EXCESSIVE GROUNDWATER EXTRACTION IN INDONESIA

GPS for Land Subsidence Monitoring

Excessive groundwater extraction in the Bandung Basin has led to rapid sinking of the water table and is hypothesised as the main cause of land subsidence. Periodical GPS surveys were conducted from February 2000 to June 2005 but did not completely confirm the hypothesis, perhaps because of unregistered groundwater extraction or hydrogeology factors.

The methods used to study land subsidence are mainly based on hydrogeology methodology such as observation of ground-water level, extensometer and piezoâ€“meter measurement, and geodetic methods such as levelling, GPS and Interferometric Synthetic Aperture Radar (InSAR). The focus here is on the use of periodic GPS survey for monitoring.

History of Subsidence
Land subsidence in the Bandung Basin may be caused by several phenomena, including groundwater extraction, construction loads, natural consolidation of alluvial soil and geotectonic forces. Its detailed characteristics and mechanisms, however, are still relatively unknown. Excessive groundwater extraction has been hypothesised as the main cause, due to growth in population and industrial activities in the Bandung Basin area. Increased extraction is blamed for reduction in the productivity of wells and drastic changes in speed and direction of underground water movement. During the 1980s, average annual fall in ground level was 1m, and where extraction was high annual falls of up to 2.5m were recorded, resulting in falls of from 20m to 100m in the 25-year period 1980 to 2004.

GPS
The GPS monitoring network consists of twenty-one monuments accurately positioned by GPS relative to a stable reference point, the PSCA station located on the ITB campus (Figure 3). The coordinates of the PSCA station are computed from an Indonesia IGS station located in an area called Bakosurtanal in Cibinong, Bogor. The precise coordinates of the monuments were determined during five surveys using dual-frequency geodetic-type GPS receivers between 21st and 24th February 2000, 21st and 30th November 2001, 11th and 14th July 2002, 1st and 3rd June 2003 and 24th to 27th June 2005. GPS sessions lasted between ten and twelve hours. The data was collected at intervals of thirty seconds and the elevation mask was set at 15o for all stations. Land-subsidence characteristics were derived by studying the characteristics and rate of change of the height component from one survey to another (epoch). GPS data processing was done in radial mode from a PSCA station, using SKIPro commercial software. Precise ephemeris and a Saastamoinen tropospheric model were used in all computations. The final coordinates were estimated using the ionospheric-free linear combination signal after fixing integer ambiguities of signals L1 and L2. For land-subsidence monitoring only ellipsoidal height is used, of which the standard deviation appeared to be at the several-millimetre level, indicating sound GPS data processing.

Geography of Bandung
Bandung, the capital of the province of West Java (see Figure 1), lies in the catchment area of the upper River Citarum and is surrounded by volcanic highlands some of which are still active (Figure 2). The central area of the intra-montane basin has an altitude of about 665m, while the mountains have altitudes up to 2,400m; basin and mountains cover in total 2,300km2. The basin encompasses three administrative units: Bandung municipality, an urban area of 81km2, Bandung regency, and part of the regency of Sumedang. The population of Bandung municipality increased from less than 40,000 in 1906 to nearly one million in 1961, and to 2.5 million in 1995. Expansion in the manufacturing and textile industries and associated urbanisation caused the population of the Bandung Basin alone to have reached more than 5 million by 1995.

Results
Based on the estimated ellipsâ€“oidal heights, height differences between two consecutive surveys (epoch) can be calculated. The significance of the subsidence values was statistically checked using the congruency test. Significant subsidence was found at all stations in all four epochs, except for stations GDBG and KPO2 in the epoch from November 2001 to July 2002, and GDBG in the fourth epoch from June 2003 to June 2005. The statistical test applied only to the negative values in height differences. In the last period, therefore, stations MJL1, UJBR and CPRY were not tested. At 99% confidence level, subsidence was observed at most of the stations during the four epochs. Land subsidence in Bandung demonstrates both temporal and spatial variation (Figure 4). Rates of subsidence vary from 2-20mm/month, or 2-24cm/year; however, several stations, such as CMHI, DYHK, RCK2, GDBG, BM9L and BM18L, show relatively higher subsidence rates of 1-2cm/month or 12-24cm/year. Stations CMHI, DYHK, RCK2 and GDBG are located in areas hosting the textile industry, where excessive groundwater extraction is expected, while BM9L and BM18L lie on the banks of the River Citarum. It may be seen in Figure 4 that subsidence rates are not always linear. Several stations show a slowing down of subsidence. Indeed, the mechanism of land subsidence in Bandung basin is not simple and may have several causal factors.

Weak Correlation

The hypothesis is that land subsidence is caused by excessive extraction of groundwater by both shallow and deep-well pumps. The majority of shallow wells are used for domestic purposes, while deep wells are operated by the regional water authority or private firms such as those belonging to the textile industry, manufacturing companies and hotels. But this hypothesis cannot always be proven; Figure 5 shows the correlation between land subsidence and registered groundwater extraction within a one-kilometre radius of the monuments, and only CMHI station shows good correlation. In addition, statistical testing using Spearmanâ€™s rank-correlation coefficients (R) showed at 99% confidence level no significant correlation between land subsidence and registered groundwater extraction during the period February 2000 to July 2002. Perhaps a role is also played in ground subsidence by other factors, such as a large volume of unregistered groundwater extraction, construction load, natural consolidation and geotectonic phenomena.

Concluding Remarks

Further research is needed to clarify the real mechanism and pattern of land subsidence phenomena in Bandung Basin. For this, GPS measurements should be integrated with other monitoring techniques such as levelling, InSAR (Interferometric Synthetic Aperture Radar) and automatic water-level recorder.

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Further Reading

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