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Land subsidence detection using JERS-1 SAR Interferometry

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ABSTRACT

Repeat-pass Interferometric SAR (InSAR) technique is useful tool for the monitor of surface deformation. This technique is applied to detect the deformed area due to land subsidence in Jakarta, Indonesia. In those areas, it is well known that the excessive pumping of ground water has caused land subsidence. Leveling survey and GPS networking survey are carried out in Jakarta, Bandung and Semarang. However, InSAR processing has not been performed for study areas so far because no digital elevation model (DEM) can be applied. In this study we have applied DEM which were derived frominterferogram using JERS-1/SAR L-band data with suitable baseline length acquired from 1992 to 1998. As the result of this study, annual amount of subsidence is estimated as approximately 10cm (1993-1995) and 6cm (1995-1998). This is supported by the results of 6-10cm (1991-1997) by level survey and 4-6cm (1997-1999) by GPS survey. Furthermore ground truth was carried out to verify the estimated rates and areas of subsidence. Therefore, L-band SAR data enable us to make interferogram to be applied to InSAR processing even though the observation period is three or five years. This result encourages us that PALSAR which is successor of JERS-1/SAR must be more powerful tool for detecting surface deformation such as land subsidence and volcanic activities on long time scales with L-band and GPS.

KEY WORDS: land subsidence, interferometry, JERS-1/SAR, L-band, three passes, Jakarta

1. INTRODUCTION

The most useful radar application is capable of preserving the signal of phase and amplitude data. Amplitude data enhance the conditions and features on the ground. Interferometric SAR (InSAR) technique realize to the small deformation of ground. InSAR is a powerful tool to detect the displaced ground surface with high accuracy. Therefore the interested researcher applied and technique has been increased in the fields of geology, volcanology, glaciology and natural hazard. The effective results are reported in many research papers (i.e.Goldstein,1993; Massonnet et al.,1993; Murakami,1996). Recently, this technique has been increasingly applied to monitor the land subsidence problem. Because land subsidence has caused serious problem in big cities such as Mexico City, Bangkok, Shanghai and Jakarta that had rapid growth in population.

Mostly, the land subsidence is caused by human-induced issues, which are ground water extraction, mining activities lerated to metal mining and oil-gas production. In Asian countries, Jakarta is the most affected by land subsidence. The result of some research by leveling and GPS have been reported (Murdohardono and

Sudarsono,1998; Abidin,2001). Remote sensing utilization and InSAR processing, however, have not been applied. The main objective of this study is to apply three passes method of InSAR technique for land subsidence detection in Jakarta.

2. LAND SUBSIDENCE IN JAKARTA

It is well known that over-pumping of ground water is major cause of land subsidence in the world. According to Murdharno and Sudarsono (1998), there are four types of causes for land subsidence in Jakarta.

1) ground water extraction,
2) settlement of compressibility
3) natural consolidation of alluvial soil
4) geological settings

Among them, the most serious cause is thought to be rapid ground water extraction. In 1970s, many people moved to Jakarta from the surrounding districts. In accordance with the migration, rapid growth of population and construction of many factories had begun. For their activities, the over-utilization of water was started to supply the water for human use and industrial facilities (Fig.1). As a result, recharging water by natural ground water system is getting shorter than discharging water and aquifers was compacted and land was subsiding gradually. The land subsidence was occurred in many places in Jakarta in 1980s. That timing seemed to be corresponding to the beginning of the occurrence of land subsidence.

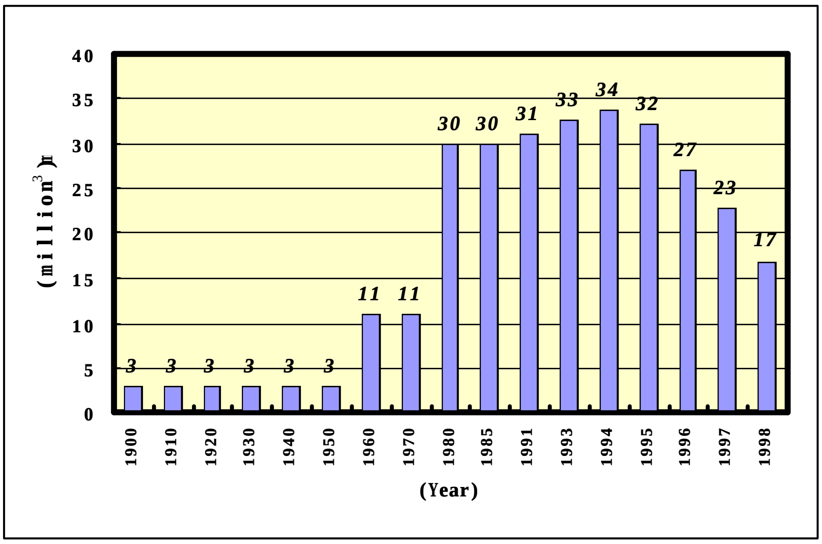


Fig.1 Annual extracted ground water from the registered drilled wells in Jakarta (Sudibyo, 1999)

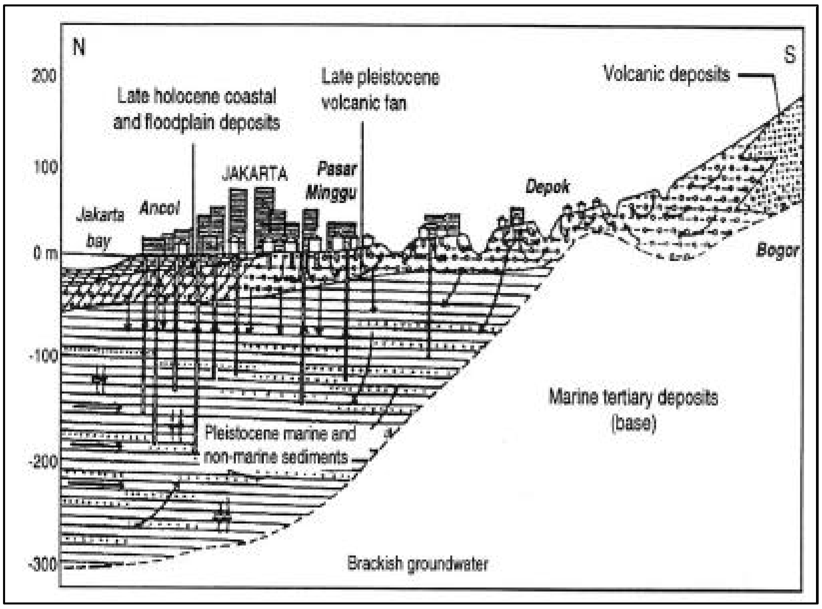


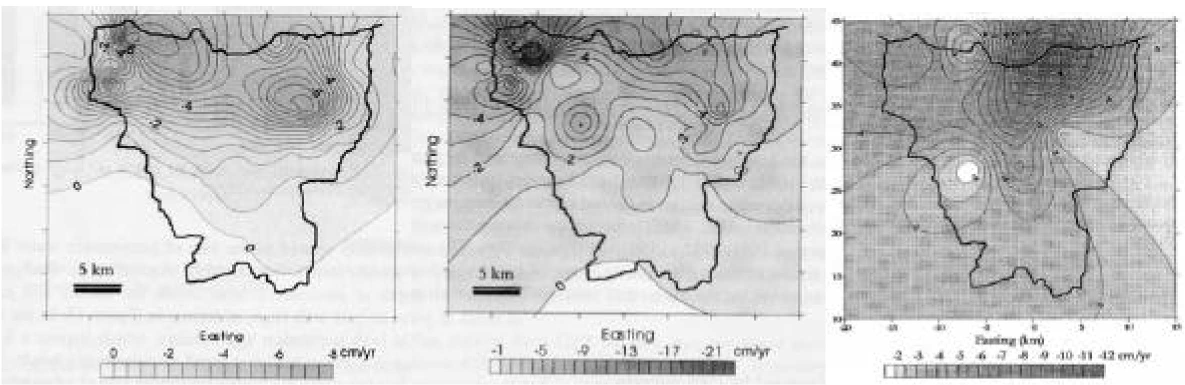
Fig.2 Schematic hydro-geological cross section of Jakarta (after Rismianto and Mak, 1993)

Generally, aquifer is composed of fine-grained sand laid on silt. According to Yong et al. (1995), the Jakarta basin is composed of Quaternary deposits and Tertiary basement rocks. Thickness of Quaternary deposits is thought to be approximately 200-300m. It is subdivided into three units as Pleistocene marine and non-marine sediments, late Pleistocene volcanic fan deposit and Holocene marine and floodplain deposits in ascending order (Fig.2). The ground water is hosted in Pleistocene and Holocene sediments at three layers as follows; ground surface - 40m (upper), 40-140m (middle), 140-250m (lower). On the basis of piezometric level monitoring

(Soetrisno et al.,1997), ground water extraction from the deeper aquifers are influential for land subsidence.
We can see the direct evidence of land subsidence in some places of Jakarta such as tilting of buildings and sinking of roads. Those evidences of subsidence were categorized by Murdharno and Sudarsono (1998) as follows;
1) destruction of the infrastructure system
2)discharging of underground water system
3)spreading of flooding area

3. LEVELING AND GPS SURVEY

Leveling has been conducted systematically by two agencies (Local Surveying and Mapping Agency of Jakarta and Local Mines Agency of Jakarta) in 1978, 1982, 1991, 1993 and 1997. Murdohardono and Sudarsono (1998) reported the land subsidence in Jakarta by leveling and piezometer monitoring. Systematic GPS survey in Jakarta area was firstly conducted by National Land Agency (BPN) in 1997 for establishing the cadastral control network. Afterward, the Department of Geodetic Engineering, Institute Technology Bandung, is conducting periodic GPS surveys for land subsidence monitoring. Abidin et al. (2001) summarized the result of detailed GPS survey referring to previous leveling and other data. The maximum depths of subsidence were observed approximately 80 cm and 160cm 20cm during 1982-1991, 1991-1997 and 1997-1999 respectively. Fig.3 shows the annual rate of subsidence in Jakarta measured by leveling and GPS survey.



a.(1982-1991) b.(1991-1997) c.(1997-1999)

Fig.3.Land subsidence in Jakarta by leveling and GPS survey
a,b: Murdohardono and Tirtomihardjo(1998), c: Abidin (2001)

4. INSAR DATA PROCESSING

In order to detect the land subsidence, we carried out the differential InSAR processing by JERS-1 SAR data. Up to now, the principle of InSAR have been well introduced by many researchers (i.e. Li and Goldstein, 1990; Zebker et al.,1994). The potentiality of the generation of DEM derived from multifrequency (X, C, L-band) two-pass interferometry were discussed by Lanari(1996). Since DEM has topographical information, InSAR processing by applying DEM is to provide the spatial deformation continuously.
In order to acquire the data for InSAR, there area two modes as single pass and repeat passes. Single pass mode acquire the data by different positions simultaneously. Repeat passes mode is done by the data taken in different time orbit. Repeat passes mode is generally subdivided into two methods such as two passes method and three or four passes method. Two passes method needs conventional DEM to remove the topographical component. Three passes method requires DEM generation from the satellite data. ERS obtain the data simultaneously by tandem flight mode. JERS-1/SAR and RADASAT obtain the data by repeat passes mode instead of single pass mode. The

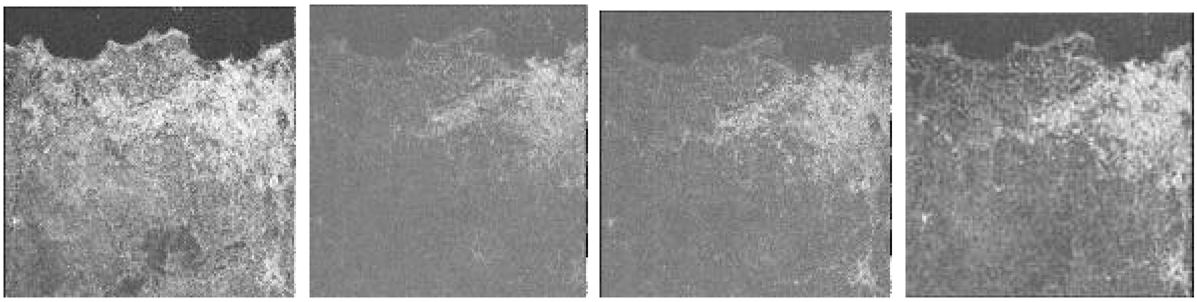
principal specification of JERS-1/SAR is L-band (23.5cm wavelength), HH polarization and about 35 degrees of the off-nadir angle. ERS is C-band (5.4cm wavelength), VV polarization and 23 degrees of the off-nadir angle. RADARSAT is C-band, HH polarization and 10-60 degrees of off-nadir angle with five observation modes. ERS and RADASAT data have been generally used for DEM generation than JERS-1 because repeat pass cycle of JERS-1 was 44 days. It is recognized to be included decorrelation of time difference and atmospheric effects more than ERS or RADARSAT. However the DEM generation by L-band of JERS-1/SAR were reported in some researches (i.e.Takeuchi 2001). In this study, the potentiality of DEM generation was investigate by using JERS-1/SAR data with assumption of no large deformation between the data recordings.

JERS-1/SAR acquired 17 scenes from Jakarta area during the period of 1993/02/25-1998/09/11 in total. We selected and co-registered for 41 pairs with convenient distance of baselines (<1000m) to be applied InSAR processing. The VEXCEL 3D SAR Processor was employed for this study. The data processing was taken from single look complex (SLC). And then Resampling SLC (co-registration), creating interferogram, filtering, uwrapping interferogram, refining were done. The size of multi-looking was 2 pixels in range by 6 lines in azimuth. The distance of baseline and surface change of time difference is influence for the result of processing. In this study suitable three pairs were found out in different time. As a result of co-registered pairs, sufficient tie points were acquired in following pairs (Table 1, pair(1)-(3)).

Table 1 Perpendicular baseline and period of days of data used in Jakarta

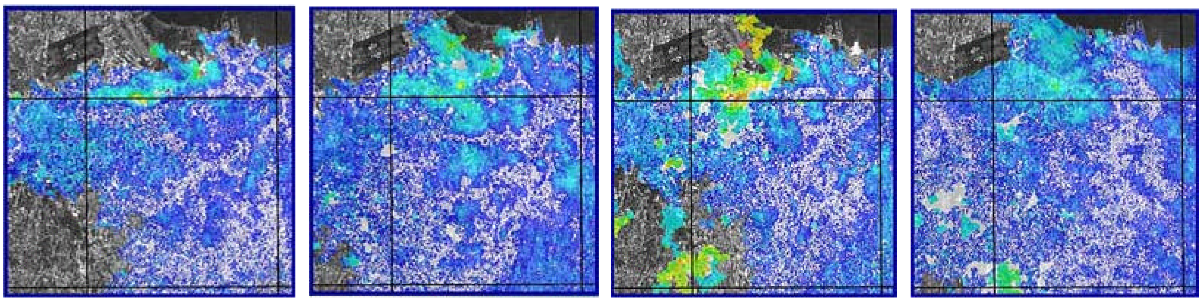
Date of pair	Perpendicular Baseline (m)	Period of days
(1).1993/10/03-1995/09/07	351	704
(2).1995/09/07-1995/10/21	707	44
(3).1995/10/21-1998/09/15	641	1056
(4).1997/01/03-1997/05/15	87	132

The combinations of baseline and period of days of pair (1), (2) are 351m and 707m during 1993/10/03-1995/09/07(704 days) and 1995/09/07-1995/10/21 (44 days) respectively. And pair (3) is 641m during 1995/10/21-1998/09/15 (1056 days). Some coherence images are shown in figure.4a-d. The pair (2) is showing high coherence on the image for the whole area (Fig.4-a) and coherence of other pairs decreased due to decorrelation noise and some factors acquired by long time difference. However the higher co-registrated points were acquired in the central part of Jakarta, which is locating upper right on the images (fig.4-b,c,d).



a.(1995/09/07-1995/10/21) b.(1993/10/03-1995/09/07) c.(1995/09/07-1998/09/11) d.(1997/01/03-1997/05/15)

Fig.4. Coherence image



a.(1993/10/03-1995/09/07) b.(1995/09/07-1998/09/11) c.(1993/10/03-1997/01/03) d.(1997/01/03-1998/09/11)

Fig.5 Displacement map from differential interferometry

The differential interferograms were generated by above data sets and displacement map were obtained(Fig.5,a-d). The land subsidence are seen in the north and northwest part of the images. And same areas of subsidence are shown in the image derived from different data sets, which are showing the same trend as NE-SW direction. It is corresponding to the results from leveling (Mordohardono and Sudarsono, 1998). And annual rate of land subsidence are estimated approximately 10cm (1993-1995) and 6cm (1995-1998). These figures of rates are supported by the results from leveling (6-10cm; 1991-1997) and GPS survey (4-6cm; 1997-1999).

Ground truth was carried out to correlate the result of this study. In 1995 a big power plant was constructed near the area where is pointed out by the result of InSAR. After that local government constructed bank along the canal near the power plant. However we saw that water was seeping from cracks of bank to around areas. Some pum stations are pumping the flooding water up from the lower areas to the river. According to Abidin et al.(2001), the strong subsiding area was shifted from the western area to the eastern part during 1991-1997 and 1977-1999.

5.CONCLUSIONS

This study presented that three passes method of JERS-1/SAR interferometry is applicable to detect the land subsidence. The estimated rate of subsidence in Jakarta is approximately 10cm (1993-1995), 6cm(1995-1998). Those rates are corresponding to the result of leveling and GPS survey. The ground water extraction is most influential factor for the land subsidence in Jakarta and it seems to be related to the rate of subsidence.

Thus L-band data is less susceptible to loss in coherence even though repeat passes period is longer. Although the some problems to be solved still remain, the ability of detection of ground deformation could be successful by generating DEM from satellite data. It is encouraging for the launch of PALSAR, which is successor of JERS-1 and have function of L-band multi polarization. Additionally, ASTER which was launched in 1999 generate the DEM by using stereo pair data. The specification of ASTER DEM is approximately 15m in height and 25m in horizontal unit. It is roughly equal to topographical map of 1/50,000-1/100,000 in scale. Therefore ASTER DEM is useful for subsiding areas and natural hazardous areas in the world. It could be powerful tool for analyzing and monitoring by using InSAR technique to be applied.

The principal mechanism of land subsidence in Jakarta seems to be not yet understood sufficiently. To understand the mechanism of subsidence and to grasp extending area of subsidence, we should better to combine the conventional data (leveling, GPS survey) with satellite data. And the systematic countermeasure should be promptly set up.

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