Land subsidence induced by agriculture activity in Bandung, West Java Indonesia

T. P Sidiq, I Gumilar, H.Z Abidin, M Gamal

1Geodesy Research Group, Faculty of Earth Science and Technology, Institut Teknologi Bandung
Labtek IX-C, 4th floor, Jl. Ganesha No. 10 Bandung, West Java, Indonesia

Abstract. Bandung, the capital city of West Java Indonesia, is known as a large basin surrounded by mountains and highlands. In the last few decades, the industries grown in the region, leaving fewer agricultural area which used to be the livelihood for the local peoples. The growth of industries and increasing of population also increase the extraction of ground water which is believed to be the cause of land subsidence in Bandung. However, the use of ground water are not only addressed to industries and household, it is also used by agricultural activity. We use 45 ALOS PALSAR images, range from January 2007 to March 2011 from both ascending and descending direction to investigate the land subsidence in agricultural area. We exploit the SBAS method on persistent scatterers to find the subsidence rate over the period. Our study shows LOS displacement associated to land subsidence in two agricultural area, Sukamanah and Rancaekek with similar rate of 5 cm/year in both location. The rate of subsidence is indeed higher in industrial area with the rate as high as 15 cm/year in Cimahi and Gedebage which shows much higher ground water extraction. Our field investigation finds that there used to be water pumping for cultivation and had been done for several years in both location. Over exploitation of ground water in those location lead to the deeper ground water level and higher the risk of drought. Further study and better data verification using GPS is still needed in the future.

1. Introduction
Bandung, the capital city of West Java Province, Indonesia, is known as a large intra-montane basin and surrounded by volcanic highlands. The city itself is located inside the basin, where a thick series of lacustrine deposit exist. According to [17], the basin is formed by Cibereum Formation where aquifers can be found, Kosambi Formation as aquitard, and Cikapundung Formation as bed rock along with some other Formations (Figure 1).

The 2010 census by Badan Pusat Statistik (National Statistics Agency) show that more than 7.6 million peoples lived in Bandung basin. The population is almost doubled since 1980 which the census showed around 4.1 million peoples lived on the basin. This rapid increasing of population also followed by increasing of water and land needs. Incapability of performing good management of surface water and its source, lead to over exploitation of ground water by industry and household. [2] asserts that
increasing of ground water extraction along with extensive change in land use including the load of manmade constructions, and damage in ecological function of surrounding upland area, cause land subsidence in Bandung basin.

The land subsidence in Bandung basin has been studied for many years, and become a well-known phenomenon in some areas of Bandung. [15] suggest natural cause of land subsidence in Bandung such as consolidation and tectonic activity. GPS campaign done by [1] and [15] show maximum subsidence in Bandung basin reach 18 cm/year, located in the industrial complex in Cimahi. Ground water over exploitation by industry is indeed cause the largest subsidence in Bandung, however, over exploitation by housing and agricultural activity also cause land subsidence.

![Figure 1: Geological formation in Bandung basin region. Adapted from [17].](image)

Here, we use Interferometry Synthetic Aperture Radar (InSAR) method to observe land subsidence in the agricultural area in Bandung. The InSAR method has proven to be effective and reliable to map and monitor deformation. Its application is widely used in volcano monitoring [10] [9], crustal movement [28], mining activity [14], and urban ground subsidence [12] [5] [22] as well. Improvement in precision, coverage, resolution and more rapid data acquisition are offered by the method from time to time. These improvement are contribution from both satellite system and data processing methodology. [13] gave the very good result of deformation monitoring in whole Sumatra and Java Islands, Indonesia, from year 2007 to 2009 using ALOS-PALSAR data. However, very small analysis was done for land subsidence Bandung, although good time-series analysis were produced. [15] used conventional differential InSAR method to map land subsidence in Bandung, and compare the result with GPS campaign result. Another good and recent application and of InSAR method to map land subsidence in Bandung was done by [20] that suggest ground consolidation has large contribution to the land subsidence in Bandung, because land subsidence still continue even when ground water level had been stable.

2. Data and Methodology

We used ALOS PALSAR-1 data to map ground subsidence in Bandung basin. There are 45 scenes of ALOS PALSAR-1 data in both ascending (path 436 frame 7040) and descending (path 110, frame 3760) direction. Figure 2 shows the area captured by images used on the study. The acquisitions are range from January 2007 to March 2011 for ascending data, while the descending data range from July 2007 to March 2011. Data comes in both FBD and FBS mode, while the look angle are the same, which is
34.4°. All data were ordered in RAW Level 1.0 format instead of Level 1.1 SLC data. Differential SAR was achieved using 3 arc-second SRTM digital elevation model refined by CGIR-CSI.

We used several open source software in order to generate ground subsidence map in Bandung. ROI PAC [7] was used to generate SLC data since the data comes in RAW format. DORIS [4] was used to generate all interferograms needed for the time series inversion. While STAMPS [16] was used to select the persistent scatterers. We use Small Baseline Analysis (SBAS) method for time series analysis [24]. In order to select best pair interferograms, we follow the procedure in STAMPS which defined as,

\[ q = \left(1 - \frac{|B_{\perp m|}}{B_{max}}\right) \times \left(1 - \frac{|t_m-t_s|}{\Delta t_{max}}\right) \]  

(1)

Where \( q \) is the correlation, \( B_{\perp ms} \) is the baseline temporal of reviewed pairs, \( B_{max} \) is the maximum baseline between all pairs, \( t_m \) and \( t_s \) are master and slave acquisition date respectively, and \( \Delta t_{max} \) is the maximum date between slave and master. In this study, all pairs with correlation below 0.45 are not included in the time-series analysis. The threshold value was chosen through several trial and error process.

Unlike the popular SBAS method performed by [3] here we follow [24] for the time series analysis and inversion. The time series inversion is done by solving following linear system using least square method,

\[ Gm = d \]  

(2)

Figure 2. Area of Study, red thin line square show the Ascending area, while the black one show descending image area. Red square in the middle show focused area of study.

Figure 3 : Schematic showing the relationship between data and model matrices in the inversion [24].
Where \( G \) is the design matrix contain of 1 and 0, \( m \) is the line of sight (LOS) change at any given acquisition date which is to be solved, and \( d \) is the LOS change for every interferogram. The parameter \( m \) is solved by using weighting from the phase noise analysis done during PS point selection \( C \),

\[
m = (G^T C G)^{-1} G^T C d
\]

3. Results

Generated subsidence rate for both ascending and descending directions are shown in Figure 6. There are 166,988 PS points out of 12,181,323 estimated points in the first step for descending data series, while in ascending data series, total number of PS points is 143,349 out of 8,678,841 points. The maximum subsidence rate for ascending and descending directions are around 140 mm/year and 120 mm/year respectively. However, for the sake of representative graphic display, we set the maximum value of subsidence rate only to 120 mm/year.

![Image of InSAR Processing result from ascending and descending direction.](image-url)

**Figure 4.** InSAR Processing result from ascending (top) and descending (bottom) direction.

Largest subsidence rate occur in Cimahi (A) and Dayeuh Kolot (B) which is confirmed to be industrial area. While location indicated by C and D are Solokan Jeruk and Haarpugur respectively, both confirmed as agricultural area, paddy field for more specific. Other area are not focus on this study, but those location are confirmed to be either industrial area or housing. Figure 4 shows the rate of subsidence occur in Solokan Jeruk and Haarpugur, both have relatively similar rate around 5 cm/year.
Figure 5. PS points overlayed with Google image in Solokan Jeruk (top) and Haurpugur (bottom).

There are no many PS points in the area showed on Figure 5 above since most of the area are watered during plantation. Most of the PS points are observed from dry season interferograms, nevertheless, the noise are relatively small so that the time series inversion result shows relatively smooth and consistent.

We also conduct a small field survey and interview with local people to validate our result. Figure 6 below shows the condition of the area taken on August 2015. Our interview with local people confirm that there were a large usage of ground water during 2007 to 2010. The local farmer pumped the water in some wells (around 20 points), with deep vary around 30 to 60 meter. Pumping were stopped completely around 2011 when the water source went too deep.

4. Discussion

Our result shows that ground subsidence is not only subjected to over exploitation of ground water by industry. Household and agriculture activity also contribute quite significant to land subsidence in
Bandung. However, our discussion will be focused only to ground subsidence induced by agricultural activity, while other anthropogenic and natural cause are not our focus on this study. Usage of ground water for agriculture is practiced all around the world as showed on Table 1 [8]. [26] list several reason why the use of ground water is popular for agriculture,

- Ground water is usually found close to the point-of-use (often only a well’s depth away)
- It can be developed quickly at low capital cost by individual private investment
- It is available directly on-demand for crop needs (given a reliable energy source for pumping) and thus affords small-holders a high level of control year-round
- Ground water is well-suited to pressurised irrigation and high productivity precision agriculture
- It has ‘democratised’ irrigation by permitting irrigated agriculture outside canal command areas.

For comparison, in US, usage of ground water for irrigation is even started back in 1900, where first large subsidence were also observed [11] where the farmers used relatively deep ground water source. [21] also mentioned about agriculture as one of the cause of land subsidence in Semarang, Indonesia, although the paper was not specifically inform the rate of subsidence caused by agriculture activity.

Our validation on this study is rely on the interview with the local peoples, since accurate data of ground water usage on the are not exist. However, to some extend, information such as the estimated deep of the wells, and both onset and end time of water pumping is also considered to be accurate. [19] divide the aquifer system in Bandung into three systems, first, shallow unconfined aquifer (0 to 20 meter deep); second, intermediate middle semi-confined aquifer (20 to 80 meter deep) and third, deep lower semi-confined aquifer (> 80 meter deep). Thus, most of the ground water source mostly pumped from intermediate quifer. Water pumping from shallow to intermediate aquifer is considered to commonly practiced to get water with relatively small capital, as many farmers do in many places in Indonesia.

The onset and end time of water pumping also consistent with the rate of subsidence as shown on Figure 5. The rate increase significantly around July 2008, and then slowed after September 2010. Maximum rate during this periode is around 6 cm/year, and then get slower afterwards to about 2-3 cm/year, and may indicate that the pumping was indeed stopped. However, since no data were available after April 2011, the estimation is quite questionable.

In Solokan Jeruk, subsidence area is not coincided with any structure nor any important facilities, so the effect of the subsidence is very local. While in Haurpugur, the maximum rate of subsidence is coincidence with the main railway, which connect Bandung to many cities in the southern part of Java Island. This route is very busy, serve many commuter trains and logistics from and to Bandung. Although the rate of subsidence were quite high, no damage or lost has been reported. Due to high potential of both safety and economical risk, it is very important to monitor this segment using a more detail and accurate method such as leveling or GPS.

Bandung groundwater management that usually focus on the technical approach. Bandung government still tries to attract more investors to build economic activity, thus make the environmental issues of groundwater are not being a priority aspect in case of development planning [23]. Moreover, before the government could provide enough and affordable water for household, industry and agriculture, ground water will be the main option for peoples to get water, especially during dry season. Although ground water usage for agriculture is not commonly practiced in Bandung, farmers will eventually use it when there is no option left. From hazard perspective, long term of ground water usage for agriculture has many downside such as [18] [13], and [25]

- Saline water intrusion,
- High concentration of water contaminate, such as arsenic, salt, pesticides and ammonium,
- Depletion of ground water table and aquifer compaction
- Phreatophytic vegetation stress
- Land subsidence and its related impacts.
- Socio-economic risk

5. Conclusion
We mapped the land subsidence and its rate from 2006 to 2011 using ALOS PALSAR-1 data. One of the causes of land subsidence is due to over withdrawal of ground water for agriculture, which occur in Solokan Jeruk and Haerpugur. The maximum rate of subsidence, reach 6 cm/year in both places. The subsidence in Haerpugur also coincide with vital railway infrastructure, which need more accurate and continuous monitoring of land subsidence.

Government involvement of managing ground water and bring the issues to higher level is needed in order to stop, or at least control, land subsidence in Bandung basin. Unregulated and uncontrolled continuous monitoring of land subsidence.

6. References
[1] Abidin, H. Z, Andreas H, Gamal M, Djaja R, Murdohardono D, Rajiyowiryono H., et al 2006 Studying landsubsidence of Bandung Basin (Indonesia) using GPS survey method Survey Review 38 397–405
[2] Abidin H, Andreas H, Gumilar I, Sidiq T P & Fukuda Y 2012 Land subsidence in coastal city of Semarang (Indonesia): Characteristics, impacts and causes. Geomatics, Natural Hazards and Risk p.1–15
[3] Berardino P, Fornaro G, Lanari R & Sansosti E 2002 A newalgorithm for surface deformation monitoring based on small baseline differential SAR interferograms. IEEE Transactions on Geoscience and Remote Sensing 40(11) p.2375–2383
[4] Bert M Kampes, Ramon F Hanssen, and Zbigniew Perski. Radar interferometry with public domain tools In Third International Workshop on ERS SAR Interferometry ‘FRINGE03’ Frascati Italy 1-5 Dec 2003 page 6 pp 2003
[5] Cabral-Cano E, Dixon T H, Miralles-Wilhelm F, Diaz-Molina O, Sanchez-Zamora O & Carande, R E 2008 Space geodetic imaging of rapid ground subsidence in Mexico City Geological Society of America Bulletin, 120(11–12), 1556–1566
[6] Cahussard E, Amelung F, Abidin H, Hong S, 2013 Sinking cities in Indonesia: ALOS PALSAR detects rapid subsidence due to groundwater and gas extraction, Remote Sensing of Environment 128 pp 150–161
[7] Caltech/Jet Propulsion Laboratory 2003 Repeat Orbit Interferometry Package, Open Channel Foundation Edition : 2.2, http://www.openchannelfoundation.org/projects/ROI_PAC
[8] Chandra A. Madramootoo 2012 Sustainable Ground Water Use in Agricultre. Irrigation and Drainage Vol. 61 (Suppl. 1) p. 26-33
[9] Chaussard E & Amelung F 2012 Precursory inflation of shallow magma reservoirs at west Sunda volcanoes detected by InSAR. Geophysical Research Letters
[10] D Massonnet., P Brio, and A Arnaud, Deflation of Mount Etna monitored by spaceborne radar interferometry Nature vol. 375 pp. 567–570 June 1995.
[11] Deverel J S, Rojstaczer S 1996 Subsidence of Agricultural lands in the Scramento-San Joaquin Delta, California: Role of Aquous and Gaseous Carbon Fluxes. Water Resources Research, Vol. 32 No. 8 p. 2359-2367
[12] Dixon T H, Amelung F, Ferretti A, Novali F, Rocca F, Dokka R, et al. 2006 Space geodesy: Subsidence and flooding in New Orleans Nature 441(7093), 587–588
[13] Foster SSD, Chilton PJ, Moench M, Cardy F and Schiffler M 2000 Groundwater in rural development: facing the challenges of supply and resource sustainability. World Bank Technical Paper No 463 Washington DC.
[14] Guéguen Y, Deffontaines B, Fruneau B, Heib Al, de Michele M, Raucoules D, et al 2009 Monitoring residual mining subsidence of Nord/Pas-de-Calais coal basin from differential and
persistent scatterer interferometry (Northern France). *Journal of Applied Geophysics* **69**(1), 24–34

[15] Gumilar I, Abidin H Z, Andreas H, Sidiq T P, Gamal M & Fukuda Y 2014 *Land Subsidence, Groundwater Extraction, and Flooding in Bandung Basin (Indonesia)*. In C. Rizos, & P. Willis (Eds.), *Earth in the Edge: Science for a Sustainable Planet* (pp. 167–173) Berlin Heidelberg: Springer.

[16] Hooper A, Zebker H, Segall P, Kampes B 2004 A new method for measuring deformation on volcanoes and other natural terrains using InSAR persistent scatterers, *GEOPHYSICAL RESEARCH LETTERS* V**OL. 31** L23611

[17] Hutasoni L M 2009 Kondisi Permukaan Air Tanah dengan dan tanpa peresapan buatan di daerah Bandung: Hasil Simulasi Numerik *Jurnal Geologi Indonesia* **Vol. 4** No. 3 Sept., pp. 177–188.

[18] IGES 2007 Sustainable groundwater management in Asian cities: A final report of research on sustainable water management policy. Hayama: Institute for Global Environmental Strategies.

[19] Lilik Eko WIDODO 2013 *Estimation of Natural Recharge and Groundwater Build up in the Bandung Groundwater Basin Contributed from Rain Water Infiltration and Interaquifer Transfer*. Procedia Earth and Planetary Science 6 (2013) p. 187 – 194

[20] Linlin Ge, Hay-Man A N, Xiaojing Li, Abidin H Z, Gumilar I, 2014 Land subsidence characteristics of Bandung Basin as revealed by ENVISAT ASAR and ALOS PALSAR interferometry, Remote Sensing of Environment 154 p.46–60

[21] Marfai M A and King L. 2007 Monitoring land subsidence in Semarang, Indonesia. *Environmental Geology* **53**: 651–659

[22] McDonald A 2012 Flood risk in Asia's urban mega-deltas: Drivers, impacts and response. *Environment and Urbanization ASIA, 3*(1) 41–61

[23] NAKAGAMI Kenichi, Dita Arif Yuwana 2012 *Groundwater Sustainability in Bandung, Indonesia*

[24] Schmidt D, Burgmann R, 2003 Time-dependent land uplift and subsidence in the Santa Clara valley, California, from a large interferometric synthetic aperture radar data set *JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 108*, NO. B9, 2416

[25] Schmidt KD, Sherman I. 1987 Effect of irrigation on groundwater quality in California. *Journal of Irrigation and Drainage Engineering ASCE 113*(1), p.16–29

[26] Shah T, Burke J, Villholth K. 2007 *Groundwater: a global assessment of scale and significance*. In Molden D (ed). *Water for Food, Water for Life, Earthscan: London and IWM* I: Colombo, Sri Lanka

[27] Soetrisno, S. 1996 *Impacts of urban and industrial development on groundwater, Bandung, West Java, Indonesia*. In: Symposium on Groundwater and Landuse Planning (Fremantle, Western Australia, 16–18 September)

[28] Zebker H A, Rosen P A, Goldstein R M, Gabriel A K & Werner C L 1994 On the derivation of coseismic displacement-fields using differential radar interferometry - the Landers Earthquake *Journal of Geophysical Research* 99 19617–19634