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Analysis of Coastal Sedimentation Impact to Jakarta Giant Sea Wall Using PSI ALOS PALSAR

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***Abstract*—The Jakarta province proposed the Jakarta Giant Sea Wall as the waterfront city for the new urban settlement zone and the deep seaport for the new economic zone along the coastal areas at northern Jakarta. This letter investigated land deformation at 11 watersheds of the West Java Mega Urban Region using the persistent scatterer interferometry technique of the Advanced Land Observing Satellite phased-array-type L-band synthetic aperture radar data. The result shows that land deformation at the study area, particularly the Bandung city area gives a significant impact to sedimentation velocity along the eastern Jakarta strait, particularly the deep seaport for 43 years later. This letter recommends to evaluate land conservation at upland watersheds and the well management of artificial canals to reduce the impact of sedimentation at the Jakarta strait, particularly the new depth seaport.**

***Index Terms*—Coastal sedimentation, interferometry, Jakarta Giant Sea Wall (JGSW), persistent scatterer interferometry (PSI), synthetic aperture radar.**

I. Introduction

JAKARTA is the capital and the largest city in Indonesia with a total area of 669 km^2, and the population increased from 4.3 million in 1967 to 10 million in 2012 [1], [2]. Fig. 1 shows land use of the study area that was derived by using the published Indonesian Digital Topographical Maps (RBI) [3]. The increasing of population in Jakarta caused the expansion of settlement and bare land areas, and the decreasing paddy field, water, forest, and plantation areas [4]. It causes environmental

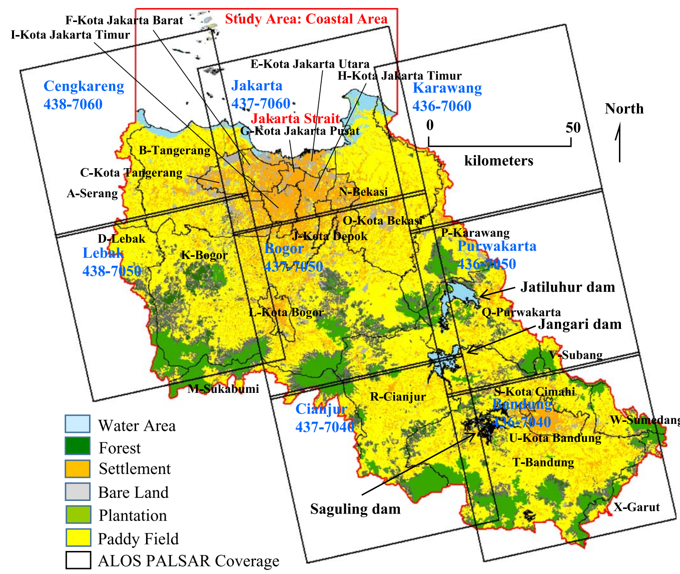

Fig. 1. Land use of the study area called WJMUR and ALOS PALSAR Data Coverage.

degradation, land subsidence, etc. [5]–[8]. The Jakarta province proposed the Jakarta Giant Sea Wall (JGSW) (see Fig. 2) plan with the Eagle bird (Great Garuda) shape as the new waterfront city for the urban settlement zone and the deep seaport for the new economic zone in the coastal area to solve the city problems [5], [9]. Based on our study at 71 river outlets along the Jakarta strait since 1915 to 1999 (see Fig. 2) [3], [10], the increasing of population and the environment degradation at the vicinity cities of Jakarta caused the sedimentation along the coastal area of Jakarta and gave a significant impact to JGSW, particularly the new deep seaport area that is suffered by the sedimentation expansion of Cikarang, Nawan, and Gabah outlets with the velocity of sedimentation expansion 39.6, 45.2, and 34.6 m/year, respectively. The sedimentation is supposed by land deformation caused by human activities and natural phenomenon, i.e., landslide, rain, land conversion, subsidence, etc. Our previous research and other papers reported the assessment of environmental degradation in Jakarta and vicinity cities using differential interferometric synthetic aperture radar, particularly subsidence monitoring [11]–[14]. These previous studies discussed the environmental degradation of the Jakarta area with analysis focused on local Jakarta; therefore, it could not figure the problems that caused the sedimentation at the coastal area along the Jakarta strait. This letter investigated land deformation in 11 watersheds W01–W11 in Fig. 3 (blue line boundary) using the persistent scatterer interferometry (PSI) technique of the Advanced Land Observing Satellite

Manuscript received March 27, 2016; revised June 9, 2016; accepted July 13, 2016. This work was supported in part by the European Space Agency Earth Observation Category 1 under Grant 6613, by the 4th ALOS Research Announcement under Grant 1024, by the 6th ALOS Research Announcement under Grant 3170, by the Japanese Government National Budget (Special Budget for Project) FY 2015 under Grant 2101, and by the Chiba University Strategic Priority Research Promotion Program FY 2016. *(Corresponding author: Josaphat Tetuko Sri Sumantyo.)*

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Digital Object Identifier 10.1109/LGRS.2016.2592940

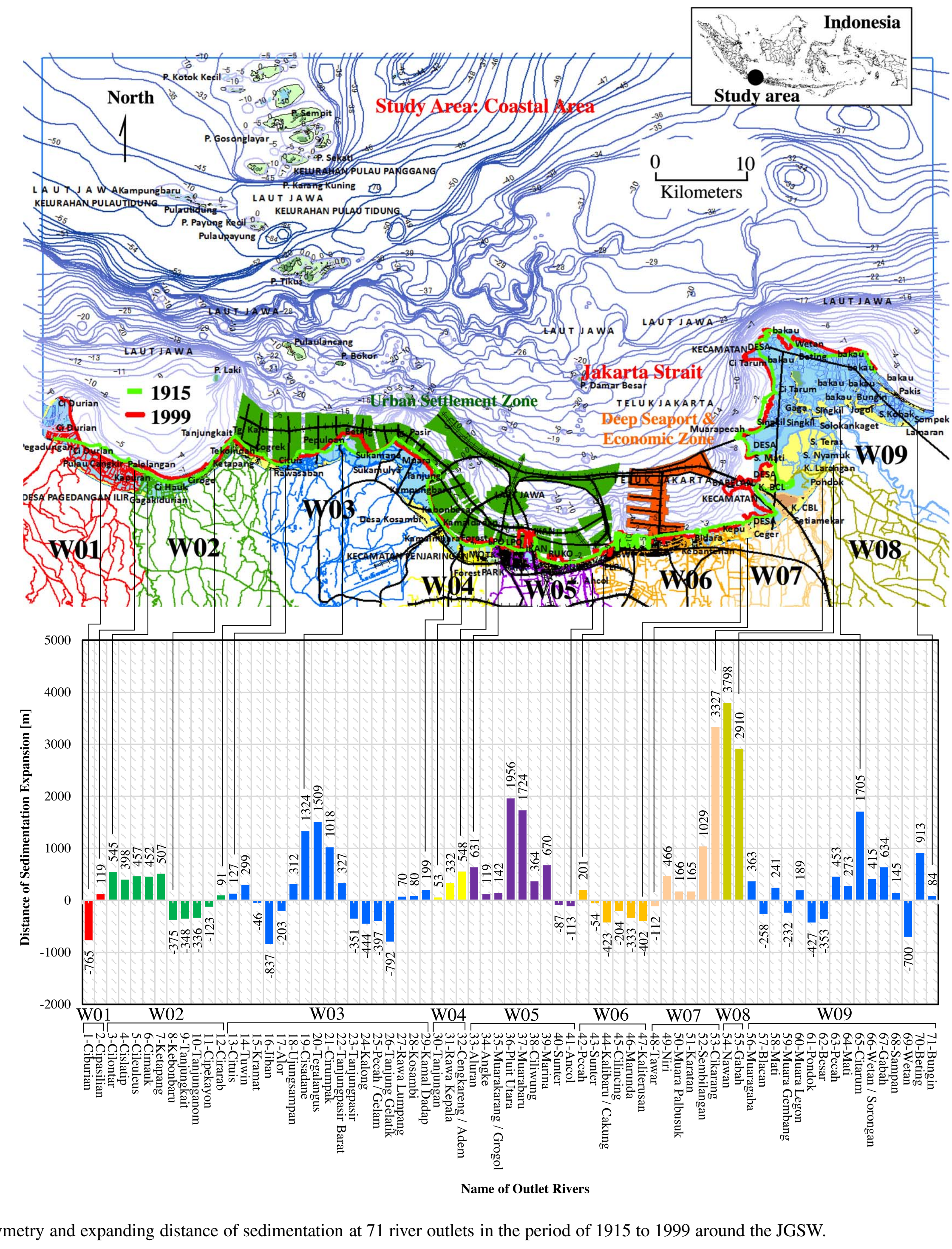

Fig. 2. Bathymetry and expanding distance of sedimentation at 71 river outlets in the period of 1915 to 1999 around the JGSW.

Phased Array type L-band Synthetic Aperture Radar (ALOS PALSAR) data observed in 2007 to 2011 in the West Java Mega Urban Region (WJMUR) (see Fig. 1). The ALOS satellite was launched on 24 January 2006 by the Japan Aerospace Exploration Agency (JAXA) and terminated in April 2011.

II. Study Area

A. Watershed, Land Use, and Contour

The study area WJMUR covers 24 regencies and 11 watersheds (12 671 km^2) (see Fig. 3). In this letter, we derived the watershed area using RBI [3] and acquired watersheds named W01–W11, (see Fig. 3). Nine watersheds W01–W09 along the Jakarta strait has 71 river outlets in northern Jakarta, where 46 river outlets contribute sedimentation or coastal line expansion at Jakarta Strait. Positive value on the graph in Fig. 2 shows the distance of sedimentation expansion from the coastal line in 1915 [10] to 1999 [3] or within 84 years. This expansion of sedimentation is considered for the suffering JGSW, particularly the deep seaport and the economic zone at the eastern Jakarta strait, where it recently remains 1715 m from outlet of the Cikarang river.

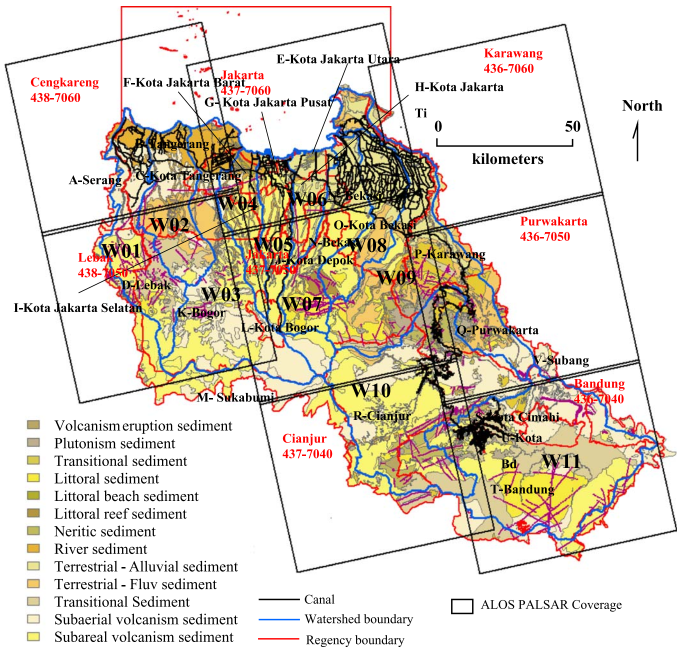

Fig. 3. Geological characteristic of study area (WJMUR).

The study area is surrounded by a mountainous area as the water catchment and flowing the material of sediment to the outlet along the Jakarta strait [4]. Fig. 1 shows the land use of WJMUR in 1999 that are classified by six classes, i.e., water area, forest, settlement, bare land, plantation, and paddy field. Jakarta city is directly flew by rivers in watersheds W04–W07, where the settlement area is dominant in this area. Annual flood frequently occurs in these watersheds caused by environmental degradation on upper watershed area, i.e., Mt. Gede, Pangrango, Salak, and Kendeng. Bandung city, the fourth largest population in Indonesia, is located in the Bandung basin or watershed W11. Bandung basin is surrounded by several mountains where watersheds W10 and W11 is collecting water at the Saguling, Jangari, and Jatiluhur dams (see Fig. 1) to generate electricity, which is distributed to paddy fields in watersheds W06–W09 through the natural irrigation network or rivers and artificial canals (bold black line in Fig. 3). In this letter, we extracted the degradation volume of sedimentation in each watershed by using PSI and investigate the relationship of this volume and sedimentation velocity, then assessing this result to investigate the sedimentation impact to JGSW.

B. Abrasion and Sedimentation

The environmental degradation in these watersheds causes abrasion and sedimentation along the coastal areas around the Jakarta strait that is shown by a change of the coastal line in Fig. 2 (green and red for 1915 and 1999, respectively) derived by the RBI and the Gaihozu maps [3], [10]. The positive and negative values of distance of the sedimentation expansion show sedimentation and abrasion distance, respectively, since 1915. Abrasion occurred in almost the whole of the watershed, except watersheds W04 and W08. The serious abrasion is occurring around the river outlets of Ciburian, Jiban, Tanjung Gelatik, and Wetan with 765, 837, 792, and 700 m of coastal line change, respectively. The sedimentation caused the expansion of the coastal line and occurred at whole river outlets of watersheds. Sedimentation expands the coastal line by more than 1000 m since 1915 and occurs at ten river outlets, e.g., Cisadane, Tegalangus, Cirumpak, Pluit Utara, Muarabaru, Sembilangan, Cikarang, Nawan, Gabah, and Citarum. The new sedimented area was converted to paddy and settlement areas.

C. Population and Land Degradation

The population of regencies in WJMUR from 1980 to 2012 shows an increasing trend, particularly Tangerang and Kota Tangerang at west of Jakarta; Jakarta Timur; Bogor at south of Jakarta; Bekasi at east of Jakarta; and Bandung. The increase in population causes an increase in settlement needs; hence, it escalates conversion of paddy field, plantation, forest area, etc., to be the settlement of Jakarta city. A lack of an irrigation system makes increasing artificial wells for daily water consumption and industry. Overconsumption of ground water caused subsidence and volume loss in the study area [11]–[14]. Conversion of plantation, forest, and paddy field to the settlement caused the loss and the increasing of land volume in the study area or upland watersheds. This phenomenon is shown as a subsidence in this letter. The material loss is supposed to flow to watersheds of the study area and river outlets in the Jakarta strait.

D. Geological Characteristics

Fig. 3 shows geological characteristics of the study area that acquired by the geological map [15] that was composed of 12 classes. This figure shows volcanism sediment as a main sediment in watersheds W01, W03, W04, W05, W07, W10, and W11. Environmental degradation in these watershed areas are assumed to produce sediment material that flows and are transported by river network and build sedimentation along coastal line of Jakarta strait.

III. PSI AND ALOS PALSAR DATA

In this letter, we employed the PSI technique to analyze land deformation on the study area. The coverage of the ALOS PALSAR data in this letter (see Fig. 1) is covered by the eight areas (path 436–438, frame 7040–7060, Fine Beam Dual Polarization (FBD) Horizontal Transmit and Horizontal Receive (HH) mode, Level 1.0, or raw data), totally 98 scenes. These scenes were employed to obtain interferograms. Then persistent scatterer (PS) was acquired using PSI by stacking the interferograms to generate land deformation velocity. The rest residual in Fig. 4 is assumed occurring during the PS weeding and the patches fitting. The same path (436–438) of PS images could be fitting easily at the azimuth direction, but fitting of different frame (7040–7060) on images shows a large error at the range direction. It is supposed to influence the incident angle at near range and far range that caused the error on scattering intensity; hence, intensity of the PS will change at the line of sight. We employed statistical value (average) of the overlap area of neighboring different frame images to fitting each images. The velocity (unit mm/year) of land deformation in vertical direction (dh or $\Delta h(i, j)$) is acquired by PSI, where i and j are the positions of each permanent scattered pixel in azimuth and range direction. The positive and negative values mean increasing (uplift) and material loss (subsidence) velocities of volume change, respectively. This letter has an interest on the

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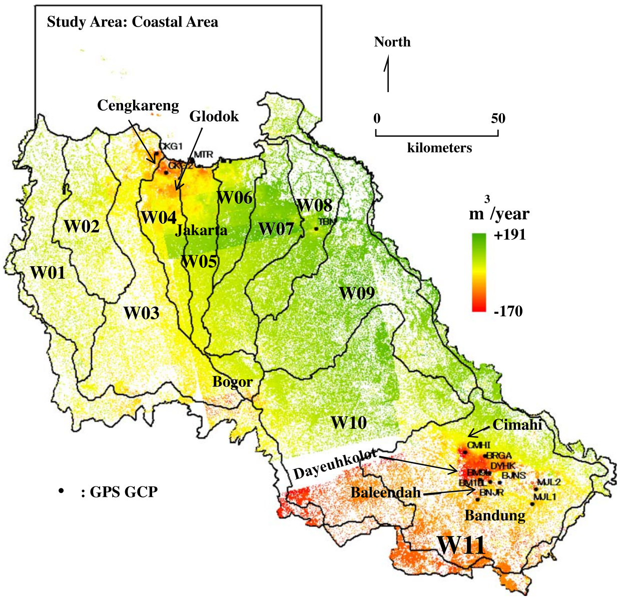

Fig. 4. Result of PSI analysis. Velocity of volume change in study area.

material loss that is considered to affect sedimentation velocity along Jakarta coastal area.

The velocity of volume change of each pixel can be calculated by multiplying this velocity in vertical direction (unit: m/year) with resolution of each pixel in azimuth direction $R_{\mathrm{az}}(i,j)$ and range direction $R_{\mathrm{rg}}(i,j)$. Fig. 4 shows the velocity of volume change in the study area with a unit of m^3/year. Fig. 5 shows statistics of volume change classes of land use and geological areas in each watershed that is derived in Figs. 1, 3, and 4. The velocity of volume change in each class of land use and geological areas is derived by the following:

$$V_{\mathrm{class}} = \int_{\mathrm{WN}} dV_{\mathrm{class}} = \int_{\mathrm{WN}} R_{\mathrm{az}} R_{\mathrm{rg}} dh \approx \sum_{i=1\in \mathrm{WN}}^{N} \sum_{j=1\in \mathrm{WN}}^{M} R_{\mathrm{az}}(i,j) R_{\mathrm{rg}}(i,j) \Delta h(i,j)$$

where V_{class} is velocity of volume change of each class of land use or geological area in watershed WN or W01 to W11.

IV. Result and Discussion

A. Confirmation of PSI and GPS GCP Results

We employed 13 of GPS ground control point (GCP) data measured in 2007–2011 of the study area to confirm the velocity of land deformation in vertical direction calculated by PSI (unit: mm/year). The location of each GCP in Fig. 4 that was collected at Jakarta and Bandung city. Fig. 6 shows a good agreement between PSI result and GCP that has mean error is 5 mm/year; therefore, the accuracy assessment is considered has enough accuracy. It causes significant land deformation at the study area, particularly the area with GCPs of MJL1 and MJL2 at eastern Bandung and CMHI at Cimahi.

B. Discussion

Volume loss of each class in each watershed is derived by using (1). The result in Fig. 5(a) and (b) shows that a large amount of material loss occurred at watershed W03, W04, W05, W10, and W11 that give significant contribution for sedimentation at river outlets at Jakarta coastal area. The material loss in W10 and W11 is considered to produce sediment material that flows to W07–W09 or outlets rivers No. 48–71 in Fig. 2 through rivers or artificial canals and generate sedimentation along the coastal line around the Jakarta strait, particularly at the outlets of Cikarang, Nawan, and Gabah. The sedimentation expansion of these rivers from 1915 to 1999 was 3327, 3798, and 2910 m or sedimentation velocity is 39.6, 45.2, and 34.6 m/year, respectively. It shows the volume and velocity of sedimentation at these outlets depend on the amount of land deformation at the study area or upland watersheds. These outlets are influencing to the deep seaport as a new economic zone of about 1715 m from the recent coastal line. The sedimentation needs 43 years to reach the new seaport and give serious impact for new deep port.

Fig. 5(a) shows that land deformation seriously happens in the water area, forest, settlement, bare land, plantation, and paddy field of watersheds W03, W04, and W05. The phenomenon in this area is considered to have no direct influence to the coastal area at north Jakarta, but the material created sedimentation along coastal line of northern Tangerang, particularly Cisadane 1324 m (16 m/year), Tegalangus 1509 m (18 m/year), and Cirumpak 1018 m (12 m/year). The result does not show significant land deformation in watershed W07, but Fig. 2 shows that outlet of Sembilangan and Cikarang at northern Bekasi show expansion of sedimentation 1029 m (12 m/year) and 3327 m (40 m/year), respectively. Based on the artificial canal network, the material is assumed to be transported from watersheds W08–W11 and seriously sedimented at river outlets of Nawan and Gabah.

Based in Fig. 5(b), land deformation on each geological class in the study area, the land deformation seriously occurred in watersheds W03, W04, W05, W10, and W11. Volcanism subaerial sediment covers at the southern part of the watershed W03, where this sediment is distributed from Mt. Salak and Mt. Pangrango. The sediment material in this area is sediment at the outlet of the Cisadane, Tegalangus, and Cirumpak rivers, and the total annual volume of sediment is 35 806 m^3/year.

The increasing of population at Bandung and Kota Bandung, particularly after opening of highway between Jakarta and Bandung caused an increase in settlement and industry development at the Bandung area intensely. It caused massive environmental change, destruction of infrastructure. Fig. 4 shows that land the deformation is seriously occurring at the center of Bandung city and vicinity, and the southern area at the foot of Mt. Wayang, Patuha, Puntang, and Kendang. The geological material loss in this watershed is supposed to flow to the main river called Citarum that flows to Saguling dam. This water and sedimentation flow through Jangari and Jatiluhur dams, then flow to watershed W07, W08, and W09 through artificial canals to outlets at these watersheds. The total annual volume of the material loss in this area is considered to give serious impact to JGSW, particularly the deep seaport and economic zone.

V. Summary

In this letter, we have investigated land deformation using the PSI technique of the ALOS PALSAR data at 11 watersheds that is supposed to influence sedimentation volume and velocity

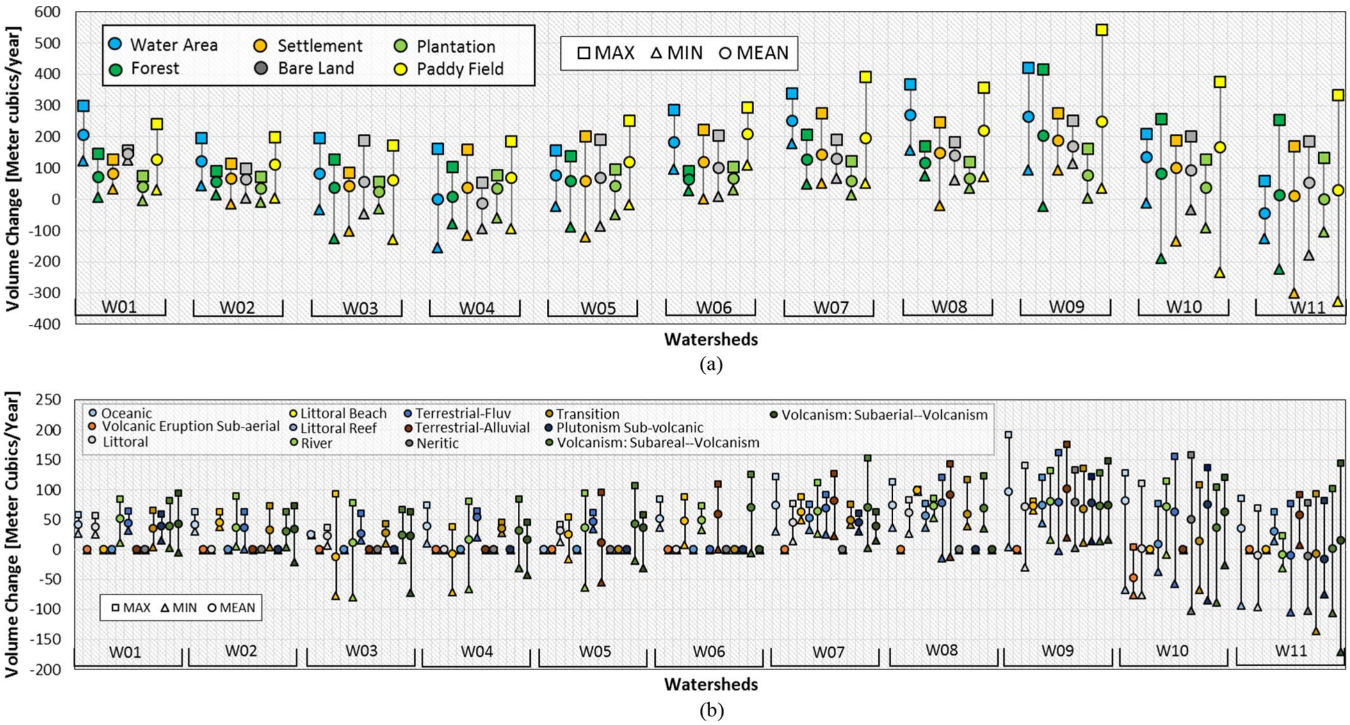

Fig. 5. Volume change of land use and geological classes in each watershed. (a) Volume change of land use classes in each watershed. (b) Volume change of geological classes in each watershed.

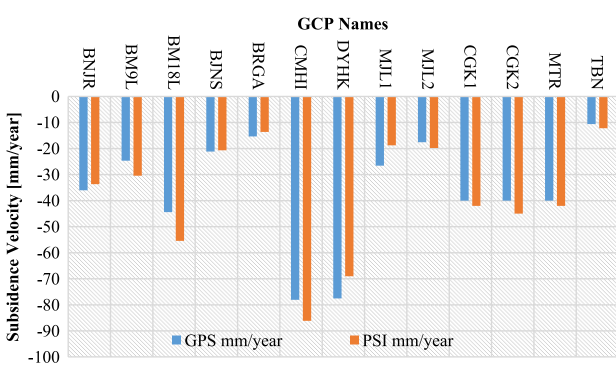

Fig. 6. PSI and GPS confirmation (subsidence velocity).

at outlets along coastal areas of Jakarta strait. The land deformation is considered to be caused by natural phenomenon and human activities, where the land deformed material is considered to flow to outlets at the coastal area through hydrological network or watershed in the study area. Therefore, the volume and velocity of sedimentation at outlets depend to the amount of land deformation at the study area. The result of PSI and GPS GCP has a good agreement in vertical direction with the mean error 5 mm/year. The analysis result of PSI, land use, and geological data shows that land deformation or material loss at Jawa Barat province, particularly Bandung and its vicinity gave significant impact to sedimentation volume and velocity at the outlets of the eastern Jakarta strait, where the sedimentation at the Cikarang outlet with the velocity of the coastal line expansion 39.6 m/year, that has a serious impact to the deep seaport and new economic zone of JGSW within 43 years.

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