Evaluating Land Surface Changes of Makassar City Using DInSAR and Landsat Thematic Mapper Images

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Abstract: Urban growth has been a major issue in environmental monitoring and changes occurred on land surfaces have been monitored by applying remote sensing as well as ground measurement. Most major cities in the world have experienced land subsidence phenomena on some parts of them due to the load of development and modernization. Excessive extraction of groundwater for the needs of industry has led to the condition where the water table drops, and this can possibly trigger subsidence, as observed in Indonesian cities. In this study the authors have shown that the application of DInSAR (differential interferometric synthetic aperture radar) technique using Japanese Earth Resources Satellite-1 Synthetic Aperture Radar JERS-1 SAR data can reveal subsidence conditions in the studied Makassar city area. Landsat TM (thematic mapper) images were used to evaluate the change of land cover during the observation period of 1994-1999. Makassar is flat, covered mainly by alluvium deposit that is vulnerable to the load of constructions, and volcanic formations which is porous and will easily be degraded by groundwater extraction. It is found that mostly the subsidence has occurred in the western part of the city, including the industrial district, reclamation area, trading center area and the seaport area. The ground survey has indicated that high human activity exists in every point of subsidence. It is likely that various human activities such as ground water pumping and construction work should have affected the local subsidence phenomena in Makassar, as in the case of other large-scale cities in Indonesia.

Key words: DInSAR, JERS-1, surface changes, urban growth, Landsat TM.

1. Introduction

The impact of modernisation often appears as urbanization. It is natural that where a centre of civilization exists, the flow of development will gather therein. It is needed to study how one city grows by accommodating the impact of civilization and to examine if the growth is safely sustainable for the people occupying the area. As the number of population increases, more and more agricultural, shrub, and even swamp land areas are changed into industrial and construction areas, especially in rural areas surrounding the former city boundary. In addition to the increase in the usage of groundwater, such land cover changes can result in shortage of water supply in the hydrologic cycle. In urban areas, one of the particular concerns is the occurrence of land subsidence that will in turn cause flood. Makassar, the capital city of the South Sulawesi Province, in relation to this issue has been a target of urbanization since the old era.

Remote sensing methodologies on the other hand are useful for the study of land subsidence, as seen in their applications to some of the big cities worldwide [1-3]. One of the most recent studies is the one over China by Perissin and Wang in 2011 [4] using the advanced technique of PS InSAR (persistent scatterer InSAR). The recent advancement of remote sensing technology has made it possible to map detailed terrain conditions ranging from local, regional to global scale with specific use and accuracy. The SAR (synthetic aperture radar) sensor onboard JERS-1 satellite provides the ability to map the earth surface...
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topography and deformations independently of weather conditions despite any cloud cover or solar illumination. SAR records simultaneously the intensity and phase of the signal reflected from the surface.

The phase is related to the travel time of the radar pulse between the spacecraft and the ground. The interferometric combination can be used to derive DEMs (digital elevation models) for an area [5]. Various methods have been employed, with the latest methods using the DInSAR [6] and Permanent Scatterer InSAR [7]. Cities in Indonesia have been investigated using this technique was Jakarta [8, 9], Semarang [10, 11] and Bandung [12, 13]. The present paper evaluates the application of DInSAR technique by measuring the dimension of land subsidence phenomena that has occurred in the city of Makassar, which has been one of the notable centers of south eastern Asian civilisation as an urban hub since 16th century. The DInSAR investigation of the Makassar city has not been sought before, to the best of people’s knowledge.

Makassar city covers an area of 175.77 km² divided into 14 sub districts. The city lies on the geographic coordinate of 119°18'27,97"-119°32'31,03" East Longitude and 5°00'30,18" -5°14'6,49" South Latitude. The landform is relatively flat, classified as alluvial plain with topography levels from 0-21 m above sea level (Fig. 1a). Geologically, the city is covered by four types of formation, Camba Volcanic Formation, Salo Kalumpang Volcanic formation (which mainly consists of fine sediment clastic of volcanic eruptive rocks but mostly eroded), a small area of Limestone Tonasa Formation and alluvium formation deposit as recent weathered material. In general, the authors can find three types of rock units, basalt, tuff and breccia derived from volcanic origins and sediment deposit like fine to coarse sand (Fig. 1b).

The population of the city was 0.94 million in 1990, which increased to 1.2 million in 2010 [14], causing the increased use of both land surface and ground water. The rapid urbanization has made Makassar as a centre for economic development in eastern part of Indonesia. On the basis of the statistics of Makassar

![Fig. 1](image-url)  Study area: (a) Makassar city boundary ; (b) The geological map of the area.
City, population has been increasing due to the development and urbanization. Hence, the situation continues while people long for development to have better lives. The population increase triggers industries to develop new areas for business and construction. When the governmental control is limited in the rural area surrounding the city, the agricultural, shrub and even swamp spaces are developed, which in the future could generate land subsidence due to the extraction of water through wells. This mechanism has been suspected as the major cause of the subsidence of the urban land phenomena.

2. Data and Methodology

This research utilized eight scenes of JERS-1 SAR images of level 0 covers a swath area of 75 km² in descending modes with 35.5 degree of incident angle with acquisition date ranging from 1993 until 1998, but the area focused for the subsidence study is only 175.77 km².

DInSAR analysis was performed using SIGMASAR software developed by JAXA [15] combined with ENVI and ArcGIS software for implementing the GIS analysis. The DInSAR processing uses two pass interferometry to create an interferogram from two pairs of intensity (single-look, complex, SLC (single look complex) images. Subsequently, the differential interferogram is flattened and unwrapped to obtain the deformation map of the subsidence area, while evaluating the depth of subsidence from the interferogram. The flow chart of the DInSAR process can be seen in Fig. 2 [16, 17].

Based on the visual observation of Landsat images, urban development can also be seen from historical changes of the land cover. Landsat image acquired in September 1999 was used to create landuse map of Makassar in 1999 and Landsat image acquired in 1994 to create landuse map 1994. The load of development can be seen from the conversion of rice paddies, dry field and homogenous forest into business, services, and industry area. This conversion can obviously be observed in the northern part of the city. The city expansion also can be seen from the settlement and landuse change that bring more urban concentration to the area. The subsidence analysis is also supported with Landsat TM acquired in 1994 and Landsat ETM acquired on September 20, 1999. These Landsat images have been chosen in line with the acquisition dates of the SAR images. These images can be seen in Fig. 3. Field campaigns were conducted in September 2009 and January 2011 with handheld GPS (global positioning system) instruments. All supporting data are georeferenced to WGS (World Geodetic System) 1984 GIS (Geographic Information System) platform. This can be observed on the northern part and the southwest near the coastal line. The new high rise apartments, hotels and public facilities were constructed on this part of the city. Industrial area where warehouses and factories were built along the highway burdens the less compacted soil of coastal land.

![Fig. 2 Schematic flow chart of DInSAR processing.](image-url)
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3. Results and Discussion

As mentioned earlier, the authors processed eight datasets of JERS-1 SAR to create seven pairs to DInSAR images. Due to satellite orbital errors and influence of atmospheric conditions during the acquisition and considering the baseline difference of the two image used as master and slave images, three of the pairs have shown incoherence hence cannot be further analysed. In Fig. 4, the authors can observe colour coding patterns on the four images in some areas that show some consistencies while other areas display bands of interferometry noises. The authors have chosen the pair image of 1995/1996 to be analysed in detail, as shown in Fig. 5, the coherence image in Fig. 5a, a subset image in Fig. 5a and the deformation image in Fig. 5a.

The subset of the image that shown the indication of slight subsidence at the western part of the City of Makassar was then overlaid with high resolution image to confirm the subsidence location supported by the pictures taken from the ground survey in Fig. 5. The colour coding estimates a slight subsidence of 5-15 cm per year in particular area especially with the load of heavy settlement.

The authors have shown that the application of DInSAR technique using JERS-1 data can reveal subsidence conditions in the study area. Mostly the subsidence occurred in the northern part of Makassar city during the time interval studied here, though the population density in northern part is lowest among the entire city regions. Industrial district, reclamation area, trading centre area, international airport and the
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Fig. 4 DInSAR processing images on the LOS (line of sight), all datasets are on descending mode: (a) pair of 1995/1996; (b) Pair of 1996/1997; (c) pair of 1997/1997; (d) pair of 1997/1998, later image is master and earlier image is slave.

Fig. 5 DInSAR processing images of Makassar City: (a) coherence image of 1995/1996; (b) DInSAR Image pair of 1995/1996 images; (c) the deformation image after the unwrapping process.

seaport are built in this region. The centre of the subsidence with the subsidence-affected coverage area can also be estimated easily. It has been found that the subsidence occurred in separated regions with different land usage. Nevertheless, the ground survey has indicated that high human activity exists in every point of subsidence.

Various human activities such as ground water pumping and construction working should have affected the local subsidence phenomena in Makassar, as in the case of other large-scale cities. The main cause of subsidence in Makassar has not been revealed because of the complex feature of the phenomena. However, the result of the present study strongly suggests that the human activity and land use alteration are influencing the geomorphological changes in this city. Field campaign conducted in September 2009 revealed some locations that indicate the incidence of land subsidence and the fact that some parts of the city are having load of building
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Fig. 6 Focus on deformation image of Tamalate area and surrounding overlaid with Quickbird image acquired on May 6, 2007.

construction that make the city experience of slight movement of its earth surface.

New building construction of warehouses can be seen in picture P1 taken in the area of Tallo, New housing and modern apartment as well as community business complex in P2. Evidence of subsidence can be seen in Paotere, in Panakkukang, in Mariso and in Tamalate. On one of the main road, the soil load can

Fig. 7 Pictures taken from the field observation indicating the occurrences of land subsidence, picture code correspond with the location in Fig. 6, red arrow indicates subsidence.
be a thickness of 15-20 cm (Figs. 6 and 7).

4. Conclusions and Future Study

DInSAR method is used to estimate subsidence phenomena which has been derived and applied in this study. Continuous information of subsidence area will be useful for urban maintenance and urban development field, as one important factor for planning and construction works. So far, only few subsidence-related studies have been carried out using SAR data over urban area. The authors have tried to apply JERS-1 SAR although not all pairs can give good coherence due to the baseline and atmospheric aspects.

The authors have successfully implemented the DlnSAR processing technique in measuring the dimension of the land subsidence. The incidences in some areas show evidence of from 5-15 cm of subsidence shown by field observation conforming the result of DlnSAR processing images. Although the main cause of subsidence in Makassar has not been revealed because of the complex feature of the phenomena, the result of the present study strongly suggests that the human activity and land use alteration are influencing the geomorphological changes in this city.

In the future, as the City of Makassar will be growing larger and denser, it needs monitoring that even slight changes on its surface can be detected as it is prone to seasonal disaster such as floods and subsidence. With this DlnSAR method, the authors hope to utilize newer SAR datasets to retrieve the rate of subsidence happened.

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