Article

Land Subsidence Monitoring From ALOS/PALSAR Data By Using D-InSAR Technique In Semarang City, Indonesia

I Nyoman Sudi Parwata [a,b]*, Kakuji Ogawara [a], Tasuku Tanaka [b], Takahiro Osawa [a,b,c]

[a] *Graduate School of Science and Technology for Innovation, Yamaguchi University, 2-16-1 Tokiwadai, Ube 755-8611, Japan; ogawara@yamaguchi-u.ac.jp (K.O.)*

[b] *Center for Remote Sensing and Ocean Sciences (CReSOS), Udayana University, PB Sudirman Street, Denpasar, Bali 80232, Indonesia; tttanaka@yamaguchi-u.ac.jp (T.T.)*

[c] *Regional Satellite Applications Center for Disaster Management (RSCD), Japan Aerospace Exploration Agency (JAXA), 4-1-1 Industrial Technology Institute Asutopia, Ube, Yamaguchi 7550195, Japan; osawa320@gmail.com (T.O.)*

* *Correspondence: sudi_jbc@yahoo.com*

Received: 27 June 2018; Accepted: 22 May 2019; Available online: 1 June 2019

Abstract

This research was focused to estimate land subsidence in Semarang City by using DInSAR Method during 2007-2010 which is based on ALOS-PALSAR data. Three pair of SAR images were processed to detect land subsidence during 2007-2010. On the other hand, three pairs of SAR images (with small perpendicular baseline and very short interval time observation) were processed to generate Digital Elevation model (DEM). This DEM used to remove topographic phase in DInSAR processing. The land subsidence in Semarang City mostly appears in Northern area (main city), with maximum subsidence value which is derived by using DInSAR Method is about -4.8 cm/year (2007-2008), -8.1 cm/year (2008-2009), and -9.9 cm/year (2009-2010). The average is 7.6 cm/year (2007-2010). The subsidence result by using DInSAR technique was compared with GPS data which was available during 2008-2011. The coefficient determination between DInSAR and GPS method is about 0.65 for 2008-2010. Its mean DInSAR method has a good accuracy and reliable to use for land subsidence monitoring in wide area. The main causes land subsidence in Semarang City is probably due to load of building structure and over extraction of ground water. The number of registered drilled wills increased rapidly during early 1990s especially is industrial areas. The total drilled wells are 1050 units in 2000s.

Keywords: *ALOS/PALSAR; DInSAR; land subsidence; GPS*

1. Introduction

The increase of human population and human activities cause escalation upon the needs on natural resources. To cover the requirements of natural resources, human exploits the earth through fluid withdrawal (water and oil) and solid extraction (coal, gold, sulfur mining). These activities cause the occurrence of land subsidence. Land subsidence does not occur only by human made, but also occur naturally such as by tectonic motion (earthquake) and rising sea level (Husnayaen *et al.*, 2018). Land subsidence (land surface sinking) occurs in many parts of the world, particularly in dense population regions (Chaussard *et al.*, 2013). Groundwater abstraction is the most major cause of land subsidence which is accelerating since World War II. More than 150 cities in the world were reported where substantial subsidence was a problem in 1995 (Barend *et al.*, 1995).

Indonesia has several major cities namely Jakarta, Semarang, Surabaya, Medan, Bandung and Denpasar. Research about land subsidence has been conducted by several Indonesian researchers (e.g., Abidin et al., 2013; Yastika et al., 2017; Yastika et al., 2019). Jakarta's Land subsidence has been conducted by Abidin *et al.*, (2001) using GPS (General Positioning System) ground survey during 1991-1997, he found that the maximum rate of land subsidence is about -26cm/year. In Semarang City, detection of land subsidence has been conducted by (Kuehn *et al.*, 2010) by using stable points network (SPN) technique. The result of this research showed that land subsidence in Semarang city during 2002-2006 was about 1 mm/year until 10 cm/year. Nowadays, many building in Semarang city was reported that severely affected by land subsidence due to over extraction of groundwater and loading compact soil by settlements (Yastika *et al.*, 2019). Land subsidence in Indonesia usually occurs due to urban development and groundwater withdrawal.

However, many methods can be applied to detect and to monitor land subsidence, such as Differential GPS (DGPS) measurements, campaign Global Positioning System (GPS) surveying, spirit-leveling surveying and Differential Interferometric Synthetic Aperture Radar (DInSAR). The most accurate method is Differential GPS (DGPS) measurements. It is possible to detect subsidence as precise as 1-3 mm, but this technique provides information at only discrete points where the equipment is installed. The other hand, Differential Interferometric Synthetic Aperture Radar (DInSAR) is very good method to be applied in wide areas (covering up to hundreds of kilometers square) to detect land subsidence and to provide the greatest spatial resolution.

2. Materials and Methods

2.1 Research Location

Research location is located in Semarang City, Central of Java, Indonesia (Figure 1). The position of Semarang City is at the -6°58' (latitude) and +110°25' (longitude), and the total area covers is about 37,367 hectares (274 km^2), the population is about 1.55 million peoples in 2010 (BPS, 2011). Semarang City can be divided into two areas, namely the northern part and the southern part. The northern part is location of city center, harbour, airport, railway station. Compared to the southern part, the northern part has relatively higher population density and also more industrial and businesses areas (Abidin *et al.*, 2012).

Figure 1. Map of Indonesia and Semarang City

2.2 Data Collection

Data which used in this research can be divided into two types namely: Primary data (ALOS/PALSAR data) and secondary data (GPS data).

2.2.1. Primary Data

The primary data is contains scenes in raw format (Level 1.0) data from ALOS-PALSAR satellite, shown in Table 1.

Table 1. List of ALOS/PALSAR scenes of Semarang City during 2007-2010

No.	Scene ID	Polarization	Obsevration Date	No. of Path	No. of Frame
1	ALPSRP093147040	FB S	2007/10/24	431	7040
2	ALPSRP099857040	FB S	2007/12/09	431	7040
3	ALPSRP106567040	FB S	2008/01/24	431	7040
4	ALPSRPl 13277040	FB S	2008/03/ 10	431	7040
5	ALPSRP 146827040	FB S	2008/10/26	431	7040
6	ALPSRP153537040	FB S	2008/12/ 11	431	7040
7	ALPSRP160247040	FB S	2009/01/26	431	7040
8	ALPSRP200507040	FB S	2009/10/29	431	7040
9	ALPSRP207217040	FB S	2009/12/ 14	431	7040
10	ALPSRP213927040	FB S	2010/01/29	431	7040
11	ALPSRP220637040	FB S	2010/03/ 16	431	7040
12	ALPSRP260897040	FB S	2010/12/ 17	431	7040

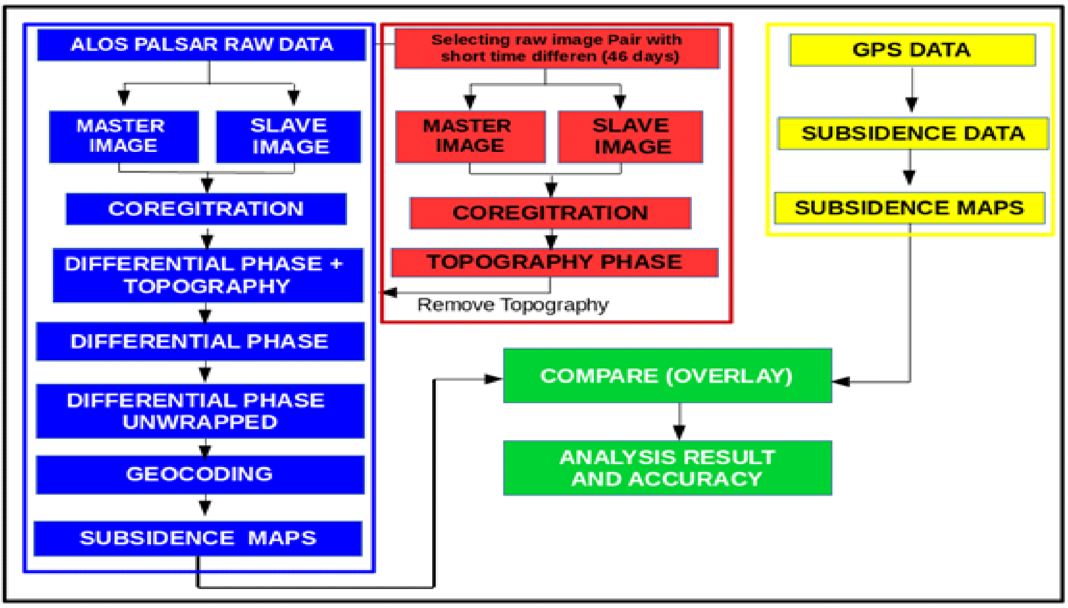


Figure 2. Research framework

2.2.2. Secondary Data

This research used GPS data as secondary data, it was provided by Geodesy Research Group of ITB (Institute of Technology Bandung). GPS data was taken during 2008 until 2011. In Table 2 shown that the subsidence rate was divided into three parts, namely 2008-2009, 2009-2010 and 2010-2011.

2.3 Data Analysis

The main stage of this research can be divided in 4 steps and it can be shown in Figure 2 The fist step (red block) is generating DEM for topography phase removing to get phase contain subsidence only. The second step (blue block) is all process for subsidence estimation. The third step (yellow block) is generating subsidence map using GPS data. The final step (green block) is comparing and analyzing DInSAR with GPS result.

The research is focused to detect land subsidence in Semarang City by using DInSAR method during 2007-2010. The primary data used ALOS-PALSAR data during 2007-2010 to generate Differential Interferometry which contained information about land subsidence. However, the result of satellite data was compared with GPS measurements. GPS data was available during 2008-2011 and it was provided by Geodesy Research Group of ITB (Institute of Technology Bandung).

Table 2. Semarang's land subsidence result by GPS during 2008-2011 (Abidin et al, 2012)

GPS Station	Latitude	Longitude	Subsidence rate (cm/year)					
			2008-2009		2009-2010		2010-2011	
			Δdh_{12}	$\sigma(\Delta dh_{12})$	Δdh_{23}	$\sigma(\Delta dh_{23})$	Δdh_{34}	$\sigma(\Delta dh_{34})$
259	6° 59' 01.53848" S	110° 24' 34.29757" E	-1	0.1	-1.64	0.11	-2.92	0.09
1106	6° 59' 41.43484" S	110° 25' 49.83667" E	-6.2	0.2	-2.21	0.19	-2.67	0.11
1114	6° 59' 13.97440" S	110° 24' 24.99820" E	-4.8	0.2	-0.44	0.16	-0.6	0.08
1124	6° 58' 48.63423" S	110° 25' 16.09457" E	-3.4	0.2	-5.23	0.17	-8.51	0.08
1125	6° 58' 49.64402" S	110° 25' 50.23961" E	-4.1	0.1	-5.6	0.09	-4.02	0.06
1303	6° 58' 01.84841" S	110° 17' 55.51349" E	-0.8	0.1	No Subsidence		-1.12	0.09
AY15	7° 00' 28.24934" S	110° 24' 58.06149" E	-2	0.1	-1.01	0.08	-1.09	0.06
BM01	6° 57' 39.19822" S	110° 26' 22.83099" E	-12.4	0.2	-10.49	0.16	-10.45	0.11
BM05	6° 57' 06.95602" S	110° 25' 09.20122" E	-4.5	0.6	-7.67	0.12	-5.44	0.08
BM11	6° 57' 21.49755" S	110° 23' 43.83551" E	-3.5	0.1	-10.66	0.09	-3.3	0.06
BM16	6° 57' 57.83834" S	110° 25' 33.21357" E	-9.4	0.2	-3.48	0.17	-3.5	0.9
BM30	6° 59' 16.34017" S	110° 22' 07.07929" E	-1.5	0.2	No Subsidence		No observation data	
BTBR	6° 56' 15.22961" S	110° 27' 34.55448" E	-8	0.1	-8.79	0.12	-8.58	0.05
CTRM	6° 58' 18.65108" S	110° 26' 31.71239" E	-6.1	0.1	-20.37	0.07	-7	0.05
ISLA	6° 57' 22.29716" S	110° 27' 33.11412" E	-11.3	0.1	-10.56	0.08	-5.76	0.12
JOHR	6° 58' 09.78469" S	110° 25' 51.25401" E	-4.4	0.1	-19.29	0.08	-8.7	0.06
K371	6° 58' 45.27787" S	110° 22' 36.38864" E	-3	0.3	No Subsidence		No Subsidence	
KO16	7° 00' 16.67290" S	110° 24' 31.55626" E	-1.8	0.2	-0.89	0.17	No Subsidence	
MP69	6° 59' 12.25143" S	110° 24' 50.23725" E	-4.7	0.2	-1.82	0.16	-0.47	0.08
MSJD	6° 57' 22.92705" S	110° 25' 26.49862" E	-7.9	0.1	-8.07	0.11	-5.77	0.08
MTIM	6° 56' 53.02872" S	110° 25' 12.20669" E	-8.6	0.1	-10.54	0.09	-5.92	0.05
PMAS	6° 56' 47.60685" S	110° 25' 28.95131" E	-4.9	0.1	-12.39	0.09	-7.67	0.06
PRPP	6° 57' 44.19683" S	110° 23' 30.20259" E	-8.3	0.1	-15.02	0.09	-10.3	0.04
SD01	6° 57' 51.75513" S	110° 24' 57.68862" E	-7.3	0.2	-5.76	0.15	-7.83	0.06
SD02	6° 58' 37.82884" S	110° 21' 56.58179" E	-3.9	0.1	No Subsidence		No Subsidence	
SFCP	6° 59' 09.28187" S	110° 25' 43.68791" E	-3.6	0.1	-7.46	0.11	-3.69	0.08
SMG2	6° 59' 02.25589" S	110° 22' 50.98895" E	-1.2	0.1	No Subsidence		-8.04	0.06
SMG3	6° 57' 48.92545" S	110° 23' 47.38281" E	-10.1	0.1	-10.8	0.11	-9.9	0.06
SMG5	6° 57' 05.62171" S	110° 28' 42.28930" E	-5.2	0.1	-14.8	0.08	-8.81	0.06
SMPN	6° 59' 42.84922" S	110° 27' 24.55411" E	-4.8	0.1	-8.65	0.09	-5.09	0.08
SP05	6° 59' 20.73137" S	110° 25' 22.27051" E	-10.4	0.3	-6.14	0.24	-4.8	0.06
T447	7° 01' 25.10252" S	110° 25' 13.90672" E	-2.8	0.1	-0.86	0.13	No Subsidence	
VTRN	6° 59' 52.40809" S	110° 25' 09.88486" E	-6.2	0.2	-0.93	0.15	-0.27	0.07
SMKN	6° 57' 58.631717" S	110° 24' 08.134543" E	No observation data		-8.99	0.09	No observation data	
T374	6° 58' 33.059812" S	110° 21' 09.091662" E	No observation data		No Subsidence		No Subsidence	
CPMR	6° 56' 43.876272" S	110° 25' 59.823423" E	No observation data		-9.25	0.04	-3.5	0.05
RMPA	6° 57' 27.979790" S	110° 26' 56.573285" E	No observation data		-11.02	0.06	-9.8	0.06
DRI1	6° 58' 08.704624" S	110° 25' 28.768514" E	No observation data		-4.95	0	-5.28	0.04
K370	6° 58' 16.723797" S	110° 23' 25.626647" E	No observation data		-12.7	0.13	-8.2	0.09
KOP8	6° 58' 23.916197" S	110° 24' 54.109307" E	No observation data		-7.67	0.13	-10.69	0.01
PAMU	6° 59' 15.220335" S	110° 23' 22.911480" E	No observation data		-0.73	0.09	No Subsidence	
PBR1	6° 58' 14.096126" S	110° 19' 59.403666" E	No observation data		No Subsidence		-2.58	0.87
QBLT	6° 57' 18.982396" S	110° 18' 53.439961" E	No observation data		-1.49	0.04	-3.42	0.06

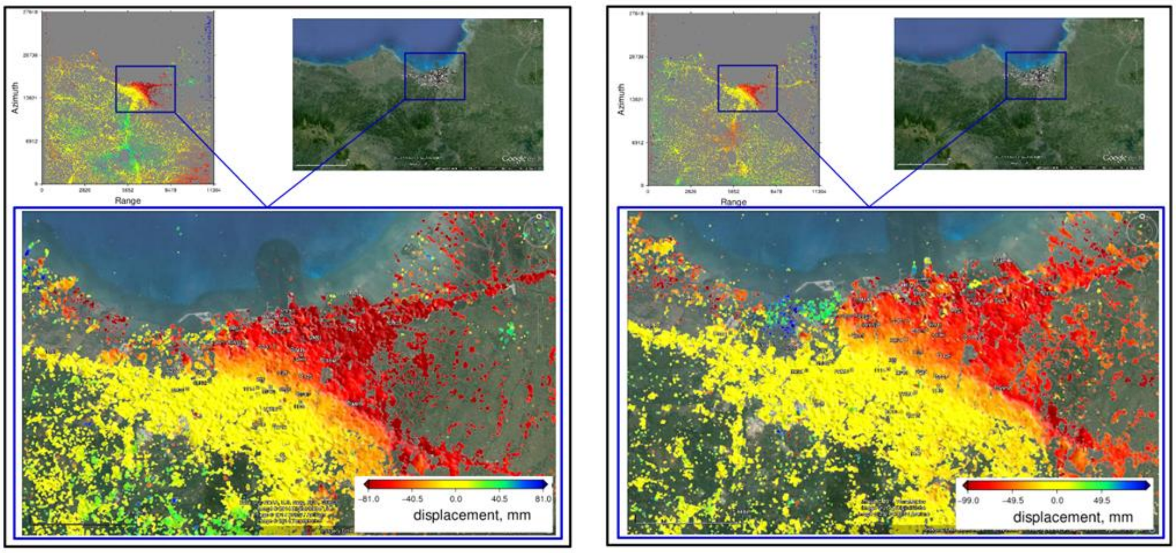
The introduction should briefly place the study in a broad context and highlight why it is important. It should define the purpose of the work and its significance. The current state of the research field should be reviewed carefully and key publications cited. Please highlight controversial and diverging hypotheses when necessary. Finally, briefly mention the main aim of the work and highlight the principal conclusions.

As far as possible, please keep the introduction comprehensible to scientists outside your particular field of research. All references should be cited in the body of the text and not in the abstract. References should be cited in the text by the last name of the authors(s) and the date of publication, with no comma before the date, according to these examples: articles by three or more authors are cited by the first author followed by "et al." and the date (Mondal et al. 2015); articles by two authors are cited by both last names joined by an ampersand (Carlson & Arthur 2000); and articles by a single author are cited by the last name and the date of publication (Schott 1997). See the end of the document for further details on references.

3. Results and Discussion

3.1 Dinsar Technique to Detect Land Subsidence in Semarang City

The land subsidence in Semarang mostly appear in northern area. From Figure 3 show the subsidence which is derived by using DInSAR and overlay with points location of GPS data. The maximum subsidence during 2008-2009 was about -8.1 cm and mostly in coastal areas. In 2009-2010 the same area, the subsidence was increasing until -9.9 cm.



(a) (b)

Figure 3. Land subsidence derived by using DInSAR technique and overlay with GPS points location, (a) during 2008-2009, and (b) during 2009-2010.

The land subsidence in Semarang city mostly caused by compaction of clay within the aquifer layer due to over ground water withdrawal. Nowadays, many building in Semarang city was reported that severely affected by land subsidence due to over extraction of groundwater and loading compact soil by settlements (Kuehn *et al*., 2010).

3.2 Data Validation of Dinsar by Using GPS Data

Data validation process compares subsidence which is resulted by DInSAR and GPS. This step makes correlation each points GPS value with same coordinates location in DInSAR map. In this research only available to compare subsidence during 2008-2009 and 2009-2010, because SAR data is available during 2007-2010 (is not available during 2010-2011). On the other hand, GPS data only available during 2008-20011 and can not provide data during 2007-2008.

The Comparison of average subsidence results by using GPS and DInSAR during 2008-2010 is shown in Figure 4. The good correlation between GPS and DInSAR is seemed in area with low subsidence (see Figure 4 points : 259, 1124, 1125, AY15, BM05, BM30, BTBR, K371, KO16, MP03, MSJD, PMAS, SD01, SMG2, SMPN, SMKN, T374, DRI1, and PAMU). Nonetheless, the largest difference result appears in points BM01, CTRM , ISLA, JOHR, PRPP, SMG3, SP05 and K370.

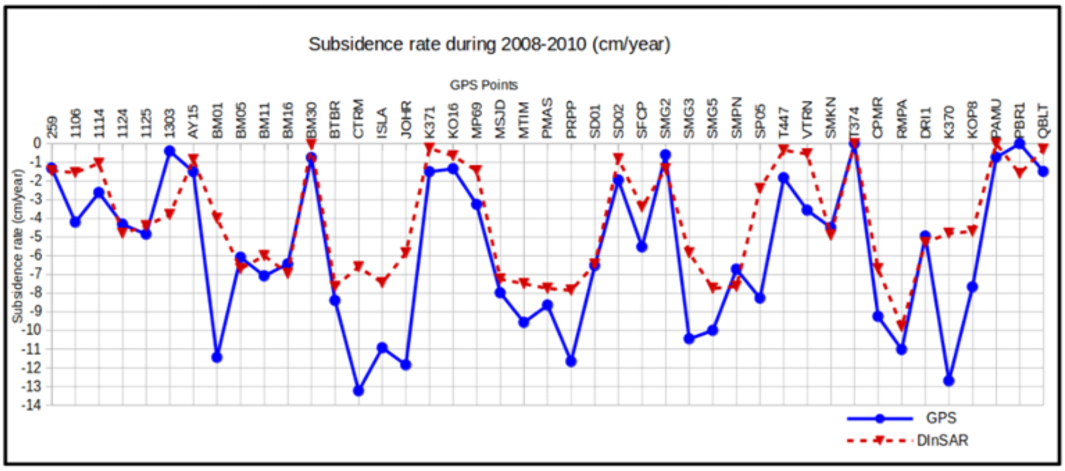


Figure 4. Comparison of average subsidence rate GPS and DInSAR results during 2008-2009.

To validate the result of DInSAR method, the GPS data was used as ground check data. This process compared average rate of land subsidence during 2008-2010 between DInSAR and GPS result. The correlation result is shown in Figure 5, where in x-axis is average subsidence rate derived by GPS data and in y-axis is average subsidence rate derived by DInSAR data. By using linear coefficient determination method (see Figure 5), the result of coefficient determination is about 0.649828424. This mean DInSAR method have a fine accuracy for land subsidence monitoring in wide area observation.

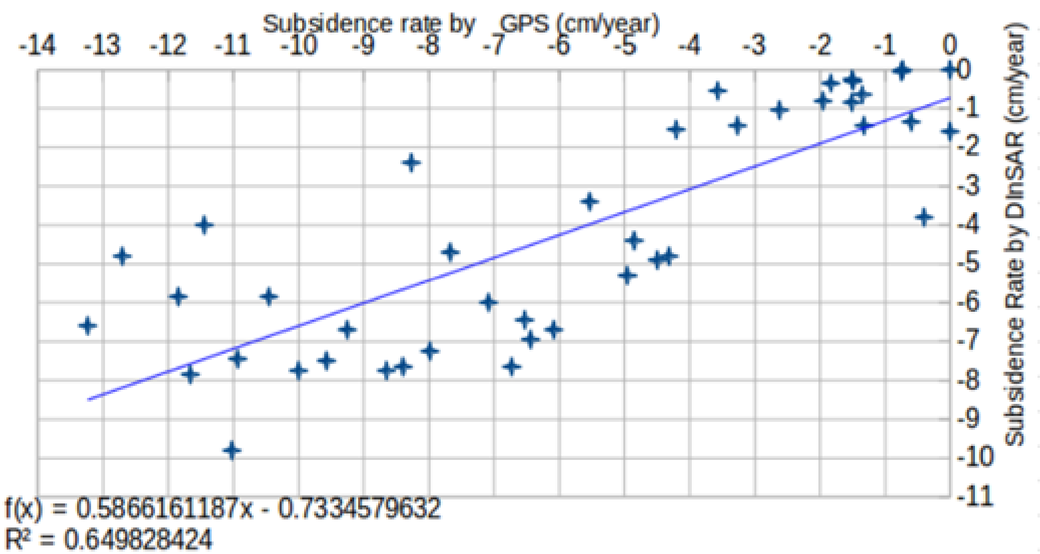


Figure 5. Correlation of average subsidence rate between DInSAR and GPS result during 2008-2010.

3.3 Causes Land Subsidence in Semarang City

From DInSAR and GPS results it was indicated that the land subsidence in Semarang City almost occur in northern area. The main city, harbour, Industrial area, and settlement was located in northern part of Semarang City. All of these places indicated that in northern area was very high human activities (included industrial activities). From this situation, the main causes land subsidence in Semarang City was caused by load of building structure and over extraction of ground water.

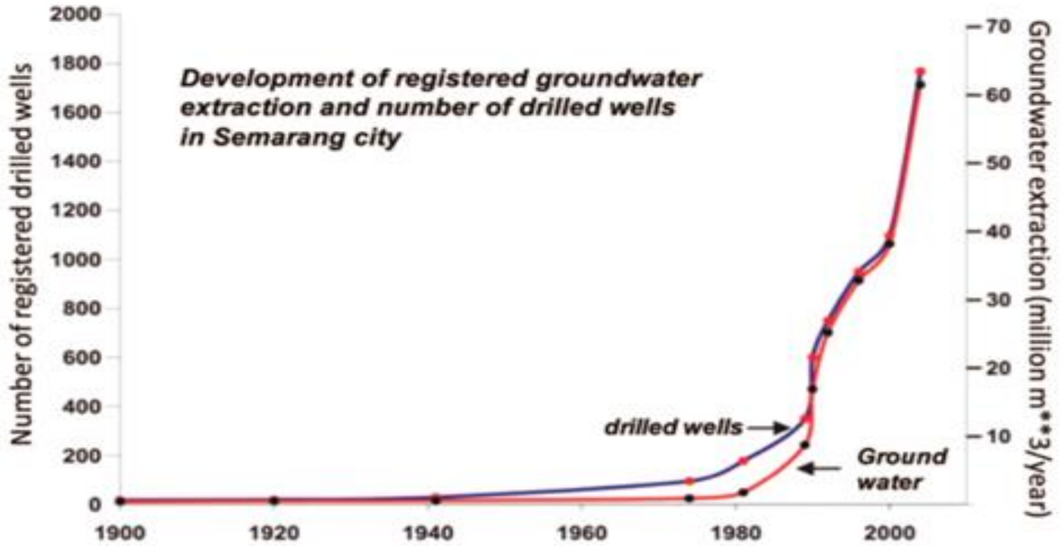


Figure 6. Ground water extraction rate and number of registered drilled wells (Murdohardono *et al.*, 2007).

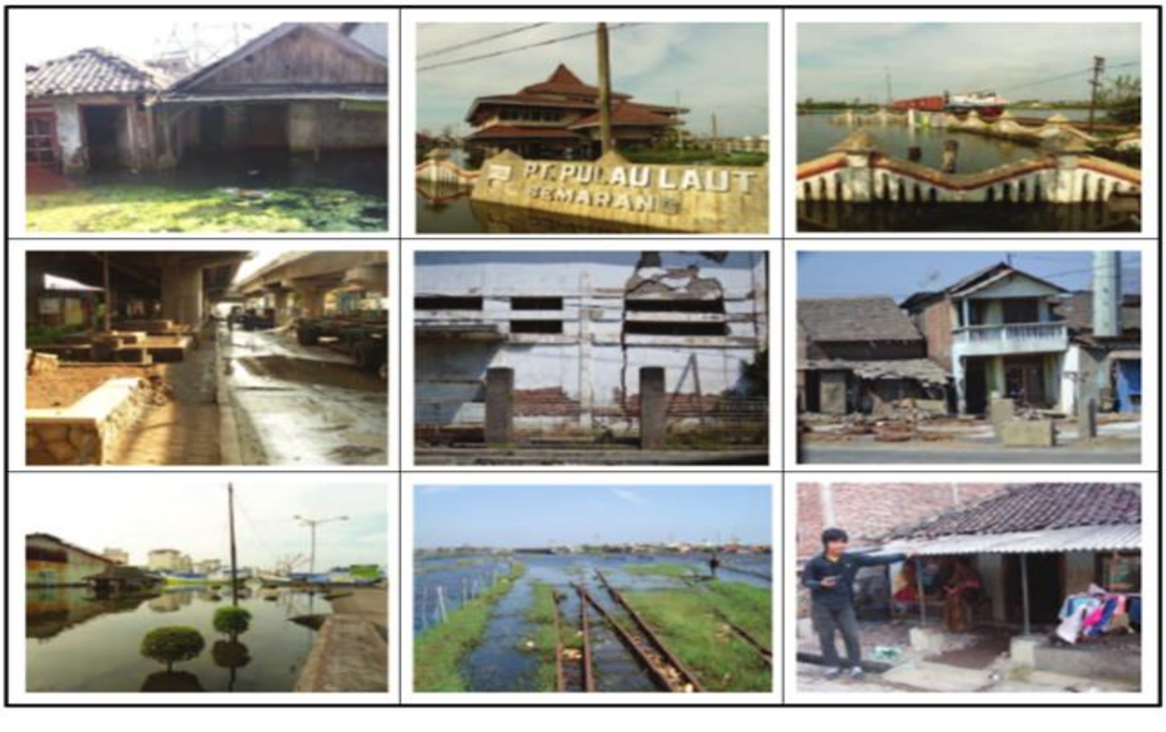


Figure 7. The Semarang's land subsidence impacts (Abidin *et al.*, 2012).

Land subsidence due to load of building structure was related to the increasing of population was Semarang City and changing land use in coastal area. Population in Semarang City is about 1.55 million peoples in 2010 (BPS., 2011) with total area only 374 km^2. It made the Semarang City was categorized as a city with a dense population. On the other hand, changing of land use from open area to the settlement or industrial area caused increasing number of building constructed.

Ground water extraction also contribute very large impact for land subsidence in Semarang City. The number of registered drilled wells increased rapidly during early 1990s especially is industrial areas. Figure 6 shows increasing number number of registered drilled wells and also increasing average ground water extraction during 1900s until 2000s.

3.4 Impact of Land Subsidence in Semarang City

The Semarang's land subsidence can be categorized as very large and harmful for environment. This phenomenon damaged the building, housing, and other infrastructures. Figure 7 shows the examples of Semarang's subsidence impacts. The Semarang's land subsidence was very complicated problem, not only damaged the building, housing, and other infrastructures, but also gave bad impact for quality of living environment (health and sanitation). On the other hand, land subsidence also increased the maintenance and rehabilitation costs due to severe damage of building and public infrastructures.

4. Conclusions

1. The land subsidence in Semarang City mostly appears in Northern area (main city), with maximum subsidence value which is derived by using DInSAR Method is about -4.8 cm/year (2007-2008), -8.1 cm/year (2008-2009), and -9.9 cm/year (2009-2010). The average is 7.6 cm/year (2007-2010).
2. The coefficient determination between DInSAR and GPS method is about 0.65 for 2008-2010. It's mean DInSAR method has a good accuracy and reliable to use for land subsidence monitoring in wide area.

Acknowledgments

I would like to express my special appreciation and thanks to Dr. Haruma Ishida and Dr. Hidenori Shingin, who have been a tremendous mentor for me. I would also like to thank Dr. Masanobu Shimada and Japan Aerospace Agency (Jaxa) for provided the ALOS/PALSAR data. In addition, a thank you to Dr. HZ Abidin and Dr. Irwan Gumilar from Geodesy Research Group of Institute of Technology Bandung (ITB) for provided DGPS data

References

Abidin, H. Z., Andreas, H., Gumilar, I., Sidiq, T. P., & Fukuda, Y. (2013). Land subsidence in coastal city of Semarang (Indonesia): characteristics, impacts and causes. Geomatics, Natural Hazards and Risk, 4(3), 226-240.

Abidin, H. Z., Djaja, R., Darmawan, D., Hadi, S., Akbar, A., Rajiyowiryono, H., Sudibyo, Y., Meilano, I., Kusuma, M.A., Kahar MA & Subarya, C. (2001). Land subsidence of Jakarta (Indonesia) and its geodetic monitoring system. Natural Hazards, 23(2-3), 365-387.

Abidin, H. Z., Andreas, H., Gumilar, I., Sidiq, T. P., & Fukuda, Y. (2013). Land subsidence in coastal city of Semarang (Indonesia): characteristics, impacts and causes. *Geomatics, Natural Hazards and Risk*, 4(3), 226-240.

BPS. (2011). *Pertumbuhan dan Persebaran Penduduk Indonesia Hasil Sensus Penduduk 2010*. Jakarta, Indonesia: Statistics Indonesia.

Barends, F. B., Brouwer, F. J., & Schröder, F. H. (Eds.). (1995). Land subsidence: Barends Land Subsidence. London, UK: Taylor & Francis CRC press.

Chaussard, E., Amelung, F., Abidin, H., & Hong, S. H. (2013). Sinking cities in Indonesia: ALOS PALSAR detects rapid subsidence due to groundwater and gas extraction. Remote Sensing of Environment, 128, 150-161.

Husnayaen, H., Rimba, A. B., Osawa, T., Parwata, I. N. S., As-syakur, A. R., Kasim, F., & Astarini, I. A. (2018). Physical assessment of coastal vulnerability under enhanced land subsidence in Semarang, Indonesia, using multi-sensor satellite data. *Advances in Space Research*, **61**(8), 2159-2179.

Kuehn, F., Albiol, D., Cooksley, G., Duro, J., Granda, J., Haas, S., Hoffmann-Rothe, A., & Murdohardono, D. (2010). Detection of land subsidence in Semarang, Indonesia, using stable points network (SPN) technique. *Environmental Earth Sciences*, **60**(5), 909-921.

Murdohardono, D., Tobing, T. M. H. L., & Sayekti , A. (2007). *Over Pumping of Ground Water as one of Cause of Sea Water Inundation in Semarang City*. In International Symposium and workshop on Current Problems in Groundwater Management and Related Water Resources Issues. Kuta-Bali, 3-8 December 2007.

Yastika, P. E., Shimizu, N., & Abidin, H. Z. (2019). Monitoring of long-term land subsidence from 2003 to 2017 in coastal area of Semarang, Indonesia by SBAS DInSAR analyses using Envisat-ASAR, ALOS-PALSAR, and Sentinel-1A SAR data. *Advances in Space Research*, **63**(5), 1719-1736.

Yastika, P. E., Shimizu, N., Tanaka, T., & Osawa, T. (2017). Multi-temporal Analysis for Differential Interferometry Synthetic Aperture Radar (D-InSAR) and Its Application to Monitoring Land Surface Displcements. *International Journal of Environment and Geosciences*, **1**(1), 1-11.
