groundwater level to the occurrence of land subsidence is 0.164, with the magnitude of the influence of the decrease in groundwater level of 2.7%. The effect value of groundwater level reduction is calculated using the square of the correlation coefficient. As for the probability value, a value of 0.248 is obtained so that the effect of groundwater reduction on the occurrence of land subsidence is not significant for southern Bali.

3.4 Discussion

Based on the results, There was a decrease in groundwater level in several monitoring wells in the southern Bali area. Many factors cause groundwater level reduction, such as excessive groundwater extraction (Ashriyati, 2011d), reduced forest areas and open land as a recharge area due to changes in land use, and climate change that disrupt the hydrological cycle. Areas that experienced a significant decrease in groundwater level are the Ubung area in Denpasar City with a considerable decrease of 11.55 meters, and the Kerobokan area in Badung Regency with a decrease of 5.95 meters. When linked between excessive groundwater uptake and changes in land use, in Denpasar City, there has been a reduction in rice fields by 1,694 Ha and an increase in residential areas by 1,735 Ha (Supardan, 2018e). Likewise, in the Badung area, especially in North Kuta (Kerobokan included), there has been a change in Subak land to become a non-agricultural area of 538.88 Ha within five years 2012 to 2017

(Lanya, 2017f). Land subsidence also occurs in the South Bali area, especially in the Denpasar area. On the displacement map (Figure 7) and velocity map (Figure 8), the Category I and Category II can be seen that the areas of Ubung, Ubung Kaja, Peguyangan Kaja, and Peguyangan. However, in the Badung area, very few areas are included in the criteria of being a Persistent Scatterer, where the coherence value owned <0.75. The coherence value needed to be P.S. is >0.75 (Ferreti, 2001). Changes and developments that are quite massive, especially in tourism, caused many areas that changed their function and shape from the rice field into tourism accommodation (Windhu Sanjaya, 2019g). This causes the value of coherence to decrease. The Denpasar area, especially in Ubung, the development and change not as fast and significant as in Badung Regency, so that the determination of P.S. still meets the criteria.

Apart from being caused by excessive groundwater utilization, other factors that influence land subsidence are geological conditions, soil and rock types, and building loads. In the study area, land subsidence was detected with a maximum deformation of -19 mm in 3 years. Compared with the land subsidence in other areas such as Jakarta, which reached 22cm (Bayuaji, 2010h), this decline is relatively low. However, when viewed from the rock characteristics in the study area and the Jakarta area, it is very different. The constituent rocks in the study area are tuff and lahar. Tuff rock and lava are products of volcanic activity and belong to the pyroclastic type. Whereas in the Jakarta area, the rocks are dominated by alluvial deposits and alluvial fans' coastal deposits. In general, volcanic rocks are more stable than alluvial deposits. In general, alluvial deposits have not undergone good compacting because new deposition continues to occur. Besides, when viewed from the building load, in the study area, the building height is limited to a maximum of 15 meters (Perda No. 16/2009), while in the Jakarta area, the building height can exceed 15 m. With a large building load and poorly compacted land conditions, land subsidence may be more generous in Jakarta.

Based on the calculation of correlation, influence, and significance, the decrease in groundwater level to land subsidence in South Bali is not significant even though there is a correlation and groundwater influence. This is due to the lack of monitoring well data held by Bali's province, especially in areas that have experienced significant land changes and population growth. Besides, additional drill well data in several locations in Denpasar and Badung are not very good in terms of data records, so it is complicated to be used as additional data to determine the decrease in groundwater level in other areas not covered by monitoring wells in Bali Province.

4. CONCLUSION

Land subsidence occurred in southern Bali, especially in the Denpasar Area and part of the Badung area. The maximum deformation was -19mm in 3 years, and the maximum velocity was -5 mm/year in 3 years. The relationship of groundwater level reduction and land subsidence in southern Bali is not significant, with the value of probability (P) is >0,05. However, there is a correlation between them with a coefficient correlation of 0,164, and groundwater level reduction influenced the land subsidence 2,7%.

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