Capabilities and Constraints of Geodetic Techniques for Monitoring Land Subsidence in the Urban Areas of Indonesia

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Key words: Land Subsidence, Leveling, GPS, INSAR, Jakarta, Bandung

SUMMARY

Land subsidence in a few urban areas (cities) of Indonesia, i.e. Jakarta, Bandung and Semarang, have been confirmed to be real phenomena. A few other cities, e.g. Medan, Surabaya and Denpasar are also suspected to experience land subsidence. There are four different types of land subsidence that can be expected to occur in the urban areas, namely: subsidence due to groundwater extraction, subsidence induced by the load of constructions (i.e. settlement of high compressibility soil), subsidence caused by natural consolidation of alluvium soil, and geotectonic subsidence.

Land subsidence phenomena can be inferred from ground water level observations, estimated using geological and hydrological parameters, or measured by using geodetic techniques such as Leveling surveys, GPS surveys and INSAR (Interferometric Synthetic Aperture Radar).

The geodetic techniques of Leveling, GPS Surveys and/or INSAR technique have been used to study and monitor land subsidence phenomena in Jakarta, Bandung and Semarang. In this paper, the capabilities and constraints of these techniques will be discussed by using the results obtained from the land subsidence study using Leveling surveys, GPS surveys and INSAR in Jakarta and the results given by GPS surveys in Bandung. The paper will be sum up with conclusions and recommendations.

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1. INTRODUCTION

Land subsidence is the phenomena expected to occur in several urban areas of Indonesia. Excessive groundwater extraction by both peoples and industries is believed to be the main factor that causes this land subsidence. *According to Pikiran Rakyat* (2003), Jakarta, Bandung, Semarang and Surabaya (see Figure 1 for their locations) are the cities which have the most significant decreases in their groundwater levels. For example in Bandung, the groundwater level has decreased as much as 50 m to 100 m in recent years. The other three cities, e.g. Medan, Denpasar and Cilegon, also have shown quite significant decreases in groundwater level, in the amount of about 1 to 15 m per year.

Figure 1. Some cities with significant decreases in their groundwater levels.

The comprehensive information on the characteristics of land subsidence would be important for several tasks such as spatial-based groundwater extraction regulation, effective control of flood and seawater intrusion, conservation of environment, design and construction of infrastructures, and spatial development planning in general. Since data and information on land subsidence characteristics will be useful for many development and environmental aspects, systematic and continuous monitoring of land subsidence in those suspected cities of Indonesia is obviously needed and critical to the welfare of the city.

In principle, land subsidence phenomenon can be studied using several measurement techniques, e.g. leveling surveys, extensometer measurements, ground water level observations, GPS (Global Positioning System) surveys, and INSAR (Interferometric Synthetic Aperture Radar). In this case leveling surveys, GPS surveys and INSAR can be categorized as geodetic techniques. These three geodetic techniques have been utilized to study land subsidence in Jakarta. Land subsidence in Bandung has been studied using GPS surveys technique, while that in Semarang has been studied using leveling surveys technique. Therefore discussion in this paper will only be related to land subsidence phenomena in those three cities.

2. LAND SUBSIDENCE IN THE URBAN AREAS OF INDONESIA

2.1. Land Subsidence in Jakarta

Land subsidence is not a new phenomenon for Jakarta. It has been reported for many years that several places in Jakarta are subsiding at different rates. According to the Local Mines Agency of Jakarta, over the period of 1982 to 1997, subsidence ranging from 20 cm to 200 cm is evident in several places in Jakarta. The occurrence of land subsidence in Jakarta was realized for the first time in 1926. Evidence for subsidence was based on repeated leveling measurements conducted in the northern part of Jakarta. Unfortunately this investigation of land subsidence using leveling had not been continued for 50 years until 1978. Starting in 1978, the impact of land subsidence in Jakarta could be seen in several forms, such as the cracking of permanent constructions located around the center of the Jakarta area (along Thamrin street), the wider expansion of flooding areas, the lowering of the ground water level, and increased inland sea water intrusion.

According to *Murdohardono & Sudarsono* (1998) and *Rismianto & Mak* (1993), there are four different types of land subsidence that can be expected to occur in the Jakarta basin, namely: subsidence due to groundwater extraction, subsidence induced by the load of constructions (i.e. settlement of high compressibility soil), subsidence caused by natural consolidation of alluvium soil, and geotectonic subsidence. From those types of subsidence, the main spectrum of land subsidence in Jakarta is thought to be caused by groundwater extraction. Excessive groundwater extraction will lead to the deepening of groundwater level (piezometric head), which in turn will cause land subsidence and also seawater intrusion [*Soekardi et al.,* 1986].

Since the early 1980's, the land subsidence in several places of Jakarta has been measured using several measurement techniques, e.g. leveling surveys, extensometer measurements, ground water level observations, and GPS (Global Positioning System) surveys. The prediction of ground subsidence, based on certain models incorporating geological and hydrological parameters of Jakarta, has also been investigated by a few researchers [*Murdohardono and Tirtomihardjo,* 1993; *Yong et al.,* 1995; *Purnomo et al.,* 1999].

2.2. Land Subsidence Bandung

Bandung is the capital city of West Java province in Indonesia. It is a large intra-montane basin surrounded by volcanic highlands, inhabited by more than five million people. The central part on basin has an altitude of about 665 m and surrounded by up to 2400 m Late Tertiary and Quaternary volcanic terrain [*Dam et al.,* 1996]. The catchment area of basin and surrounding mountains covers 2300 km2, and the Citarum river with its tributaries forms the main drainage system of the basin catchment. Deposits in the basin comprise coarse volcaniclastics, fluvial sediments and notably a thick series of lacustrine deposits. A more detail explanation on geologic and morphologic setting of Bandung basin can be seen in [*Dam et al.*, 1996].

Population of Bandung municipality increased from less than 40,000 in 1906 to nearly one million in 1961 and had expanded to two and half million in 1995. In addition, with expansion of manufacturing and textile industries in Bandung basin, urbanization was increased and in 1995 more than 5 million peoples inhabited the basin. This increases in population and industrial activities in turn increase the groundwater withdrawal from the aquifers in Bandung basin. According to [*Soetrisno*, 1996] at the end of 1991, 70% of the total clean water required in the Greater Bandung area are supplied by groundwater. Industry relies nearly 100% of its required water on groundwater resources. In 1995, from the total extraction of about 66.9 Qabs (million m^3), 80% is estimated to be used by the industry. Considering the illegal extraction, it is estimated that 80 Qabs of groundwater was pumped by the textile industries alone in 1995. Increased groundwater extraction led to a rapid sinking of water tables on the plain and in turn can cause land subsidence. During the 1980s, the average annual drop in water tables in the basin was one meter, and in the most heavily abstracted areas annual drops of up to 2.5 meters were recorded [*Soetrisno*, 1996]. Increased extraction will also decrease the well productivity and also led to drastic changes in the time and direction of travel of water underground [*Braadbaart and Braadbaart*, 1997]. Although the main spectrum of land subsidence in Bandung is thought to be caused by excessive groundwater, especially by the textile industries, its detail characteristics and mechanisms are still relatively unknown.

2.3. Land Subsidence in Semarang

Semarang is a coastal city and the capital of Central Java province in Indonesia inhabited by about 2 million peoples. According to *Tobing and Murdohardono* (2004), land subsidence rates detected in Semarang vary spatially up to about 17 cm/year. These rates were calculated based on leveling surveys conducted from 1996 to 2001. Land subsidence in Semarang mainly due to excessive groundwater extraction and natural consolidation of alluvium soil. According [*Suara Merdeka*, 2003] the number of registered groundwater extraction wells in 1994 is only 181, but in 2000 it becomes 1029 wells. The volume of extracted groundwater increases from 23 million m^3 in 1990 to 38 million m^3 in 2000.

3. THE USE OF GEODETIC TECHNIQUES FOR MONITORING LAND SUBSIDENCE IN THE URBAN AREAS OF INDONESIA

In principle, land subsidence phenomenon can be studied using several measurement techniques, e.g. leveling surveys, extensometer measurements, ground water level observations, GPS (Global Positioning System) surveys, and INSAR (Interferometric Synthetic Aperture Radar). In this case leveling surveys, GPS surveys and INSAR can be categorized as geodetic techniques. These three geodetic techniques have been utilized to study land subsidence in Jakarta. Land subsidence in Bandung has been studied using GPS surveys technique, while that in Semarang has been studied using leveling surveys technique.

3.1. Leveling Technique

The establishment of vertical control in Jakarta was started in 1925 at the time of Dutch colonization by using optical leveling measurements. The first precise leveling network was established between May 1925 and April 1926. This network has a leveling line of about 38 km. Unfortunately the data and results of these leveling surveys are lost and unknown at the present time. After these first surveys, the next systematic leveling surveys covering Jakarta area were conducted in 1978, 1982, 1991, 1993, and 1997. Except for the last survey, which was performed by the Local Mines Agency of Jakarta, other leveling surveys were done by the Local Surveying and Mapping Agency of Jakarta.

After some quality control and validation checking, only three surveys were considered for investigating the land subsidence in Jakarta, i.e. those conducted in 1982, 1991, and 1997. Moreover, only the results from several leveling points in the network, which are considered the most reliable, are used for investigating land subsidence. In this case, repeatability of the heights obtained from different surveys and different loops and stability of the monument with respect to its local environment are used as the main criteria for selecting the points. The distribution of these leveling points is shown in Figure 2.

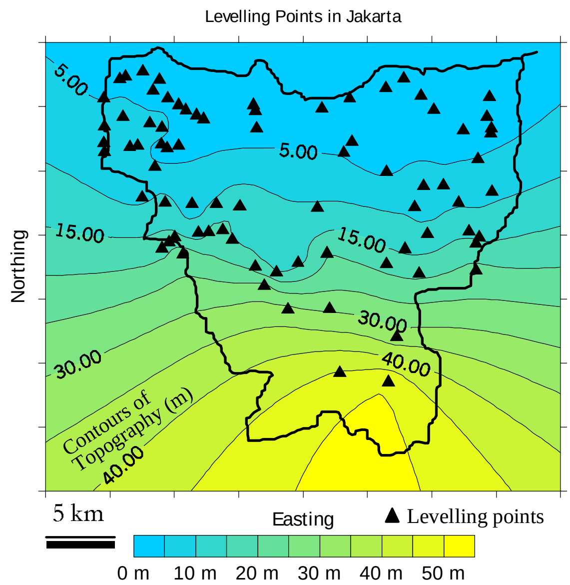
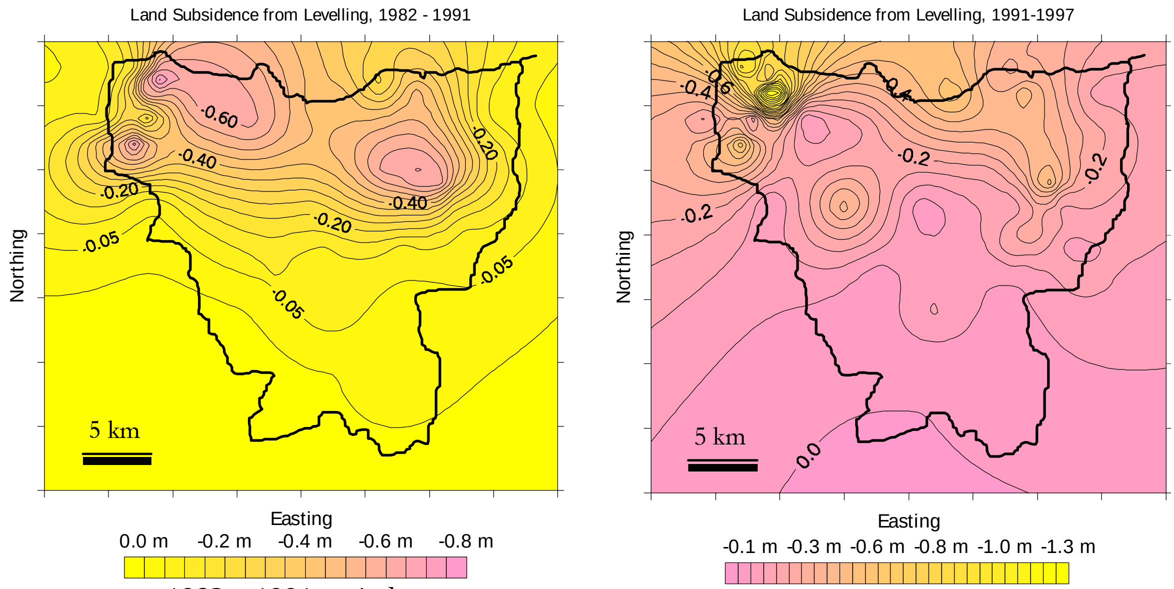


Figure 2. Leveling network in Jakarta

The network consists of about 80 points distributed across Jakarta. Land subsidence is studied using 45 selected points from the leveling networks of 1982, 1991, and 1997. The obtained land subsidence pattern is shown in Figures 3. From these figures it can be seen that land subsidence in Jakarta varies both spatially and temporally.

Leveling surveys has also been used to monitor subsidence in Semarang area [*Tobing and Murdohardono*, 2004]. The surveys, conducted by the Mining Office of Central Java and the Directorate of Environmental Geology and Mining Area Management, have been done between 1996 and 2001, involving 29 monitoring piles, one benchmark and three drilling locations. The surveys detected the subsidence that has spatial variation, with the rates ranging from about 1 to 17 cm/year. The relatively large subsidence were detected in the northern part of Semarang, e.g. around Tanjung Mas harbour, Pondok Hasanuddin, Poncol railway station down to the south of Tawang railway station.



1982 – 1991 period. 1991 – 1997 period.

Figure 3. Land subsidence in Jakarta measured from leveling surveys (in metres).

3.2. GPS Survey Technique

GPS survey technique [*Hofmann-Wellenhof et al.*, 1994; *Abidin et al.*, 2002] has been used to study land subsidence in Jakarta and Bandung. The configuration of this GPS monitoring network at the present time is shown in Figure 4. BAKO, the southern most point in the network and also the Indonesian zero order geodetic point, is considered as a stable reference point. BAKO is an IGS station, operated by the National Coordinating Agency for Survey and Mapping (BAKOSURTANAL). Seven GPS surveys have been conducted, namely on the periods of 24 - 26 Dec. 1997, 29 - 30 June 1999, 31 May - 3 June 2000, 14 - 19 June 2001, 26 - 31 Oct. 2001, 02 - 07 July 2002, and 21 - 26 Dec. 2002. The GPS surveys at all stations were all carried out using dual-frequency geodetic-type GPS receivers. For GPS surveys, the length of sessions was between 12 to 24 hours, respectively. The data were collected with a 30 seconds interval, and elevation mask was set at 15^0 from all stations. The data of GPS surveys was processed using the scientific software Bernesse 4.2 [*Beutler et al.*, 2001]. Since we are mostly interested with the relative height component of the coordinates with respect to a stable point, the radial processing mode was used instead of network adjustment mode.

Land subsidence of Jakarta derived from GPS surveys in summary are shown in Figures 5 and 6. In general the estimated subsidence rates are around 1 to 10 cm per year, depending on the location. In comparison with previous rates obtained from leveling results, it can be concluded that land subsidence phenomena in Jakarta is still continuing with a mean rate of about 5 to 7 cm per year. A more detail results can be seen in [*Abidin et al.*, 2001].

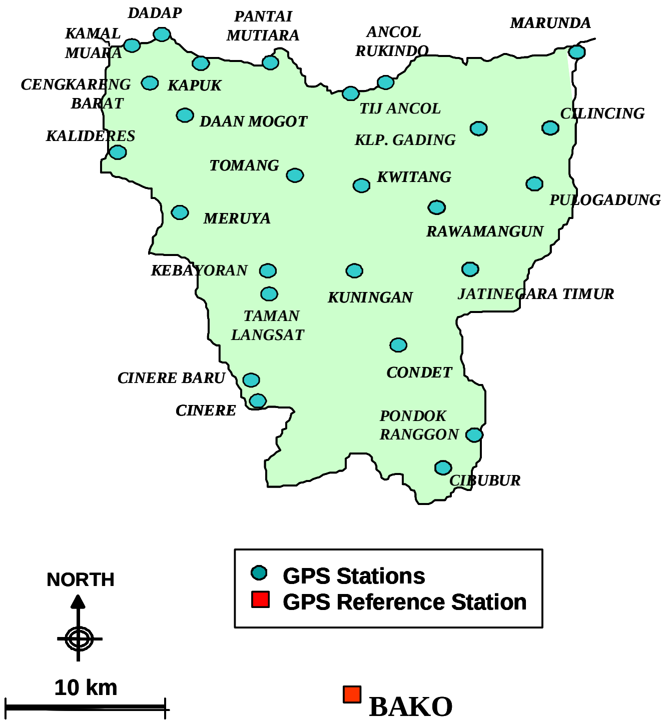


Figure 4. Distribution of GPS stations for monitoring the land subsidence in Jakarta basin.

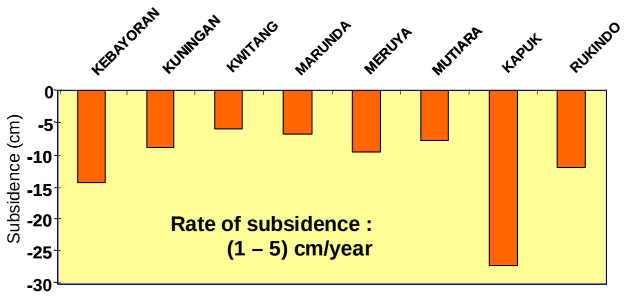


Figure 5. GPS derived land subsidence (cm) in the period of Dec. 1997 to Dec. 2002.

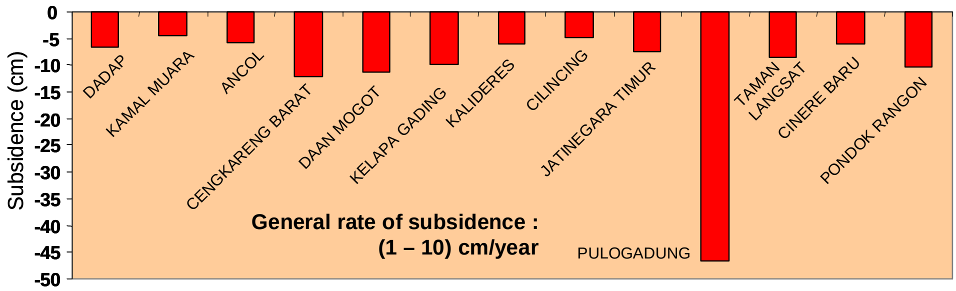


Figure 6. GPS derived land subsidence (cm) in the period of June 2001 to Dec. 2002.

In order to study land subsidence phenomena in Bandung basin, four GPS surveys have been conducted, namely on February 2000, November 2001, July 2002 and June 2003. The GPS surveys at all stations were all carried out using dual-frequency geodetic-type GPS receivers.

In this case PSCA station located inside ITB campus is used as the reference (stable) point with known coordinates. For GPS surveys, the length of sessions was between 10 to 12 hours, respectively. The data were collected with a 30 seconds interval, and elevation mask was set at 15^0 from all stations. Configuration of the GPS monitoring network is shown in Figure 7.

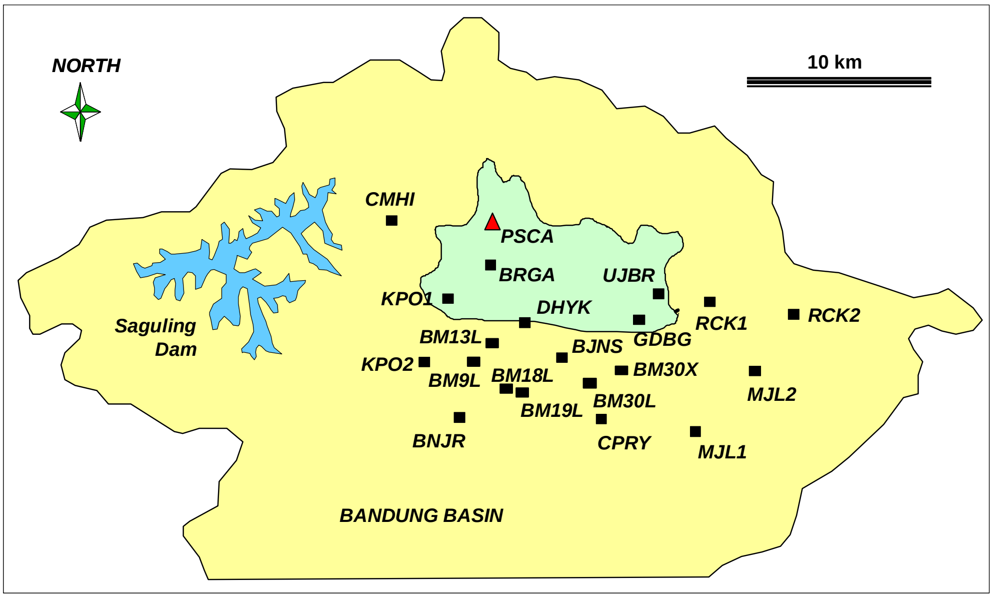


Figure 7. Distribution of GPS points for studying land subsidence in Bandung basin.

Based on four GPS (Global Positioning System) surveys conducted on February 2000, November 2002, July 2002 and June 2003, it can be concluded that in the period of 2000 to 2003 several locations in Bandung basin have experienced land subsidence. The GPS survey results show land subsidence in Bandung has both temporal and spatial variations. In general rates of subsidence about 2-20 mm/month, or 2-24 cm/year. Several stations, e.g. CMHI, DYHK, RCK2, GDBG, BM9L and BM18L, have relatively higher subsidence rates compared to other, namely around 1-2 cm/month or 12-24 cm/year. Stations CMHI, DYHK, RCK2 and GDBG are located in the textile industry areas, where excessive ground water extraction are expected to occur; while BM9L and BM18L stations are located in the bank of Citarum river. A more detail results can be seen in [*Abidin et al.*, 2003a; 2004].

3.3. INSAR Technique

Preliminary study of land subsidence in Jakarta by using INSAR technique [*Massonnet & Feigl*, 1998] has been initiated by using JERS-1 SAR data. JERS-1/SAR in total acquired 17 scenes from Jakarta area during the period of 1993/02/25-1998/09/11. For INSAR processing, 41 image pairs were selected and co-registered. The VEXCEL 3D software was used for processing. Two estimated subsidence maps are shown in Figure 8. These figure cover the northwestern part of Jakarta with the size area of about 10 by 10 km. Gray/white areas in Figure 8 are just power images of SAR and have no relation with INSAR result images. They are just reference images.

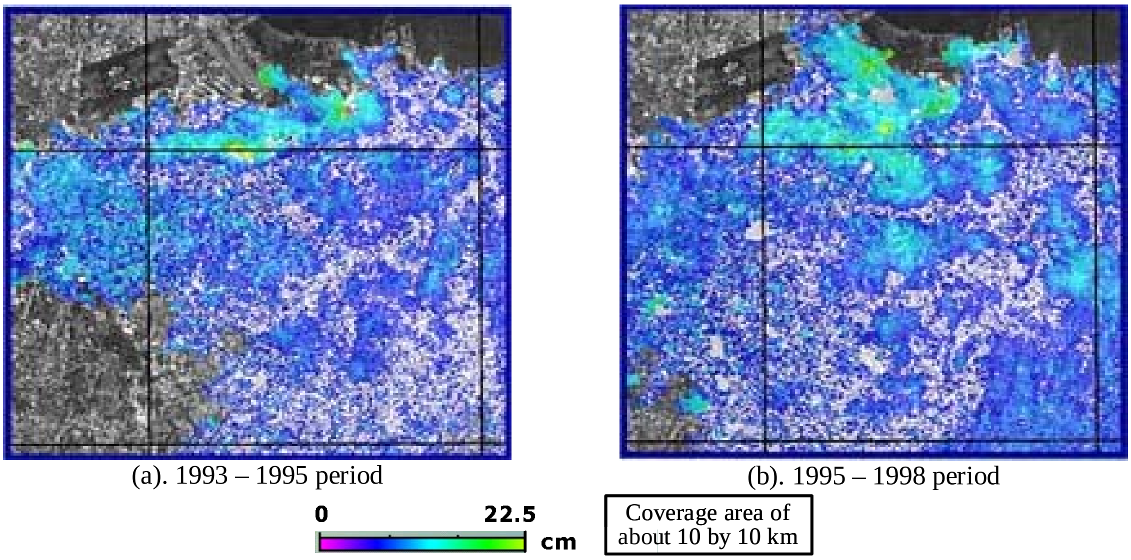


Figure 8. INSAR derived land subsidence (cm) in the northwestern part of Jakarta, after [*Hirose et al.*, 2001].

Figure 8 shows that land subsidence are seen in the north and northwest part of the images. The same areas of subsidence are shown in the images derived from different data sets, which are showing the same trend as NE-SW direction. It is corresponding to the results from leveling survey. The annual rate of land subsidence are estimated approximately 10 cm/year (1993-1995) and 6 cm/year (1995-1998). These figures of rates are supported by the results obtained from leveling and GPS surveys. A more detail results can be seen in [*Abidin et al.*, 2003b; *Hirose et al.*, 2001].

4. CAPABILITIES OF GEODETIC TECHNIQUES

In studying land subsidence phenomena, Leveling, GPS and INSAR techniques has its own capabilities that should be utilized whenever possible.

4.1. Leveling Technique

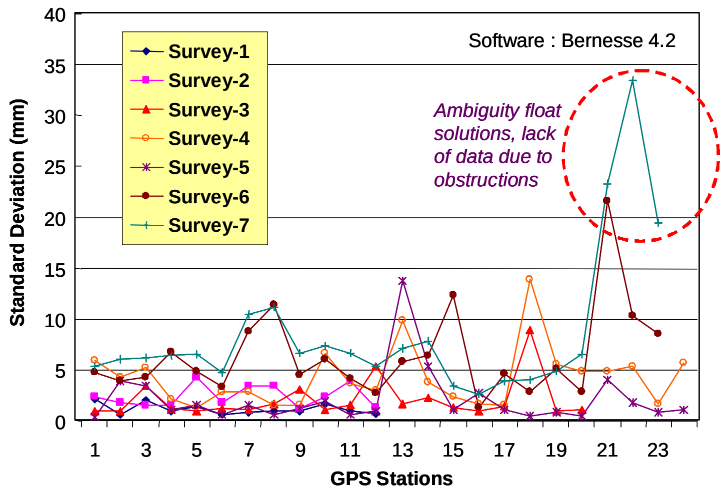
Leveling technique is the geodetic technique that can provide very precise height differences up to a few mm accuracy level. This technique is relatively flexible to be implemented in the Indonesian urban areas which have usually dense housing, building and/or vegetation. In other words, leveling technique can flexibly handle a relatively dense and crowded urban area. Its observed benchmarks can also be easily located. Its data processing and analysis of the obtained results is also not complicated.

4.2. GPS Survey Technique

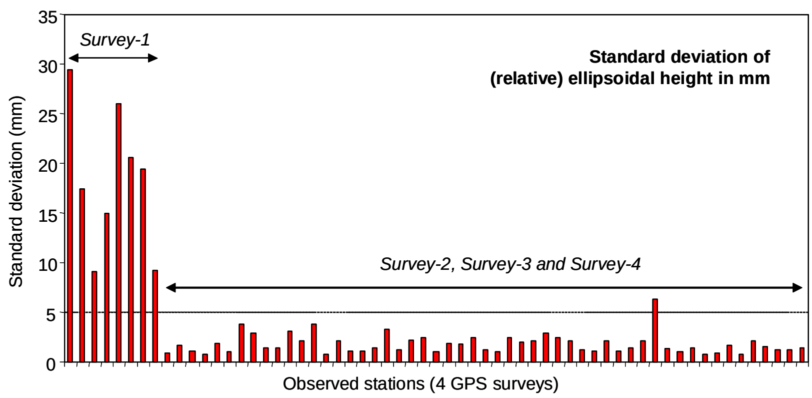
At the present times, GPS static surveys technique has been quite intensively used for studying and monitoring land subsidence. There are several advantages of using GPS surveys technique that should be noticed, such as:

– GPS provides the three-dimensional displacement vector with two horizontal and one vertical components, so it will give not only land subsidence information, but also land motion in horizontal direction;
– GPS provides the displacement vectors in a unique coordinate reference system, so it can be used to effectively monitor land subsidence in a relatively large area;
– GPS can yield the displacement vectors with a several mm precision level which is relatively consistent in temporal and spatial domain, so it can be used to detect even a relatively small subsidence signal;
– GPS can be utilized in a continuous manner, day and night, independent of weather condition, so its field operation can be flexibly optimized.

GPS surveys for studying land subsidence in Jakarta and Bandung have shown that the standard deviation of GPS derived relative ellipsoidal height in several mm level can usually be obtained, as shown in Figures 9.



(a) Jakarta GPS surveys.



(b). Bandung GPS surveys

Figure 9. Standard deviations of the estimated ellipsoidal height of GPS stations.

In the case of Jakarta GPS surveys a few points have slightly worse standard deviations due to the lack of observed data caused by the signal obstruction by trees and/or building around the station. In the case of Bandung GPS surveys, the obtained precision level of the first survey are in the level of 1-3 cm while for the next surveys is in several mm level. It is due to a relative shorter session length of the first survey compared to the next surveys.

4.3. INSAR Technique

In comparison with Leveling and GPS techniques which give the subsidence information just on the observation points, INSAR can provide accurate subsidence information on a more continuous spatial domain with a few cm accuracy level. Therefore it can give more insights into characteristics of subsidence phenomena in a regional sense. With more Radar satellites on space (e.g. ERS, Radarsat, Envisat and ALOS) and more INSAR data processing packages available (e.g. Atlantis, Gamma, Vexcel, Roi-Pac and Doris), it can be expected that the use of INSAR technique for studying land subsidence phenomena will be increasing.

5. CONSTRAINTS OF GEODETIC TECHNIQUES

In studying land subsidence phenomena, Leveling, GPS and INSAR techniques has its own constraints and limitations that should be considered and taken into account..

5.1. Leveling Technique

Although it can give very accurate height differences, leveling technique is relatively slow and time consuming in its execution, especially when precise leveling procedures are being implemented. Its operation also dependent on time, weather and also condition of traffic and human activities along the leveling routes. Considering the urban areas of Indonesia which are usually crowded with traffic and human activities during the day, leveling technique is indeed not the best technique for studying land subsidence phenomena in relatively large cities of Indonesia.

It should be noted that in studying land subsidence phenomena, the monitored points should generally be connected to a certain benchmark located on a stable area outside the subsiding area. When the subsiding area is large, then connecting to the stable benchmark will be another limiting constraint for implementation of leveling technique.

5.2. GPS Survey Technique

Based on our experience, the main constraint for using GPS survey technique in studying land subsidence in large cities of Indonesia such as Jakarta and Bandung, is the signal obstructions and/or multipath caused by high rise building, housing, trees and/or billboards. The other problem is due to relatively active development activities inside the urban areas which sometimes destroy or alter the observation monuments.

It should also be noted that in order to detect land subsidence signal with an accuracy level of about several mm, the use of dual frequency geodetic type receivers are necessary along with good survey planning, stringent observation strategy, and stringent data processing strategy using the scientific software. Expertise in GPS data acquisition and precise data processing is therefore required for accurate detection of land subsidence.

5.3. INSAR Technique

In order to use INSAR technique for studying land subsidence, multi temporal radar images of the area are needed along with the INSAR processing software and hardware, and also expertise to process the images. Indeed at present times in Indonesia, all of those requirements can not still be easily realized.

Time frames for studying land subsidence will also be dictated by the passing times of radar satellites over the studied area. In the context of data processing, the relatively dense vegetation of urban areas in Indonesia, its relatively rapid environmental changes and its relatively dynamic atmospheric condition can also limit the potential of INSAR for accurate detection of land subsidence.

6. CLOSING REMARKS

The geodetic techniques of Leveling, GPS Surveys and/or INSAR technique have been used to study and monitor land subsidence phenomena in Jakarta, Bandung and Semarang. Each technique has its own capabilities and constraints as previously described.

Previous studies show that combination of leveling, GPS surveys, and INSAR results are useful for studying and monitoring land subsidence phenomena. Besides complementing each other, both spatially and temporally, they can also check against one another for quality assurance purposes. For example, Leveling can flexibly handle relatively dense and crowded urban areas; GPS is good for relatively open areas; and INSAR is relatively not good for vegetated areas and other areas with relatively rapid environmental changes. In case of urban areas of Indonesia, e.g. Jakarta, Bandung and Semarang, the combination of these techniques will be useful in studying the spatial and temporal characteristics of land subsidence phenomena in both local and regional sense.

However it should be emphasized that in order to be more meaningful and to obtain more insights into land subsidence mechanism, the results of these geodetic techniques should be correlated with the hydrogeological and geotechnical characteristics of the subsiding areas.

REFERENCES

Abidin, H.Z., A. Jones, J. Kahar (2002). *GPS Surveying*. In Indonesian language. P.T. Pradnya Paramita, Jakarta. ISBN 979-408-380-1. Second Edition. 280 pp.

Abidin, H. Z., R. Djaja, D. Darmawan, S. Hadi, A. Akbar, H. Rajiyowiryono, Y. Sudibyo, I. Meilano, M. A. Kusuma, J. Kahar, C. Subarya (2001). "Land Subsidence of Jakarta (Indonesia) and its Geodetic-Based Monitoring System." *Natural Hazards*. Journal of the International Society of the Preventation and Mitigation of Natural Hazards, Vol. 23, No. 2/3, March, pp. 365 - 387.

Abidin, H.Z., H. Andreas, M. Gamal, R. Djaja, D. Murdohardono, H. Rajiyowiryono, M. Hendrasto (2003a). " Studying Land Subsidence of Bandung Basin (Indonesia) Using GPS and EDM Surveys". *Proceedings of the International Symposium and Exhibition on Geoinformation 2003 (ISG03),* Shah Alam, Malaysia, 13-14 Oct., pp. 228-240.

Abidin, H.Z., R. Djaja, H. Andreas, M. Gamal, K. Hirose, Y. Maruyama, D. Murdohardono, H. Rajiyowiryono, C. Subarya (2003b). " Monitoring Land Subsidence of Jakarta (Indonesia) Using Leveling, GPS Survey and InSAR Techniques." Paper presented at *IUGG (International Union of Geodesy and Geophysics) 2003 General Assembly Meeting*, Sapporo, 30 June – 11 July, Session G05, 4 July, 09:15-09:30.

Abidin, H.Z., H. Andreas, M. Gamal, M. Hendrasto, O.K. Suganda, Surono (2004). " The Use of GPS Surveys Method for Natural Hazard Mitigation in Indonesia". *Proceedings of the Monitoring, Prediction and Mitigation of Disasters by Satellite Remote Sensing,* Awaji, Jepang, 19-21 Januari, pp. 95-112.

Beutler, G., H. Bock, E. Brockmann, R. Dach, P. Fridez, W. Gurtner, U. Hugentobler, D. Ineichen, J. Johnson, M. Meindl, L. Mervant, M. Rothacher, S. Schaer, T. Springer, R. Weber (2001). *Bernese GPS software version 4.2*. U. Hugentobler, S. Schaer, P. Fridez (Eds.), Astronomical Institute, University of Berne, 515 pp.

Braadbaart, O. and F. Braadbaart (1997). “Policing The Urban Pumping Race: Industrial Groundwater Overexploitation In Indonesia”. *World Development*. Vol. 25, No. 2, pp. 199-210.

Dam, M.A.C., P. Suparan, J.J. Nossin, R.P.G.A. Voskuil and GTL Group (1996). “A Chronology for geomorphological developments in the greater Bandung area, West-Java, Indonesia”. *Journal of Southeast Asian Earth Sciences*. Vol. 14, Nos. 1-2, pp. 101-115.

Hirose, K., Y. Maruyama, D. Murdohardono, A. Effendi, H.Z. Abidin (2001). " Land subsidence detection using JERS-1 SAR Interferometry." Paper presented at *22nd Asian Conference on Remote Sensing (ACRS 2001),* Singapore, 5-9 November.

Hofmann-Wellenhof, B., H. Lichtenegger, and J. Collins (1994). *Global Positioning System, Theory and Practice*. Third, Revised Edition, Springer Verlag, Wien.

Murdohardono,D. and H. Tirtomihardjo (1993). "Penurunan tananh di Jakarta dan rencana pemantauannya." *Proceedings of the 22nd Annual Convention of the Indonesian Association of Geologists,* Bandung, 6-9 December, pp. 346 - 354.

Massonnet, D. and K.L. Feigl (1998). "Radar Interferometry and its Application to Changes in the Earth's Surface." *Reviews of Geophysics,* Vol. 36, No. 4, Nov., pp. 441-500.

Murdohardono,D. and U. Sudarsono (1998). "Land subsidence monitoring system in Jakarta." *Proceedings of Symposium on Japan-Indonesia IDNDR Project : Volcanology, Tectonics, Flood and Sediment Hazards*, Bandung, 21-23 September, pp. 243 - 256.

Pikiran Rakyat (2003). "*Dampak Eksploitasi Besar-besaran Air Tanah di Cekungan Bandung Permukaan Air Tanah Turun 100 M*", Harian Umum Pikiran Rakyat, Bandung, Selasa, 08 Juli 2003

Purnomo, H., D. Murdohardono, and H. Pindratno (1999). "Land Subsidence Study in Jakarta." *Proceedings of Indonesian Association of Geologists, Volume IV : Development in Engineering, Environment, and Numerical Geology*, Jakarta, 30 Nov.-1 Dec., pp. 53-72.

Rismianto,D. and W. Mak (1993). "Environmental aspects of groundwater extraction in DKI Jakarta: Changing views." *Proceedings of the 22nd Annual Convention of the Indonesian Association of Geologists*, Bandung, 6-9 December, pp. 327 - 345.

Soekardi, P., A. Djaeni, H. Soefner, M. Hobler, and G. Schmidt (1986). "Geological Aspect of the Aquifer System and the Groundwater Situation of the Jakarta Artesian Basin." Paper presented at *Seminar on Geological Mapping in the Urban Development*, Economic and Social Commission for Asia and the Pacific, Bangkok, 29 October.

Sutrisno (1996). *Pemanfaatan Airtanah, Dampak dan Penanggulangannya. Studi Kasus Cekungan Bandung, Jawa Barat*. Direktorat Geologi Tata Lingkungan, Bandung.

Suara Merdeka (2003). "*Semarang Alami Penurunan Tanah*". Harian Umum Suara Merdeka, Semarang, Kamis, 9 Oktober 2003.

Tobing, TMHL and Dodid Murdohardono (2004). "*Peta Amblesan Tanah Daerah Semarang Dan Sekitarnya, Jawa Tengah*". Artikel di Situs Direktorat Tata Lingkungan Geologi dan Kawasan Pertambangan, Alamat situs: http://www.dgtl.esdm.go.id/geotek/ exsum20.htm, Tanggal akses 16 Juli 2004.

Yong,R.N., E. Turcott, and H. Maathuis (1995). "Groundwater extraction-induced land subsidence prediction: Bangkok and Jakarta case studies." *Proceedings of the Fifth International Symposium on Land Subsidence*, IAHS Publication no. 234, October, pp. 89-97.

BIOGRAPHICAL NOTES

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