On Mapping and Evaluating the Impacts of Land Subsidence in Bandung Basin (Indonesia)

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Key words: Land subsidence, GPS, InSAR, flooding, economic losses, Bandung

Abstract

Rising of the urbanization rate and industrial activity in Bandung Basin have increased the degree of groundwater withdrawal from the aquifers. The increased groundwater extraction has then led to land subsidence phenomenon. Based on GPS (Global Positioning System) survey method and analysis of InSAR (Interferometry Syntetic Aperture Radar) data, we found that the estimated subsidence rates at all observed areas vary highly from 2-20 cm/year. In order to map and evaluate the impacts of the land subsidence, we caried out visual observations at all areas in Bandung Basin.

Based on our visual observations, the impacts of land subsidence can be seen in several forms such as cracks in a building, damage of infrastructures (road and bridges), tilting and damaged houses. Interestingly, floodings frequently occur at the area where the subsidence rate is high. For example, the 2010 heavy flooding covers over the areas where the subsidence rates are about 7-10 cm/year. This proves that the land subsidence can aggravate the flooding in Bandung Basin.

The heavy flooding can bring another negative impacts such as huge economic and social losses in the affected area. Using spatial statistical analysis in combination with the subsidence map, we estimated that the flooding covers over the total area of about 6420 Ha and the flooding area caused by subsidence is 1388 ha or 21% from the total area.

This paper will discuss briefly the results of maping and evaluating the impact of land subsidence in Bandung Basin.

I. INTRODUCTION

Bandung Basin is a large intra-montane basin surrounded by volcanic highlands, located in West Java province, Indonesia (Figure 1). The central part of the basin has an altitude of about 665 m and is surrounded by up to 2400 m high Late Tertiary and Quaternary volcanic terrain [*Dam et al.,* 1996]. The catchment area of the basin and surrounding mountains covers approximately 2300 km^2, and the Citarum River with its tributaries forms the main drainage system of the basin catchment. It is one of the largest watersheds on the island of Java, which provides water for drinking, agriculture and fisheries, as well as the main supply for three reservoirs (hydroelectric dams), with a total volume of about 6147 million cubic meters [*Wangsaatmaja*, 2004]. Mean annual temperature in the basin is about 23.7°C, with mean annual precipitation amounts to about 1700 mm [*Iwaco-Waseco,* 1991]. Deposits in the basin comprise of coarse volcaniclastics, fluvial sediments and notably a thick series of lacustrine deposits.

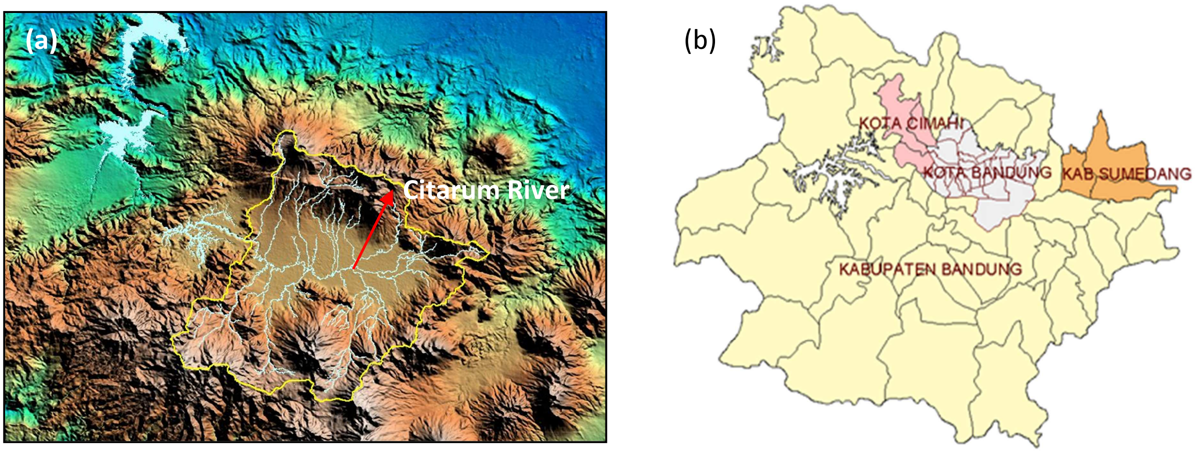


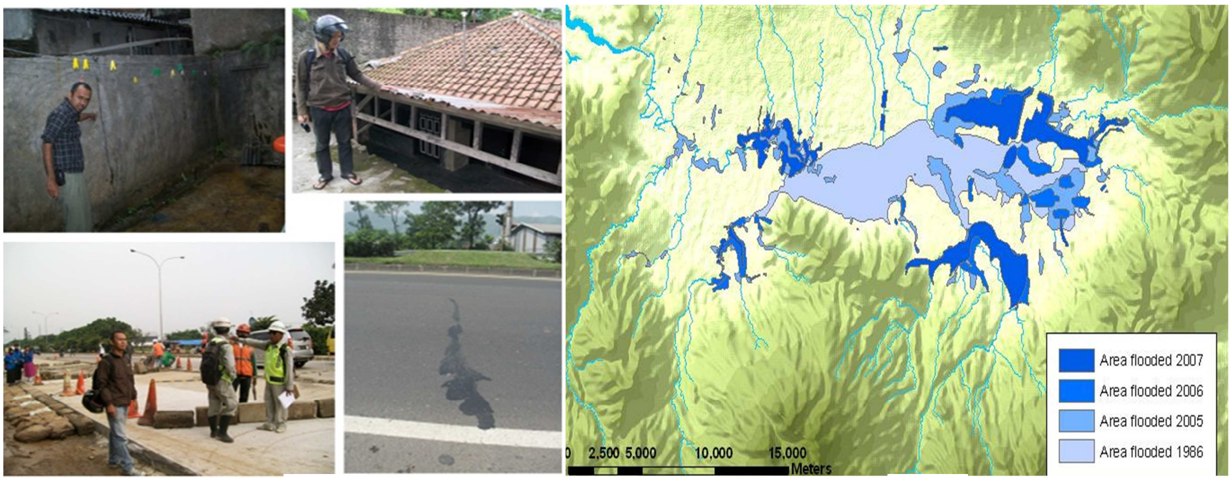
Figure 1. Bandung Basin and Citarum River (a) and its location in West Java, Indonesia (b)

On the basis of its hydraulic characteristics and its depth, the multi-layer aquifer configuration of the Bandung Basin may be simplified into two systems [*Soetrisno,* 1996]: *shallow aquifers* (a few metres to around 40 m below the surface) and *deep aquifers* (more than 40 m to 250 m below the surface). These aquifers are composed of *volcanic products* from the volcanic complexes that bordered this basin, and *lake sediments* that were deposited when the central part of the basin was a lake. The lake was fully formed about 50.000 years ago, and was drained away about 16.000 years ago [*Dam et al.*, 1996].

The basin has an area of about 2300 km^2 and encompasses five administrative units: the Bandung city (municipality) which is an urban area 81 km^2 in size perched against the northern mountain range; the surrounding Bandung regency; part of the Sumedang and West Bandung regencies; and the city of Cimahi (Figure 1b). The central part of the basin, mostly comprising urban and industrial areas, is a plain measuring about 40 km east–west and about 30 km north–south. Bandung city itself is the capital of West Java province, Indonesia. The population of the Bandung municipality increased from less than 40,000 in 1906 to nearly one million in 1961, and had grown to about two and half million by 1995. The population in Bandung basin itself was about 3.4 million in 1986, became about 4.4 million in 1994, and in 2003 the population is about 5.9 million peoples. In addition, with expansion of manufacturing and textile industries in the Bandung Basin, urbanisation increased and in 2005 more than 7 million people inhabited the basin (Abidin et al., 2011). The increase in both population and industrial activity in turn increased the degree of groundwater withdrawal from the aquifers in the Bandung Basin. Increased groundwater extraction has led to a rapid sinking of water tables on the plain.

The expected groundwater extraction is believed tobe one of the causes of land subsidence beside the load of man made construction, natural consolidation of alluvium and geotectonic.

The impacts of land subsidence can be seen in several forms such as cracks in buildings, damage of infrastructures (road and bridges), tilting and damaged houses (direct impact) (Figure 2a), and also affecting the flooding inundation area (indirect impact). Flooding in Bandung Basin has been widely reported, in which it occurs many times in a year and heavy flooding usually happens after heavy rainfall. The history of flooding in Bandung Basin can be seen in Figure 2b. Flooding in Bandung Basin has brought huge economic losses to household, business interuption, industrial, agriculture, infrastructure, public facilities and social activities in affected area.



(a) (b)

Figure 2. Direct impact of land subsidence (a) and map of flooding history (UCBFM, 2010) (b) in Bandung Basin

This paper will discuss briefly about land subsidence derived by GPS and InSAR, and also the impact of land subsidence in Bandung Basin.

II. LAND SUBSIDENCE DERIVED BY GPS DAN INSAR METHODS IN BANDUNG BASIN

Several methods have been conducted to monitoring land subsidence in Bandung Basin such as GPS (Global Positioning System) survey method and InSAR (Inteferometry Syntetic Aperture Radar) method (Abidin et al., 2008).

In order to study land subsidence phenomena in Bandung Basin, eight GPS surveys have been conducted by Geodesy Research Division, Institute of Technology Bandung (ITB). Schedulle of GPS measurement and distribution of observed sites can be seen ini Table 1 and Figure 3.

Table 1. GPS Champaign for studying land subsidence in Bandung Basin

Champaign	Date
1	21- 24 February 2000
2	21- 30 February 2001
3	11-14 July 2001
4	1-3 Juny 2003
5	24-27 Juny 2005
6	21-23 August 2008
7	26-29 July 2009
8	29-31 July 2010

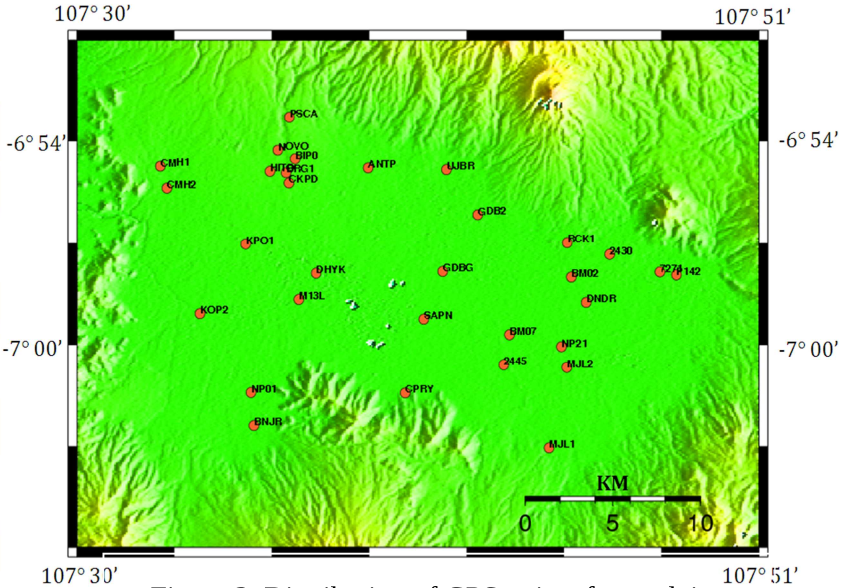
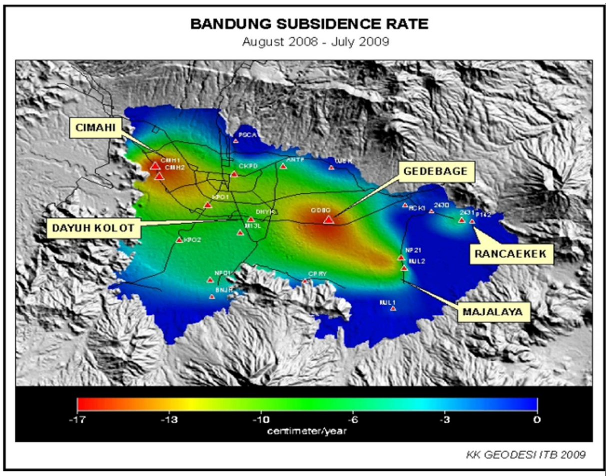


Figure 3. Distribution of GPS points for studying land subsidence in Bandung Basin

The survey at all stations were carried out using dual-frequency geodetic-type GPS receivers. In this case PSCA station located inside the Institute of Technology Bandung was used as the reference point with known coordinates and assumed stable. The data were processed using the software Bernese 5.0 [*Beutler et al.,* 2007]. Since we are mostly interested in the relative heights with respect to a stable point, the radial processing mode was used instead of a network adjustment mode. In this case, the relative ellipsoidal heights of all stations were determined relative to PSCA station. For the data processing, a precise ephemeris (SP3) was used instead of the broadcast ephemeris. The effects of tropospheric and ionospheric biases were mainly reduced by the differencing process and the use of dual-frequency observations. The residual tropospheric bias parameters for individual stations were estimated to further reduce the tropospheric effects. The algorithms for the tropospheric parameter estimation can be found in *Beutler et al., (*2007). In the processing of GPS baselines, most of the cycle ambiguities of the phase observations were successfully resolved.The GPS results for last two years can be seen in Figure 4.



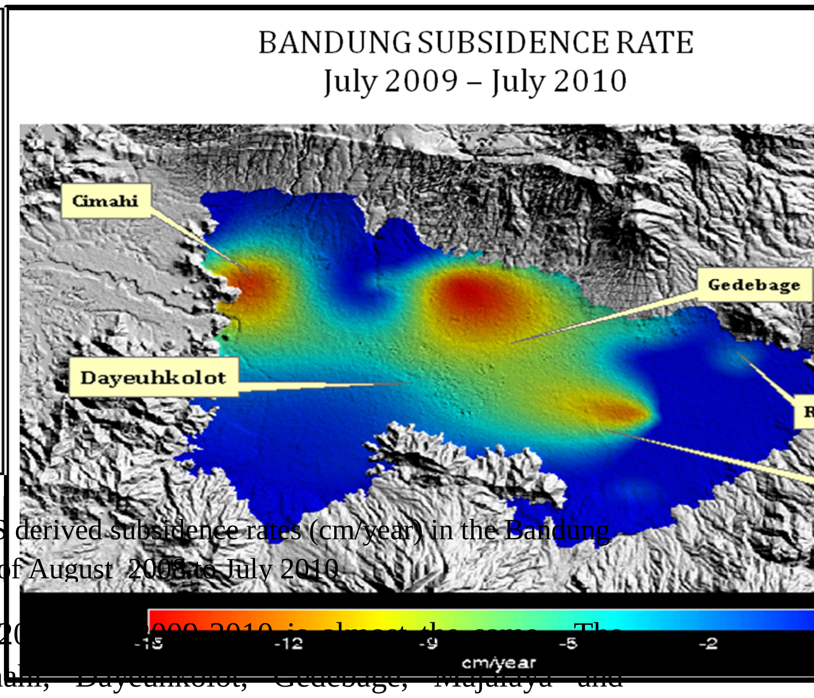


Figure 4. Temporal and spatial variation of GPS derived subsidence rates (cm/year) in the Bandung Basin during the period of August 2008 to July 2010.

The pattern of land subsidence from 2008-20[illegible]009-2010 is almost the same. The largest land subsidence occured in Cimahi, Dayeuhkolot, Gedebage, Majalaya and Rancaekek where they are located at industrial area. Maximum rate of land subsidence in 2008-2009 is 17 cm/year, while in 2009-2010 is 15 cm/year.

Wee have also analyzed InSAR data in Bandung Basin from the ALOS/PALSAR satellite. All the data were processed by the Gamma software. In this research, we used dual-pass differential method to produce the deformation image in Bandung Basin. Dual-pass DInSAR (Differential InSAR) needs only twoSAR images, consisting of master and slave images to produce the deformation image. The Data used in this paper can be seen in Table 2. InSAR result for the last two years can be seen in Figure 5.

Table 2. The InSAR data used in this research

1	06 March 2007	Ascending	Fine Beam Sensor
2	14 January 2007	Ascending	Fine Beam Sensor
3	18 April 2009	Ascending	Fine Beam Sensor
4	28 January 2009	Descending	Fine Beam Sensor
5	16 December 2009	Descending	Fine Beam Sensor
6	3 Mei 2010	Descending	Fine Beam Sensor

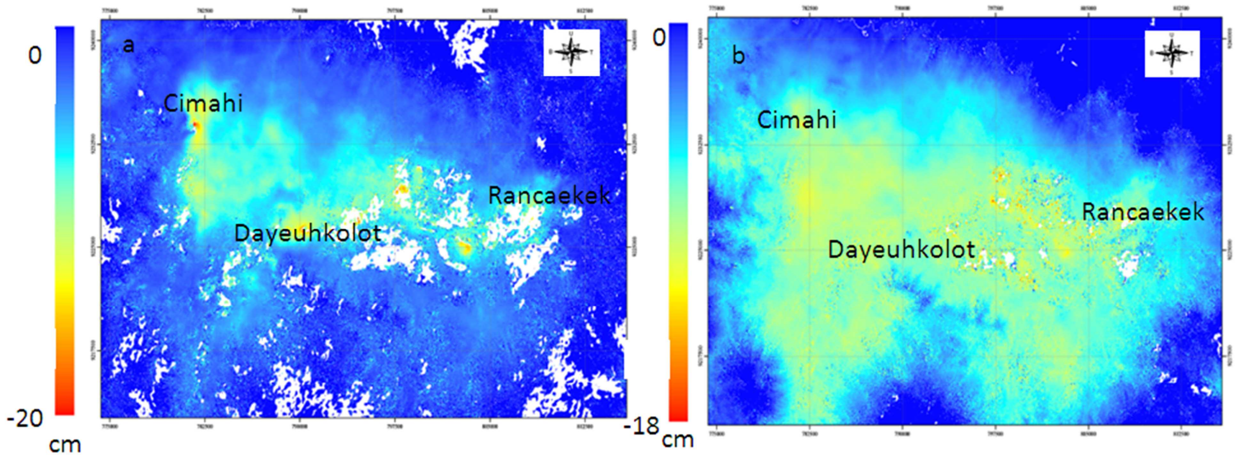


Figure 5. Land subsidence derived by InSAR on Januari 2009-December 2009 (a) dan December 2009-May 2010 (b)

Based on InSAR results in Figure 4, the subsidence from January 2009 to December 2009 could reach as large as 20 cm, while from December 2009 to May 2010, it could reach 10-12 cm. Comparing to GPS results (Figure 3), the InSAR derived subsidence rate is larger than that of GPS. It should be noted that the subsidence rate derived from InSAR is still affected by noise due to wrong phase unwrapping process and very low correlation of images. Regardless of noise effect in InSAR data, the results show that large subsidence seems to occurs at Cimahi, Dayeuhkolot, Rancaekek, and Gedebage sites.

As has been known that GPS provides better accuracy results than that of InSAR. However, InSAR provides better spatial resolution than that of GPS. Therefore integration of GPS and InSAR method provides a better solution to obtain high accuracy and wide spatial information of land subsidence. In this research, we model the subsidence by assimilating the result from GPS and InSAR data. Assimilating technique used by Karabatic (2011) for the case of water vapour assimilation is adopted. Integration result without weighting can be seen in the Figure 5.

In the weighting method, to obtain the integrated value of Land Subsidence (LS) at each point of the model grid the LS from the InSAR are multiplied with the f_{ij} coeficients for each grid point i, j:

$$PV_{ij} = f_{ij} PV_{ij}^{InSAR} \quad (1.1)$$

To calculate the coefficients f_{ij}, the following function has been applied:

$$f_{ij} = \sum_{k=1}^{N} W_{ij}^{k} fk(\theta, \emptyset) \quad (1.2)$$

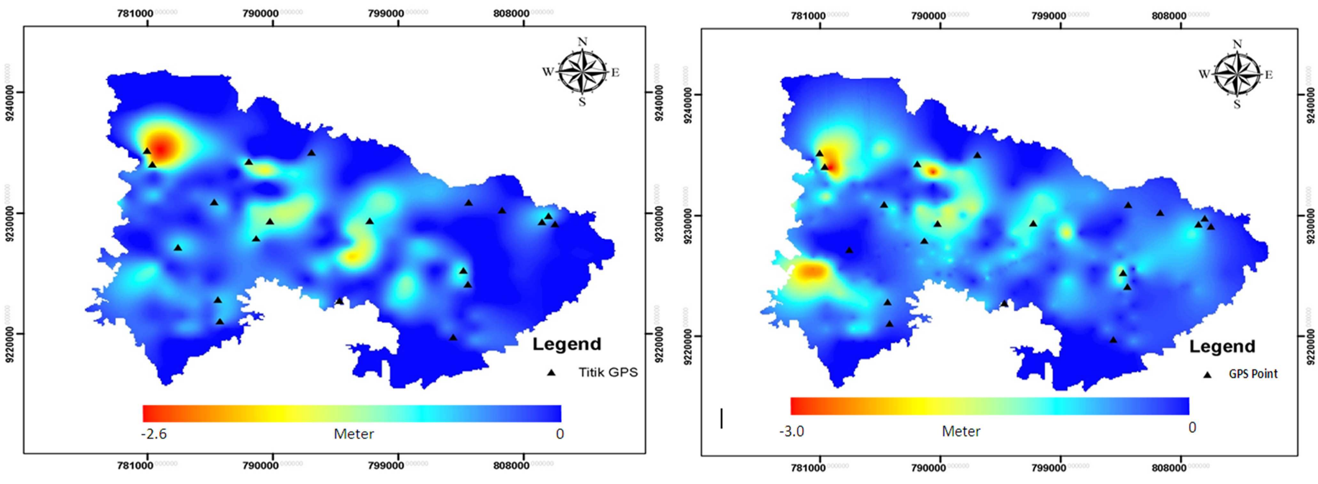
The coefficient are weighted with respect to distance r of the GPS station k (r_k) to the grid point using the following weighting function:

$$W_{ij}^{k} = \begin{cases} \dfrac{\frac{1}{r_k^2}}{\sum_l \frac{1}{r_l^2}} & untuk\ r_k \leq 15\ km \\ 0 & untuk\ r_k > 15\ km \end{cases} \quad \ldots\ldots\ldots\ldots\ldots..\ldots\ldots\ldots\ldots..(1.3)$$

r_l represent the distance of all relevant stations, i.e. the ones within 15 km (denoted with l). The multipliers fk for each of the GPS stations are calculated using following expression:

$$fk(\theta, \emptyset) = \frac{LS^{GPS}}{LS^{InSAR}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1.4)$$

Where LS^{GPS} reperesent land subsidence derived from GPS observations and LS^{InSAR} represents land subsidence derived from InSAR data , and θ *and* $\emptyset$ are geographic longitude and latitude of station k, respectiveliy. The weigting result can be seen in Figure 6.



(a) (b)

Figure 6. Land Subsidence derived by GPS and InSAR data on 1999-2010 without weighting (a) dan with weighting (b)

Based on combination result of GPS and InSAR, land subsidence in Bandung Basin reached 3 meter from 1999 until 2010. The largest subsidence occurred in Cimahi, Gedebage, Dayeuhkolot, Rancaekek, Majalaya and Leuwigajah.

Most large subsidence occurs in the industrial area which is expected taking a groundwater from deep aquifer in the large number. The industry relies 100% supplied of groundwater resources. The land subsidence in these area has an impacts such as cause cracks on building, damaged house, cracks on road/highway, and wider expansion of flooding area. In the next chapter will discuss briefly groundwater extraction and its impacts to land subsidence in Bandung Basin.

III. IMPACT OF LAND SUBSIDENCE IN BANDUNG BASIN

Field survey has been done to map and evaluate the impacts of land subsidence in Bandung Basin.

The survey was focused in the areas where the subsidence rates are very high. Beside collecting pictures of damaged building or road, we also interviewed the local people to achieve further information (Figure 7).

Figure 7. Field survey documentation to evaluate and map the impact of land subsidence in Bandung Basin

Based on field survey, the impacts of land subsidence in Bandung basin could be seen in several forms, such as cracking of permanent constructions and roads, changes in river canal and drain flow systems, tilting and damaged houses, wider expansion of flooding areas, and malfunction of drainage system (see Figures 8, 9, 10, and 11)

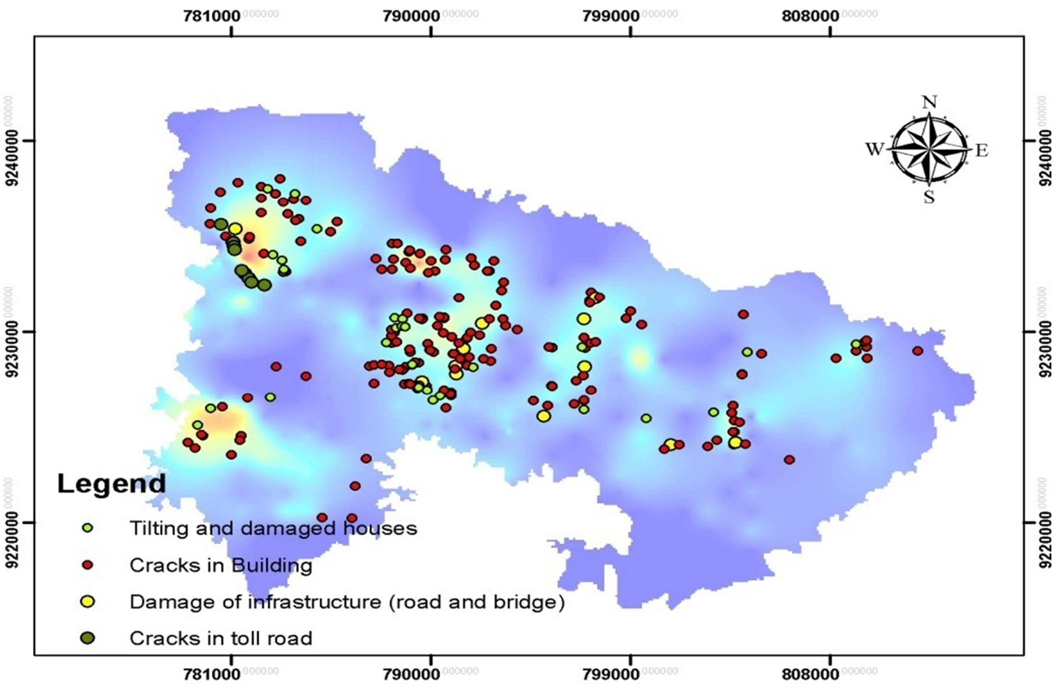


Figure 8. Mapping of land subsidence impact in Bandung Basin

Figure 9. ImpactS of land subsidence on permanent constructions in Bandung Basin

Figure 10. Impact of land subsidence on cracking of road and highway road in Bandung Basin

Figure 11. Impact of land subsidence on tilting and damaged houses in Bandung Basin

Cracks on the building and road do not occur in the subsiding area, but they occur at the boundary of the two different subsiding areas (differenciate subsidence). Size of cracking varies between 1 mm to 10 mm. it is interesting to note that the cracking on highway road occurs mostly close to industrial factories (building). According to result from interviewing local people, they do not realize that the cracks on their houses are due to land subsidence.

Another impact of land subsidence in Bandung Basin is wider expansion of flooding, as it has been widely reported. Regular flooding occurs many times every year in Bandung Basin and heavy flooding usually happens in the areas along Citarum River when heavy rainfall. Main possible causes of flooding in Bandung Basin are: Population Pressure, poorly waste management, poorly flood management system, poorly drainage, rainfall, geophisic of river impact, poorly river capacity, erosion in upper course and sedimentation in lower course and land subsidence and groundwater extraction (Bappeda Kab. Bandung, 2009). Flooding with or without land subsidence impact has to be modelled to estimate the contribution of land subsidence to heavy flooding 2010.

The heavy rainfall occurred in 2010 and it caused heavy flooding in Bandung Basin, the data of rainfall in Bandung basinn can be seen in Figure 12.

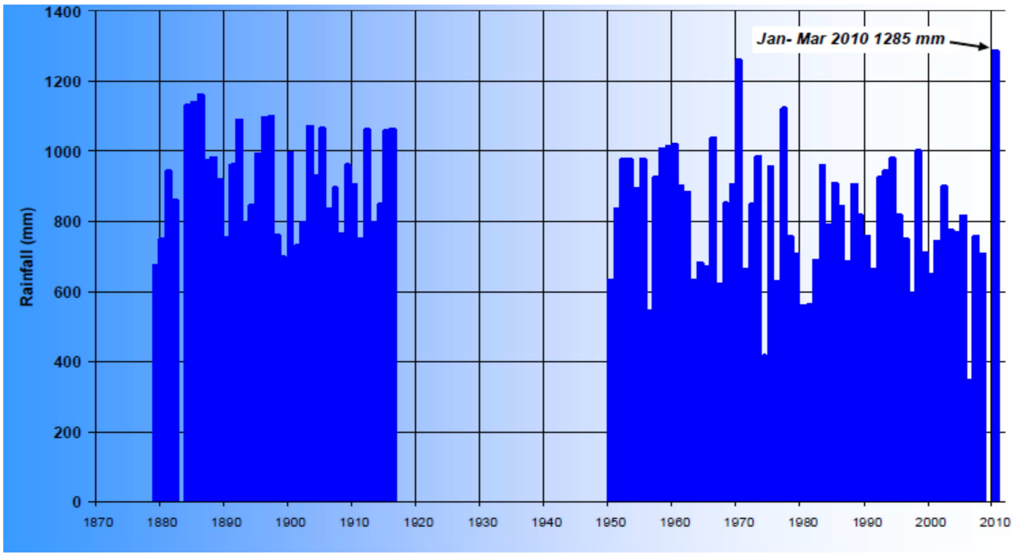


Figure 12. Rainfall data in Bandung Basin in 1970-201 (UCBFM, 2010)

The flooding area in Bandung Basin were modelled by using SOBEK software from Deltares (Holland). Sobek software was designed to estimate 2D flooding area. The input of this software are the rainfall data, geometry of Citarum river, land use, and Digital Elevation Model (DEM) in 2010. DEM data and the land use data can be seen in Figure 13.

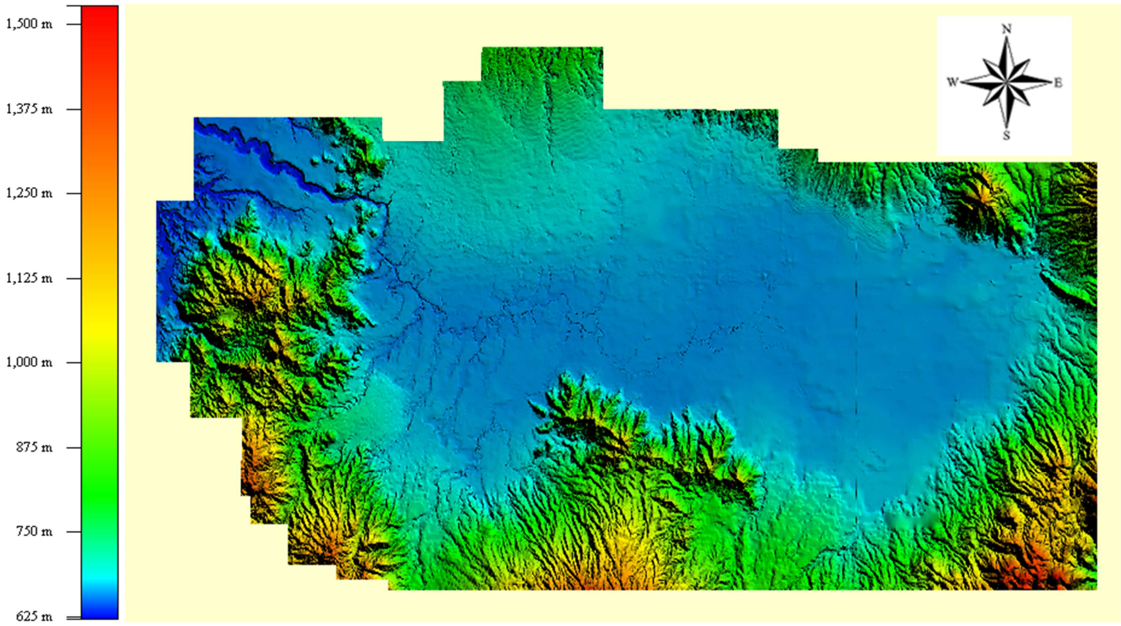


Figure 13. Digital Elevation Model of Bandung Basin 2010

The DEM data were generated from many kind data such as: levelling data, Shuttle Radar Topography Mission (SRTM) data, fotogrametry data, and Base Map of Indonesia. The land use map in 2006 can be seen in Figure 14.

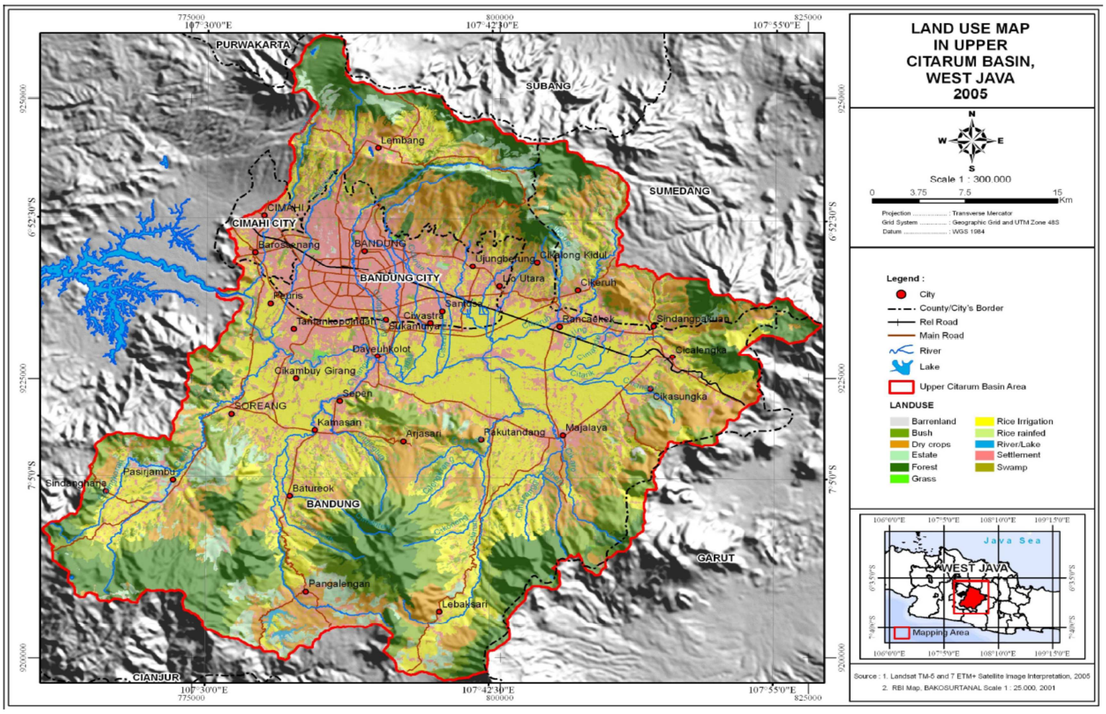


Figure 14. Land use map of Bandung Basin 2006 from Landsat image (UCBFM, 2010)

The result of flooding area and its depth in 2010 with land subsidence impact can be seen in Figure 15.

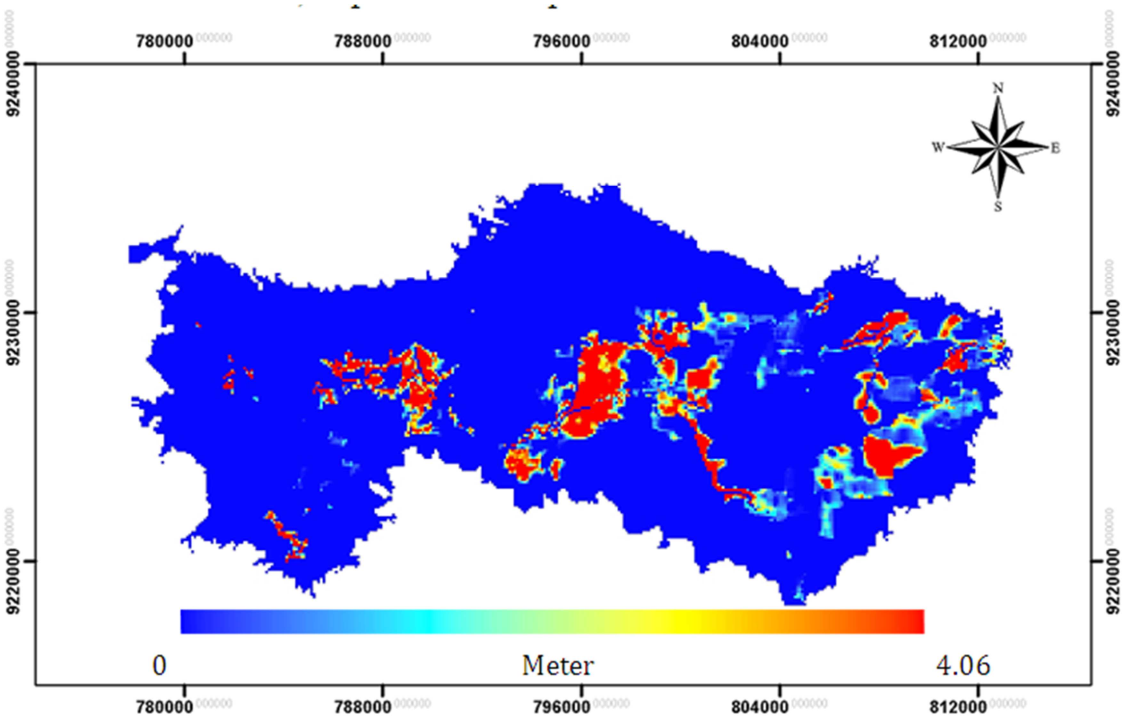


Figure 15 . Flooding area 2010 and its depth include subsidence impact

To generate flooding area and its depth without land subsidence impact, the DEM 2010 were corrected by land subsidence 1999-2010 data from combination GPS and InSAR data with weighting. This corrected DEM were used to estimate flooding area without subsidence impact (Figure 16).

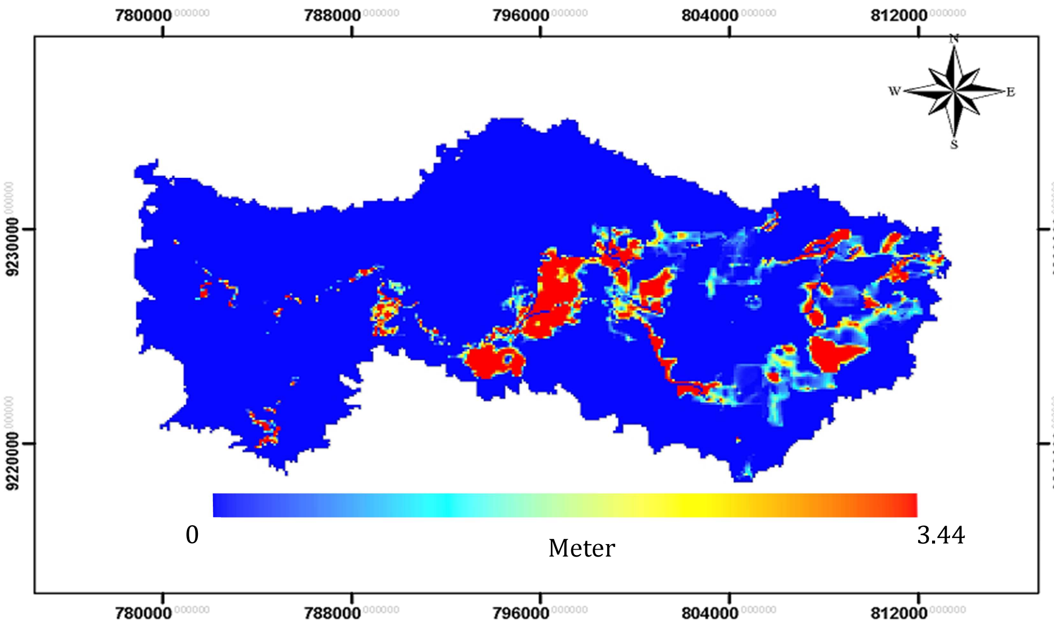
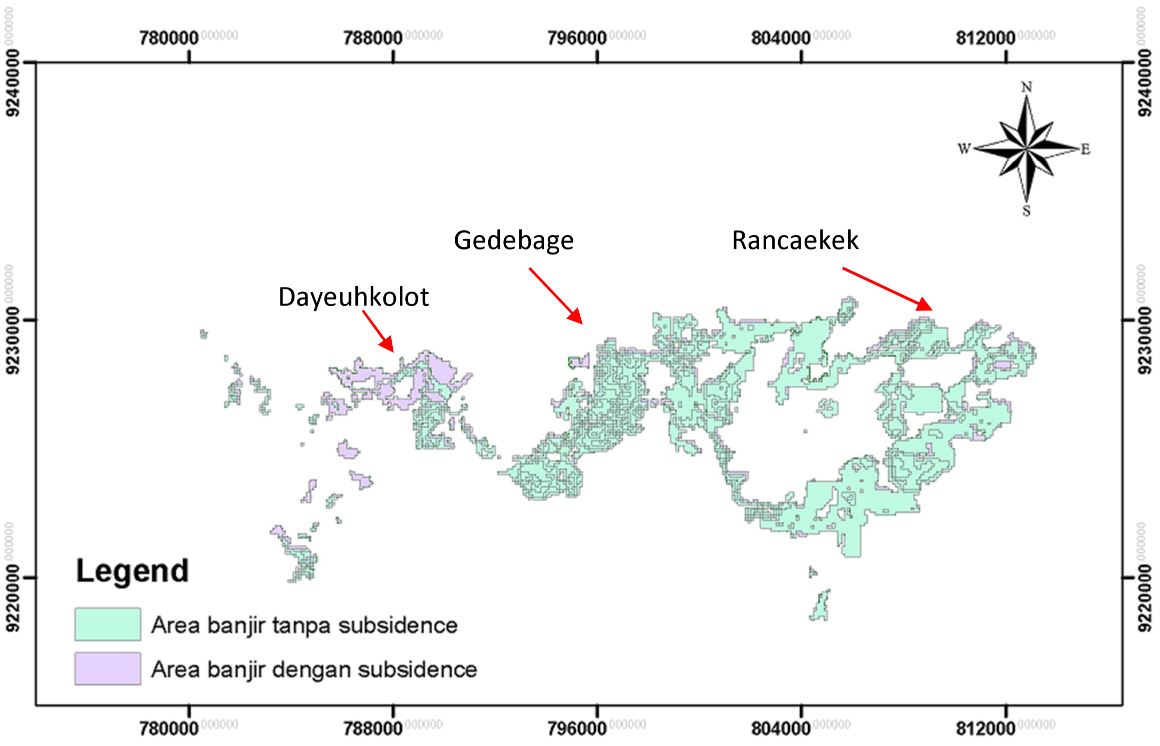


Figure 16. Flooding area 2010 and its depth without subsidence impact

The data above show that land subsidence give impact to wider flooding in Bandung Basin. Figure 17 shown clear difference between flooding area with and without subsidence impact. Total area flooded in Bandung Basin are 6420 ha. Flooding in the areas which have relatively large subsidence in Bandung Basin are shown in Figure 16, namely Gedebage, Majalaya, Rancaekek, and Dayeuhkolot. The subsidence rates in these areas are larger than those in the other areas with the rate of subsidence is about 7-10 cm/year. The difference in flood area with or without subsidence is 1388 ha, so that it can be concluded that flooding area caused by subsidence is 1388 ha or 21% from total area flooded.



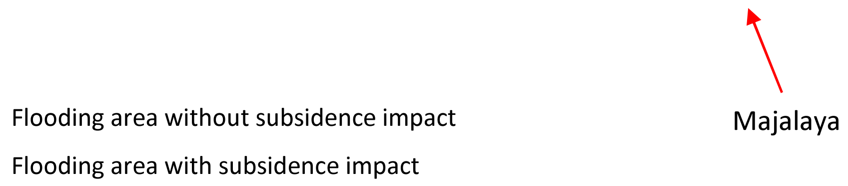


Figure 16. diffrences Flooding area with and without subsidence impact

The impacts of land subsidence above show that the direct and indirect impacts of land subsidence are terrible and they are potential causes of economic losses in Bandung Basin. Alternative solution to reduce the impact of land subsidence is to propose proper regulation for groundwater extraction. Groundwater extraction is one of cause land subsidence in Bandung Basin.

Increasing in both population and industrial activity increase the degree of groundwater withdrawal from the aquifers in the Bandung Basin, as ilustrated in Figure 17. According to Wirakusumah (2006), approximately 60% of the total clean water required in the Greater Bandung Area (i.e about 512 million cubicmetres) are supplied by groundwater, and industry relies nearly 100% on groundwater resources. The two primary categories of groundwater withdrawers in the basin are shallow well pumps and deep well pumps. The majority of shallow wells are used for domestic purposes, while deep wells are operated by

the regional water company or by private firms such as textile industries, manufacturing companies and hotels [*Braadbaart and Braadbaart*, 1997].

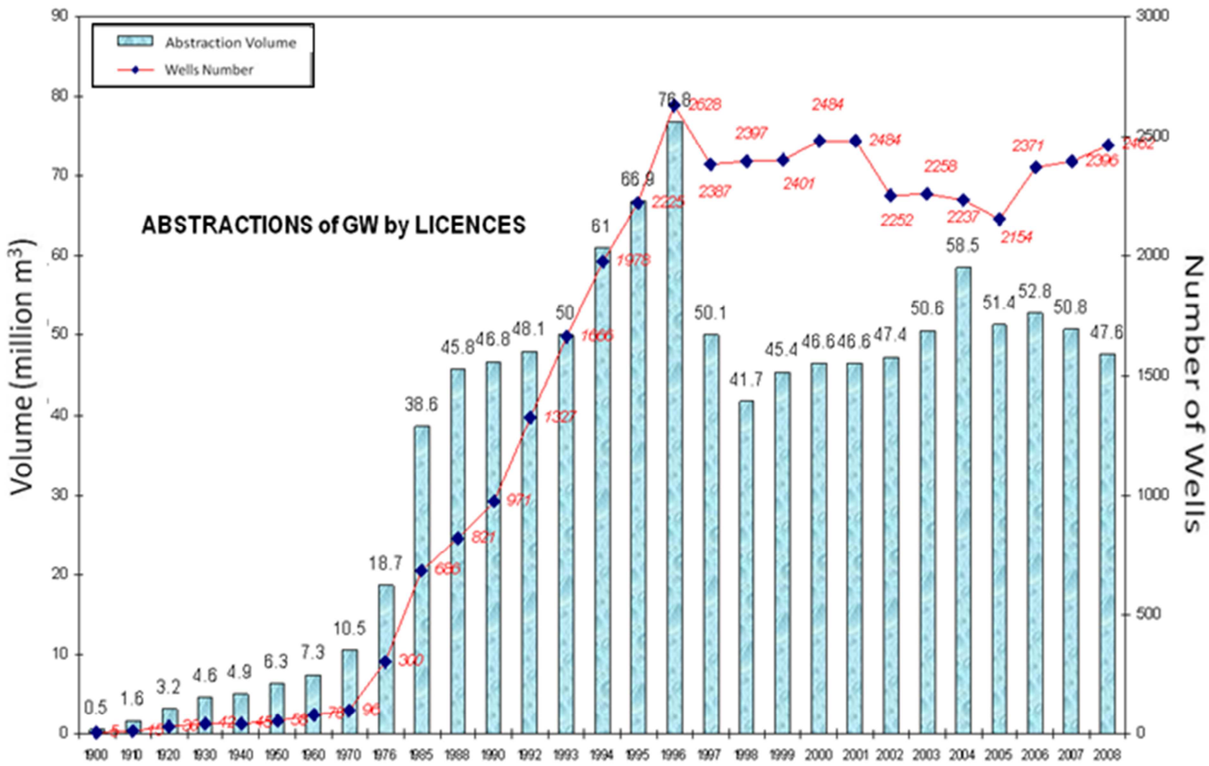


Figure 17. Groundwater extraction in Bandung Basin (1900-2008) from deep aquifers (40-250 m) below the surface; courtesy of Geological Agency of Indonesia

Correlation between land subsidence and groundwater extraction can be done by utilizing the registered groundwater extraction volume and the observed groundwater level. In case of the correlation with groundwater extraction, *Abidin et al.* (2006; 2008) have shown that the GPS-derived land subsidence do not always have a positive correlation with the registered volume of groundwater extraction around the corresponding GPS stations (i.e. inside 1 km radius). This fact could imply two things; firstly the registered groundwater extraction volume does not reflect the real groundwater use, and secondly the amount of land subsidence is also influenced by other factors, such as the different geological structures and soil compressibility at the observed locations. In some wells, there is strong correlation between land subsidence and decrease of groundwater table as shown in Figure 18.

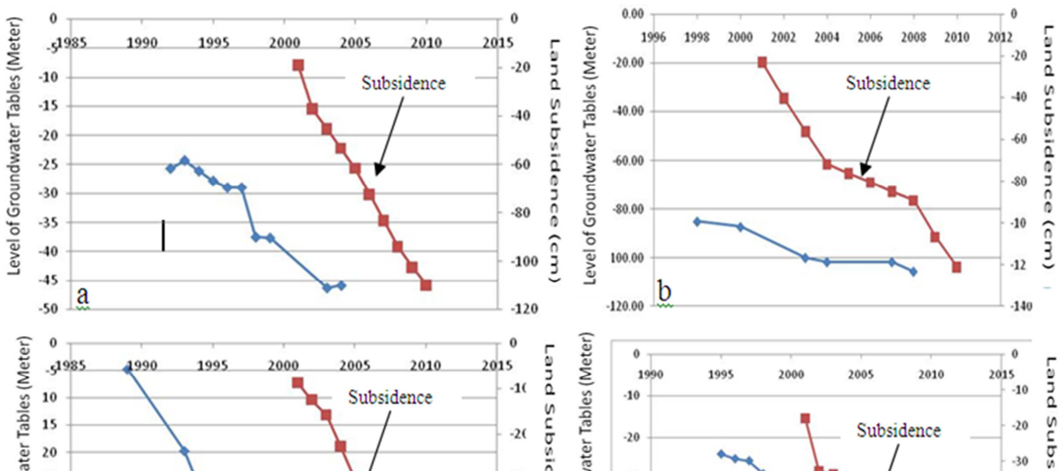


Figure 18. Land subsidence and decrease of groundwater water tables at Dayeuhkolot (a), Cimahi (b), Banjaran (c), dan Rancaekek (d)

In Cimahi, Banjaran, Dayeuhkolot, and Rancaekek areas, land subsidence rate is obviously due to the decrease of groundwater tables, since there is a strong correlation between land subsidence and decrease of groundwater tables in these area.

One of the government's policies for groundwater conservation is to implement of high groundwater tax. Unfortunately, this policy of groundwater tax has not been applied optimally to obtain the preferred condition.The tariff for groundwater surface is very high in Bandung and its tariff has been increasing every year. No choice for the industry but to continue the extraction. For this case the government have to regulate strictly the groundwater extraction by industry, find out another water resources and the most important is the government must pay attention to land rehabilitation, re-forestation and spring conservation in the recharge area.

IV. DISCUSSION AND CONCLUSION

Base on the result obtained from land subsidence monitoring in the Bandung Basin, it can be concluded that a combination of GPS Survey and InSAR result are useful for studying and monitoring land subsidence in Bandung Basin. Several places such as: Dayeuhkolot, Gedebage, Banjaran, Majalaya, and Cimahi has higher subsidence rate compared to others with rates of subsidence about 7-10 cm/year.

Base on field survey, land subsidence in Bandung Basin has a direct impact such as: cracking on houses/building, damaged and cracking on road and highway road, and cause damaged and tilting houses of buildings that potential cause economic losses. The Indirect impact of land subsidence is wider expansion of flooding in Bandung Basin. The flooding mainly occurred in the areas along the Citarum River and its tributaries and subsidence in these areas will worsen it. Total area flooded in 2010 flooding in Bandung Basin are 6388 ha and 21% or 1388 ha from total area flooded caused by land subsidence.

Regulation of groundwater extraction is one solution to reduce the impact of land subsidence. We can learn from Osaka and Bangkok experiences facing the groundwater problem. The regulation was strictly implemented by the governments of each city, including designation of critical areas, development of permitted system of grounwater pumping, enforcement of technical standars, construction of waterworks, and implementation of groundwater charge system. Among these options, the most effective solution was the construction of waterwork because without scs system groundwater users would have no choice but to continue extraction (Endo, 2010).

V. REFERENCES

Abidin, H. Z., Andreas, H., Gamal, M., Djaja, R., Murdohardono, D., Rajiyowiryono, H. & Hendrasto, M. (2006) Studying landsubsidence of Bandung Basin (Indonesia) using GPS survey method. *Survey Review* **38**(299), 397–405.

Abidin, H. Z., Andreas, H., Gamal, M., Wirakusumah, A. D., Darmawan, D., Deguchi, T. & Maruyama, Y. (2008) Land subsidence characteristics of the Bandung Basin, Indonesia, as estimated from GPS and InSAR. *Journal of Applied Geodesy*, **2**(3), 167 -177. DOI : 10.1515/JAG.2008.019.

Abidin. H. Z, Gumilar. I, Andreas, H, Sidiq. T. P, Fukuda. (2011). Study on Causes and Impacts of Land Subsidence in Bandung Basin, Indonesia. Paper presented in FIG Working Week 2011, Bridging the Gap Between Cultures, Marrakech, Marocco, 18-22 May 2011.

Beutler G, H. Bock, R. Dach, P. Fridez, A. Gade, U. Hugentobler, A. Jaggi, M. Meindl, L. Mervant, L. Prange, S. Schaer, T. Springer, C. Urschl, and P. Walser (2007). *Bernese GPS software Version 5.0*. In: R. Dach, U. Hugentobler, P. Fridez, and M. Meindl (eds) Astronomical Institute, University of Berne, 612 pp.

Braadbaart, O. & Braadbaart, F. (1997), Policing the urban pumping race: industrial groundwater overexploitation in Indonesia, *World Development* **25**(2), 199–210.

Dam, M. A. C., Suparan, P., Nossin, J. J., Voskuil, R. P. G. A. & G. T. L. Group (1996) A chronology for geomorphological developments in the greater Bandung area, West-Java, Indonesia. *J. Southeast Asian Earth Sci.* **14**(1–2), 101–115.

Endo, T. (2010). The Roles of Government in Groundwater Management-Institutional Responses to Land Subsidence Problem in Asian Mega city. Paper presented at *The 3rd International Symposium, Human Imapct on Urban Subsurface Environment*, 17-20 November 2009.

Iwaco-Waseco (1991) *Bandung Hydrological Study*. Main Report Annex 1: Surface water resources.

Karabatic, Anna. (2011). Precise Point Positioning (PPP) – an Alternative Technique for Ground Base GNSS Troposphere Monitoring. Dissertation. Technisce Universitat Wien, Vienna.

Soetrisno, S. (1996). Impact of Urban and Industrial Development on Groundwater, Bandung, West Java, Indonesia. Paper presented at the *Symposium on Groundwater and Landuse Planning*, Fremantle, Western Australia, 16-18 September 1996.

Upper Citarum Basin Flood Management Project. (2010). Institutional Strengthening For Integrated Water Resourches Management in the 6 CIS River Basin Territory (Package C). Deltares, PUSAIR, ITB, MLD.

Wangsaatmaja, S., Sutadian, A. D. & Prasetiati, M. A N. (2006) A review of groundwater issues in the Bandung Basin, Indonesia: Management and Recommendations. *The International Review for Environmental Strategies (IRES)* **6**(2), http://www.iges.or.jp/en/pub/ires/volume6_2.html.

Wirakusumah, A. D. (2006). Airtanah Bandung Raya, Makalah disajikan pada Lokakarya Pemenuhan Kebutuhan Air Baku di Cekungan bandung Tahun 2025, Bandung, 28 February 2006.

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