SUITABILITY OF LEVELLING, GPS AND INSAR FOR MONITORING

Land Subsidence in Urban Areas of Indonesia

Excessive groundwater extraction is probably the main factor causing land subsidence in urban areas of Indonesia. Decreases in groundwater level may reach 15 metres a year. Monitoring of land subsidence in suspected cities is required for groundwater extraction regulation, effective flood control and seawater intrusion, conservation of environment, construction of infrastructure, and spatial development planning in general. The author treats the capabilities and constraints of levelling, GPS and INSAR for monitoring land subsidence in Jakarta, Bandung and Semarang.

The relatively large urban areas of Indonesia usually have dense housing, building and/or vegetation (Figure 1). Land subsidence in urban areas may be caused by factors including groundwater extraction, load of constructions, natural consolidation of alluvium soil and geotectonic subsidence. The concentrated population and industry is extracting a lot of groundwater from underground sources. This extraction is likely to cause subsidence. Land subsidence can be inferred from groundwater-level observations, estimated using geological and hydrological parameters or measured by surveying techniques such as Levelling, GPS surveys and INSAR (INterferometric Synthetic Aperture Radar). We used the survey approach. The occurrence of subsidence has been proven by the measurements taken over the years.

Jakarta

Several areas of Jakarta have been subsiding at annual rates ranging from 20cm to 200cm over the years. The subsidence in Jakarta was detected for the first time in 1926. Subsidence was measured by repeated levelling in the northern part of Jakarta. Unfortunately, these measurements were discontinued for fifty years, until 1978, when the impact of land subsidence appeared in the form of cracking of permanent constructions, expansion of flooding areas, lowering of groundwater-level and increased inland-sea water intrusion. Since the early 1980s, subsidence in several parts of Jakarta has been measured using levelling, extensometer measurements, groundwater-level observations and GPS surveys.

Bandung

Bandung is the capital city of West Java. The central basin has an altitude of about 665m and is surrounded by up to 2,400m-altitude volcanic terrain. The catchment area of the basin and its surrounding mountains covers 2,300 km2 and the Citarum River, with its tributaries, forms the main drainage system of the basin. The population of the basin increased from less than 40,000 in 1906 for the Bandung municipality alone to more than 5 million inhabitants for the total basin in 1995. This increase in population and industry in turn increased groundwater withdrawal from the aquifers in the Bandung basin. As a result, the rapid sinking of water tables caused land subsidence. During the 1980s, the average annual drop in water tables in the basin was 1m, and in the most heavily abstracted areas annual drops of up to 2.5 metres were recorded. The main cause of land subsidence in Bandung is thought to be groundwater extraction. However, its detailed characteristics and mechanisms are relatively unknown.

Semarang

The coastal city of Semarang is the capital of Central Java province, with about 2 million people. Based on levelling surveys conducted from 1996 to 2001, land subsidence rates were calculated at about 17cm per year. Land subsidence in Semarang is mainly due to excessive groundwater extraction and natural consolidation of alluvium soil. The number of registered groundwater-extraction wells rose from 181 in 1994 to 1,029 in 2000. The volume of extracted groundwater increased from 23 million m3 in 1990 to 38 million m3 in 2000.

Levelling in Jakarta

Vertical control in Jakarta was established with Dutch colonisation in 1925 and 1926 brought measurement of a precise levelling network. Unfortunately, the data and results got lost. The next levelling surveys were conducted in 1978, 1982, 1991, 1993, and 1997. The Local Surveying and Mapping Agency of Jakarta performed these measurements, except for the last survey, which was performed by the Local Mines Agency of Jakarta. After quality control and validation, only the surveys conducted in 1982, 1991, and 1997 were considered suitable. Figure 2 shows the distribution of the levelling points. The network consists of about eighty points distributed across Jakarta. Land subsidence is studied using the 45 most reliable points from these levelling networks. Figure 3 shows the derived land subsidence pattern. From these figures it can be seen that land subsidence in Jakarta varies both spatially and temporally.

Levelling in Semarang

Levelling surveys have also been used to monitor subsidence in Semarang. The Mining Office of Central Java and the Directorate of Environmental Geology and Mining Area Management carried out these surveys between 1996 and 2001. The surveys involved 29

monitoring piles, one benchmark and three drilling locations, and they detected spatial variation in annual subsidence rates from 1 to 17cm.

GPS in Jakarta

GPS survey technique has been used to study land subsidence in Jakarta and Bandung. Figure 4 shows the configuration of the GPS monitoring network. BAKO, the southernmost point in the network, and also the Indonesian zero order geodetic point, is considered a stable reference point. BAKO is an IGS station operated by the National Co-ordinating Agency for Survey and Mapping (BAKOSURTANAL). Seven GPS surveys have been conducted: 1997, 1999, 2000, two in 2001 and two in 2002. The GPS surveys were carried out using dual-frequency geodetic-type GPS receivers. Figures 5 and 6 show the land subsidence derived from these GPS surveys. The annual subsidence rates are in the order of 1 to 10cm, depending on the location. Combining these results with the levelling results reveals that land subsidence in Jakarta is still continuing at a mean annual rate of 5 to 7cm.

GPS in Bandung

Four GPS surveys were conducted in Bandung in 2000, 2001, 2002 and 2003: all using dual-frequency, geodetic-type GPS receivers. A PSCA station located on the campus of the Institute of Technology Bandung was used as the reference (stable) point with known coordinates. Figure 7 shows the configuration of the GPS monitoring network. The four campaigns show that in the period of 2000 to 2003 land subsidence took place at several locations, with temporal and spatial variations. In general, annual rates of subsidence vary from 2 to 24cm. The areas hosting textile industry, where excessive ground water extraction takes place, show considerably more subsidence than other areas.

INSAR Techniques

Preliminary study of land subsidence in Jakarta using INSAR techniques was initiated using JERS-1 SAR data. JERS-1/SAR acquired a total of seventeen scenes from the Jakarta area over the period 1993-1998. For INSAR processing, 41 image pairs were selected and co-registered, and processed using VEXCEL 3D software. Figure 8 shows two estimated subsidence maps, covering an area of about 10 x 10km of the north-western part of Jakarta. The annual rate of land subsidence was estimated at 10cm over the period 1993-1995 and 6cm over the period 1995-1998. These rates are supported by the results obtained from levelling and GPS surveys.

Concluding Remarks

The combination of levelling, GPS surveys, and INSAR results are useful for studying and monitoring land subsidence. Besides complementing each other both spatially and temporally, they can also be checked against one another for quality assurance purposes. However, in order to be more meaningful and to obtain more insights into land-subsidence mechanisms, the results of these geodetic techniques should be correlated with the hydrogeological and geotechnical characteristics of the subsiding areas.

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