Population condition analysis of Jakarta land deformation area

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Abstract. Jakarta is located in the North West area of West Java Province which geographically positioned on 106º33'00"-107º00'00"BT and 5º48'30"-6º24'00"LS. Land subsidence has occurred in several types of landuse such as trade, industrial and settlement area of the urban area of Jakarta. The land subsidence disaster is one of the consequences of building and road construction in Jakarta. This is caused by massive groundwater utilization and failure in landuse planning. This study aim to analyze the population density and settlement pattern in the urban area of Jakarta which the occurrence of land subsidence has been detected. It is important to understand landuse and settlement planning processes in the area which land subsidence occurred. Detection of land subsidence distribution become a necessary parameter in landuse planning. While the land subsidence area detected using Differential Synthetic Aperture Radar (DInSAR) method. The result shows the area which land subsidence occurred has a very high population density and clustered and linear settlement pattern. This area is mainly used as industrial, trade, and settlement.

1. Introduction
Special capital district of Jakarta is located geographically between 106º33’00”-107º00’00”BT dan 5º48’30”-6º24’00”LS. According to the topographic characteristic of Jakarta, it shows Jakarta has a flat relief in the north and gentle slope in the south with slope between 0 and 2. The south part of Jakarta has a mean elevation of 60 above sea level, while the north part about 20 above sea level. The topographic characteristic map of Jakarta (figure 1). This sediment tends to be younger than the river sediment.

The study area has a tropical climate with average annual precipitation of 1.755 mm or about 146 mm monthly. Jakarta increased in population very fast as the city develops. According to the 2011 population census, the population density of Jakarta reached 15,400 for each square kilometer. In six districts in Jakarta, population density ranged from 2.112 to 23.312 inhabitants per square kilometer.
This phenomenon of land subsidence is one of consequences of urban development in Jakarta. In 1926, a Dutch surveyor estimated the land level lowering in the center of Jakarta city. The measurement using leveling method has been done since 1982 to 1999 by the scientist. The measurement of lowering land level using GPS has also been held at various point. The study of land deformation using radar image satellite data has begun since 2010 [1][2]. This study will apply DinSAR method to determine land subsidence area with TerraSAR-X data.

Jakarta is one of the biggest city in Indonesia and plays an important role in Indonesia central government and economic activities. The characteristics of Jakarta often identified as high population density, high economic activities, and center of the government. According to the statistical bureau of Indonesia, per capita income of Jakarta is about four times average national per capita income. Jakarta role as the center of governance and economy in Indonesia has become a traction for people to come and settle. On the other side, Jakarta constantly declines in physical geographic condition. The flood in Jakarta city was occur in the rainy season intensively. At the same, coastal flood occur in the north part of the city. Land subsidence has been suspected as causes of flooding in Jakarta area. The land subsidence in Jakarta caused by the increase in population density and settlement area [3][4]. Hence, the aim of this study is to analyze population density and settlement pattern in Jakarta, particularly in the area where the occurrence of land subsidence detected.

Population density is proportion between specific number of population and area. Population density has a positive correlation to carrying capacity of a certain area. Population and economic growth constantly require space expansion. On the other side, space is stagnant but the composition, both in physical, economic, and social, is dynamic as the space utilization change. The change of space utilization without considering the geobiophysical factors may cause man-made disaster and space usage efficiency may be in vain. Jakarta is one of the biggest city in Indonesia with 10,187,595 population in 2011 [5]. Jakarta, as a capital city of Indonesia, is a province which plays an important role in both economic and governance. Urban development followed by increase in population in Jakarta become a trigger to environmental problem in the last decade [6].

Figure 1. Intensity map of Jakarta City.
2011, settlement is a part of settled environment which consist of more than one house provided with public infrastructure. Settlement also has other function to support activities in both urban and rural area. Settlement is a primary need in human life. It ranked third in human needs (foods, clothing, settlements, health, and education). It may be concluded that settlement is has a central role in human needs. Hence, the improvement of settlement quality will also improve living quality standard. Nowadays, settlement is not only to provide safety, but also include drinking water provision, lighting, transportation, education, etc.

Land subsidence has become an attention to both government and citizen in some big cities in Indonesia. This problem mostly caused by factors such as exploitation of groundwater exceeding its capacity and natural condition where the land become compressed [7]. Land subsidence may trigger other problems such as change in topographic gradient, land surface damage, and decrease of groundwater aquifer capacity. In Jakarta, land subsidence becomes an important factor which cause flood in January, 2003 [8]. Thus, detection and analysis of land subsidence in Jakarta become important to support flood mitigation so that Jakarta has a better development planning. This land subsidence phenomenon, and also monitoring of landuse change in Indonesia, have already been studied using ALOS PALSAR data with 10 m spatial resolution [9]. This study was using TerraSarX which provide higher spatial resolution of 1-3 meters; DLR Cluster Applied Remote Sensing, 2006. TerraSAR-X is using short wave at 3.1 cm and having highest spatial resolution between all SAR data. This research is aimed to understand the population density in the subsided land area in Jakarta, the analysis of the settlement and landuse distribution pattern in land deformation area, and create recommendation of spatial planning in the land subsidence area in Jakarta.

2. Methods
This study is using a descriptive statistic as illustrating the object of study through actual sample or population data. Using this method, this study will describe characteristic of study area according to the actual condition, particularly the population density and settlement pattern. Hence, it can identify and analyze the correlation between land subsidence to settlement pattern and population density.

2.1. Population density
Population density in the land subsidence area calculated according to number of population recorded in the Indonesia Bureau of Statistics. Residential area calculated according to satellite imagery interpretation in the land subsidence area.

Prediction of demographic data requires high resolution satellite imagery, for instance high resolution aerial photography or IKONOS imagery which have spatial resolution of 1 meter. This resolution means terrestrial object with size of 1 meter or bigger will be able to be shown in the imagery. If we can detect individual settlement, so we can count the numbers of resident in each house according to the population density information. The formula to calculate population density is mentioned below:

\[
\text{Population Density} = \frac{\text{Number of Population}}{\text{Area}}
\]

2.2. Land subsidence
Differential Interferometry Synthetic Aperture Radar (DInSAR) is a technique in satellite imagery data processing to know the lowering of land surface elevation by calculating accuracy and resolution. Benefit of this method is able to detect a wide area, whereas GPS method unable to cover research area.

The first step to do in DInSAR method is analysing local topographic condition using InSAR. Land elevation difference calculated by comparing two Synthetic Aperture Radar imagery with temporally different acquisition time. The difference between land elevation detected by comparison of temporally different images. Both radar data overlaid point to point in each location to create
interferogram map which indicates lowering land surface elevation. Phase difference of the result of interferogram calculated using equation mentioned below [10] :

\[ \phi_{\text{int}} = \phi_{\text{disp}} + \phi_{\text{topo}} + \phi_{\text{atm}} + \phi_{\text{noise}} + \phi_{\text{flat}} \]  

Where \( \phi_{\text{disp}} \) is lowering land surface phase, \( \phi_{\text{topo}} \) is changing in elevation according to topography, \( \phi_{\text{atm}} \) according to atmospheric effect, \( \phi_{\text{noise}} \) is noise effect of the device, \( \phi_{\text{flat}} \) is error associated phase by assumption the earth is a flat surface. Extraction process of phase difference on land subsidence, topographic, earth surface flat can be eliminated using accurate DEM data. This study used TerraSAR-X DInSAR of the years of 2010-2015. Validation process calculated using analysis of statistic calculation result between DInSAR data and GPS data. The result of this study is to analysis of population density in the land subsidence area. The flowchart of research design (figure 2).

![Research flowchart.](image)

3. Result and Discussion

3.1. Land Subsidence Analysis

Observation on land subsidence in Jakarta focuses on three observation point, which is Pantai Mutiara (P1), Cengkareng (P2), and Cakung (P3). Result of TerraSAR-X imagery data processing shows that the most severe land subsidence occurs in Cengkareng (P2) with 5.6 Km² area and 17.5 cm/years. Table 1 shows measurement result of land subsidence.
The effect of land subsidence in Cengkareng (P2) is the most distinctive among the others, as shown in figure 3. Cengkareng is located in West Jakarta with an extensive area of 27.9 Km². The lowering land elevation surface rate in Cengkareng reaches 17.5 cm/years. This is mostly influenced by human activity in this area such as building construction and groundwater extraction. According to 2014 statistics data, the population density in Cengkareng reaches 19363 Km². This area is characterized with landuse of settlement (1.10 ha), Industrial area (97.25 ha), business area (328.92 ha), Agriculture (118.64 ha), Park (31.90 ha), empty land (619.12 ha) and the others (715.57 ha). Table 1 described the prediction of land subsidence rate in Cengkareng. The result is vary between 10.0 cm/years to 17.5 cm/years.

The maximum subsidence according to DInSAR calculation result is ranged from 9.5 cm/years to 17.5cm/years. Figure 3 shows the most severe subsidence occurs in Cengkareng (P2) as shown in both, GPS and DInSAR calculation. According to the government report, the land subsidence phenomenon in Jakarta mostly caused by some factor such as exploitative groundwater usage, landuse change, land consolidation and alluvial construction building.

Table 1. Land Deformation Measurement Result.

| Point | Location       | Landuse                        | Land Subsidence Area (Km²) | Land Deformation Rate (cm/year) |
|-------|----------------|--------------------------------|----------------------------|---------------------------------|
| P1    | Pantai Mutiara | Settlement, Trade and Port     | 1.98                       | 10.95                           |
| P2    | Cengkareng     | Settlement                    | 5.75                       | 17.58                           |
| P3    | Cakung         | Industry and Settlement       | 0.94                       | 9.57                            |

Figure 3. Land deformation pattern mapping.
Figure 4. Land subsidence mapping.

Table 2. Average land deformation rate.

| Pair Number | Acquisition Date | Pantai Mutiara Subsidence Rate (cm/year) | Cengkareng Subsidence Rate (cm/year) | Cakung Subsidence Rate (cm/year) |
|-------------|------------------|-----------------------------------------|--------------------------------------|---------------------------------|
| 1           | 20100809         | 9.5                                     | 17.5                                 | 8.8                             |
| 2           | 20100809         | 8.5                                     | 11.5                                 | 9.2                             |
| 3           | 20100809         | 10.5                                    | 11.7                                 | 8.3                             |
| 4           | 20110613         | 9.3                                     | 10.0                                 | 7.7                             |
| 5           | 20110613         | 9.9                                     | 10.5                                 | 7.5                             |
| 6           | 20121214         | 10.9                                    | 11.8                                 | 9.5                             |

DInSAR analysis results in Cakung is shown in figure 4. The lowering rate of land surface elevation here is ranged 7.5-9.5 cm/years as shown in table 2. The area of subsidence in Cakung reaches 42.47 km² where the landuse in Cakung dominated by industrial activity. The biggest industrial area found in Pulogadung district, which established about 24,000 small and medium factories inside 6.86 km² area. (Jakarta Timur, 2010). According to 2010 population census, population density in Cakung reaches 11,919 inhabitant/km². The landuse dominated by settlement (45.27%) and industrial area (24.33%).

Landuse in PantaiMutiara (P1) characterized in elite settlement, business area, harbor, and resort area tourism. Cengkareng has a landuse of settlement area with more than 30,000 households, besides business and offices area. Cakung (P3) is the most extensive industrial area in Jakarta, including an area bigger than 10.33 km². DInSAR calculation result for each study area, which is P1 to P3 respectively (figure 4). The phenomenon of land subsidence, as expected, caused by the forming of alluvial geologic structure. Generally, lowering of land surface elevation occur in urban area of Jakarta and the estimation of land subsidence can be more accurate as temporal change. Some pairs result in noise coming from the atmosphere, but the other pairs have a distinctive result. The DInSAR result in PantaiMutiara (P1) indicate distinctive interference pattern in north west part, though the amount of the edge a bit different. The result varies between 8.5 to 10.9 cm/years. The highest rate is 10.9


3.2. Population Density Analysis

According to demographic statistics of Jakarta, the population density in Pantai Mutiara (P1), Cengkareng (P2), and Cakung (P3) is 8.635, 19.363, 11.919 inhabitants/km$^2$. Inhabitant of Jakarta increase every year. According to Indonesia Bureau of Statistic (BPS), in 2010, the population of Jakarta reaches 9.780.000. For each administrative area which is South Jakarta, East Jakarta and West Jakarta have the population of 2 million inhabitants. The requirement for population density in Central Jakarta and West Jakarta exceed 18.000 per square kilometer. The demographic composition of Jakarta dominated by productive population (15-64 years old) with proportion of 72.52% of the total population.

Theoretically, the population density of an area is proportional to land subsidence rate. The higher population density will accelerate the land subsidence. Population density is proportional to total population so that the increase in total population will directly impact the population density. An example of human activity which may induce land subsidence is groundwater overexploitation. Increase in population in an area will increase need in clean water. Indeed, the exploitation of groundwater has become a way to supply clean water.

According to 2016 statistical data Cakung divided into eight villages (urban communities). Among those urban communities, Penggilingan has the highest population density with 23.277 inhabitants per square kilometer (figure 7). While, the densest area in Penjaringan and Cengkareng subdistrict is Penjaringan urban village with 29.868 inhabitants per square kilometer and West Cengkareng 20.217 inhabitants per square kilometers respectively. Based on the population density, those area has the highest potential for the occurrence of Land Subsidence in each subdistrict.

### Table 3. Population in study area.

| District    | Population |
|-------------|------------|
| Penjaringan | 304,941    |
| Cengkareng | 498,130    |
| Cakung     | 484,517    |
Figure 5. Population density in Penjaringan (P1).

Figure 6. Population density in Cengkareng.
4. Conclusion
Land subsidence mapping using X-band of TerraSAR-X imagery has a higher accuracy when compared to L-band ALOS PALSAR imagery. The result of this study shows Cengkareng, Cakung, and Penjaringan subdistrict has a very high population density. Cengkareng has clustered, scattered, and linear settlement pattern covering 18.2 km$^2$ with the population density of 20.217 inhabitants per square kilometer. In Cakung, has the linear and clustered settlement pattern which covers 19.15 km$^2$ with population density of 23.277 inhabitants per square kilometer. While in Penjaringan, settlement has the clustered and linear pattern which cover 19.88 km$^2$ with population density of 29,868 inhabitants per square kilometer. Demographic problem and environment degradation are correlated each other. Environment degradation may disrupt natural resources balance and human life in macro scale. Furthermore, imbalance between population growth and natural resources quality may destruct human civilization. Hence, we need to plan wisely to ensure the sustainability and quality of environment. This concept attempts to balance population growth and their.

5. Acknowledgement
The authors would like to thank The World Academy of Sciences UNESCO, Center for Environmental Remote Sensing Chiba University and Faculty of Geography Gadjah Mada University for the support of this paper.
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