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Application of Multi-Temporal Interferometric Synthetic Aperture Radar (MT-InSAR) technique to Land Deformation Monitoring in Warri metropolis, Delta State, Nigeria

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Abstract

Warri is one of the mega cities in Delta State in the coastal region of Nigeria hosting many industries. One of the three of Nigeria oil refineries is located in Warri. This study reveals the occurence of land deformation in the Warri area which is not only because it was formed in a tectonic setting but because of the high demand of the underground water for indutrial and domestics uses, high population density and oil and gas exploration in the area. Land deformation in this area is currently being accelerated by this indiscriminate withdrawal of underground water from the aquifers and exploration of the oil and gas leading to the compacting sediments. In this study Multi-Temporal Interferometric Synthetic Aperture Radar (MT-InSAR) technique was applied to monitor land deformation in Warri metropolis in the period between 09/02/2006 and 12/08/2010 with Envisat data obtained from European Space Agency (ESA). The processing was done using Stanford Method for Persistent Scatterers/Multi-Temporal InSAR (StaMPS). From the analysis of the results, land deformation is occurring in Warri metropolis at a moderate rates (±5 mm/yr). During the

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preliminary investigations, structures, particularly buildings, were physically observed subsiding while some others with cracks of various types and degrees.

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Keywords: Land deformation; InSAR; Envisat; Warri

1. Introduction

[1] in the Environmental Engineering Dictionary (EED) defines land deformation as the sinking or settling of land to a lower level in response to various natural and anthropogenic factors, such as Earth movement, lowering of fluid pressure (or lowering of the ground water level); removal of underlying supporting materials by mining or solution of solids, either artificially or from natural causes; compaction caused by wetting (hydro-compaction); oxidation of organic matter in soils; or added load on the land surface. With respect to ground water, land deformation most frequently results from overdrafts of the underlying water table or aquifer, excessive exploration of oil and gas and its inability to fully recharge at the same rate of withdrawal, a process termed aquifer compaction.

[2] reported that the Nigerian coastal geosyncline is subsiding not only because it was formed in a tectonic setting but because of the continuing dewatering and compaction of its sediments which were deposited rapidly. Land deformation in these areas is presently been accelerated by the indiscriminate withdrawal of fluids, including oil and gas particularly in Warri, Yenagoa and Port Harcourt cities from underground aquifers and reservoir strate. Land deformation associated with fluid withdrawal results from the reduction of fluid pressure in the reservoir or aquifer thus leading directly to an increase in effective stress in the system. Compaction results and the basin subsides.

Available records have also shown some structural failures, particularly along the coastal areas of Nigeria, which are suspected to be caused by the sedimentary nature, excessive withdrawal of the underground water, oil and gas exploration ([3]). The mega cities in the coastal region of Nigeria are highly populated and highly industrialized (with quite a large number of industries). The need for water is thus progressively increasing in the study area. Since surface water could not meet such needs, thousands of uncontrolled boreholes drilled and wells were bored for water pumping in the last 40 years. Between 1990 and 2006 more than 152,096 boreholes and about 376,165 hand dug wells were recorded to have been bored and dugged ([4]). This uncontrolled exploitation of the groundwater has led to progressive decline of the aquifer level and a continuous need for opening deeper drillings to exploit deeper aquifers. Similarly, between 1991- 2006, the mean aquifer head level dropped to between 20 - 70 meters with a maximum of 120 meters in some areas.

The study area is one of the mega cities in Delta State in the coastal region of Nigeria hosting many industries, being one of the three of Nigeria oil refineries located in Warri. This city is located within 5° 30′ N to 7° 35′ N of the Equator and Longitude 5° 29′ E to 5° 48′ E east of the Greenwich Meridian. It comprises of three local Government Councils namely: Warri South, Udu and Uvwie (Fig. 1) and has a population of about 536,023 according to National Population Census, 2006 ([5]). Warri metropolis has a land mass of approximately 453 Km^2.

The topography is flat, with an average of about 13 m above the sea level (Fig. 2). The flat and low relief features encourages flooding after rain events. The drainage is dendritic with major tributaries entering into the Forcados River ([6]). The vegetation of the study area is humid tropical rainforest type and comprises of abundant trees and grasses. It consists of coastal fresh water on the barrier beach ridges, mangroves swamps of tidal zones and fresh water swamps forest in the region beyond the limit of tidal influence ([6]).

2. Data and method

The study area is covered by 23 descending Envisat ASAR SLC C-band scenes (track 36) acquired between 09/02/2006 and 12/08/2010. Fig. 3 shows the location of this track over the study area. No data from other spaceborne SAR sensors until Sentinel-1A started to acquire data in 2014 is available over this area so it is not possible to perform an historical analysis of land deformation before 2006 using satellite radar interferometry.

In this study, the Stanford Method for Persistent Scatterers/Multi-Temporal InSAR (StaMPS) ([7,8,9]), that combines both persistent scatterer (PS) and small baselines (SBAS) methods, allowing the identification of scatterers that dominate the scattering from the resolution cell (PS) and slowly-decorrelating filtered phase (SDFP) pixels, was applied. The Shuttle Radar Topography Mission (SRTM) C-band DEM with resolution of 3 arc-second geographic resolution (90 m) and 10 m height accuracy was used as external DEM in this study to remove the topographic phase from the differential interferograms.

Fig. 1. Map of the study area.

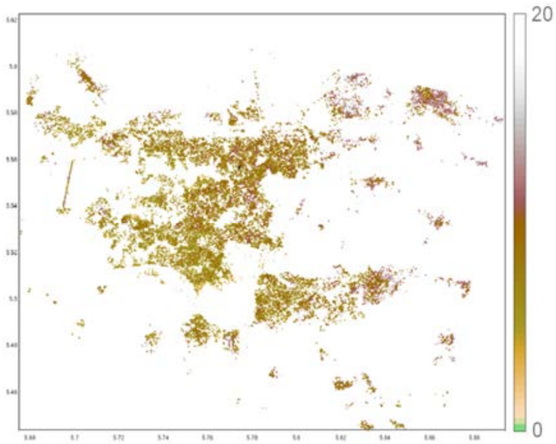

Fig. 2. Heights in m above the sea level from selected points in the interferometric processing.

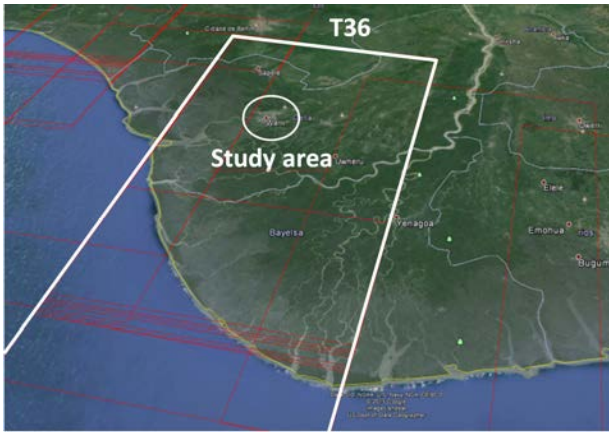

Fig. 3. Envisat ASAR Satellite track 36 covering Warri, Delta state, Nigeria.

The StaMPS framework was initially developed for PS applications in natural terrain ([7,9]) and since, has been expanded to include short baseline analysis ([8]). StaMPS PS analysis uses primarily spatial correlation of the phase to identify phase-stable pixels, as opposed to temporal correlation and it does not assume any approximate model of displacements (e.g. [10,11]). A requirement is that the displacement gradients in space and time should not be steep for proper unwrapping. Once coregistering master and slave images, a series of interferograms is constructed, which also uses the most precise orbit information available. An evaluation of interferometric phase differences in time is done to obtain the potential PS points. Finally, temporally coherent of natural reflectors in SAR images are detected due to their correlated phase behavior over time. Then, the displacement of each individual PS point is estimated by the technique.

In addition, SBAS ([12]) (Small BASeline) analysis aims to detect pixels whose phase do not suffer a rapid decorrelation over short time intervals. Interferograms having mutual small baselines combinations are created based on the available of image. SBAS method searches to ease phase unwrapping by means of selecting small baselines interferograms and filtering the phases. It creates a network of interferograms to estimate heights and deformation with respect to one single master image. Finally, StaMPS/MTI combines both sets of results to improve phase unwrapping and the spatial sampling of the signal of interest. Fig 4. shows the network of interferograms for the PS (in red) and the combined processing (in green). The image of 27/08/2009 was selected as a master image in the PS analysis, processing a total of 22 interferograms. This master image minimizes the temporal, perpendicular and Doppler baselines. In the SBAS processing, 132 interferograms were initially selected whereas after removing some interferograms with spatially-correlated residuals, 109 interferograms were finally used for estimating the deformation rates. After merging both PS and SBAS interferograms, 106 interferograms where computed in the combined processing. After carefully checking the residuals between the unwrapped phase of the small baseline interferograms and that predicted from the model values for the single master phase in the case of the combined processing, no spatially-correlated residuals were found indicating that all the interferograms were correctly unwrapped.

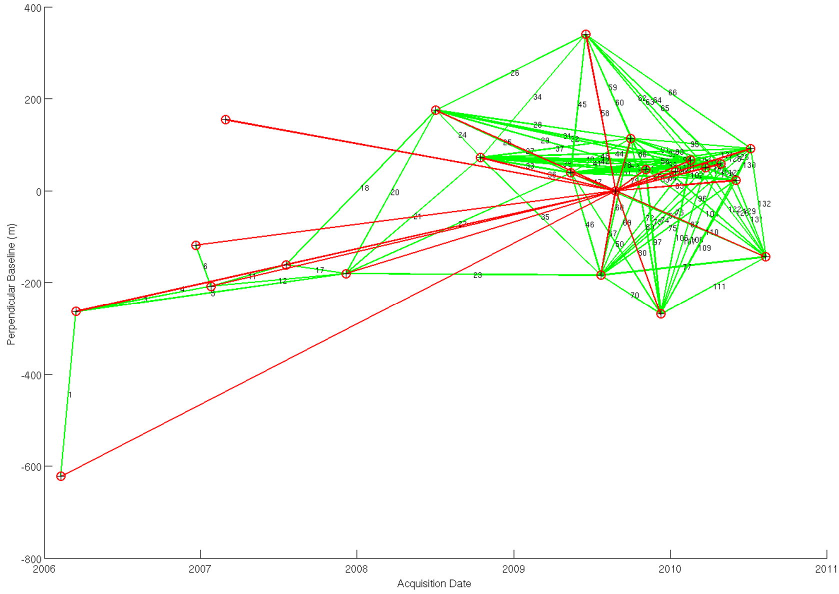

Fig. 4. Perpendicular vs. temporal baselines distribution for the PS processing (in red) and the combined (PS+SBAS) processing (in green).

Warri metropolis has a dimension of 24.5 km in longitude by 18.5 km in latitude. For this area, considering the size of the crop, 21388 and 98992 stable-phase pixels were identified in the PS and the SBAS processing. Finally, after merging both sets of pixels, a total of 107880 pixels were finally selected in the final combined processing. After phase unwrapping step and filtering spatially correlated noise, a mean velocity line-of-sight LOS rates for each persistent scatterer (PS+SDFP) was calculated relative to a reference area located in a stable zone. In this case we selected Effurun, in the north of Warri, as the stable part of the city assuming no deformation.

3. Results

Fig. 5 shows the time evolution of deformation referred to the first date where some seasonal effects can be observed. The mean 1D LOS velocity map superimposed over a Google Earth image is shown in Fig. 6. According to this pattern some sectors are subsiding while some others are uplifting in relation to the reference area. Both subsidence and uplift rates reach maximum values of ±5 mm/yr. Detailed views of this mean 1D LOS velocity map are shown in Figure 7. They point out some areas of the city where differential movements occurred in very close sectors. As an example six time deformation time-series plots of the six points located in Fig. 7 are shown in Fig. 8. Points 1 and 6 have an uplifting trend whereas points 2, 3, 4, and 5 tend to go down. A seasonal effect can be clearly visible in these plots. This seasonal effect can also be seen over Warri Refinery looking at Fig. 9 where the deformation evolution referred to the first data is displayed.

Calculating the difference between the deformation time-series of two points, in Fig. 10a we can observe the differential movement between points 1 and 2, two places very close and located on the Jetty road (Figs. 6 and 7a) or between points 6 and 5 for instance (Fig. 10b), located in the east part of the South Warri Council and with a different trend (Figs. 6, 7b and 7d).

4. Conclusion and Recommendation

In this work we present the interferometric results retrieved in Warri, Delta state, Nigeria. Several deformation phenomena have been found for the first time in this region with velocity rates up to ±5 mm/yr. Flooding after rain events as well as the excessive withdrawal of the underground water can be probably an explanation of this deformation phenomena. A further analysis of the aquifer system in the area and its recharge after rainfall water infiltration, as well as the time evolution of the piezometric level, together with meteorological and rainfall data could help to understand the deformation pattern. It is therefore recommended that the concerned authorities, particularly, Delta state government, Federal Ministry of Niger Delta and Niger Delta Development Corporation to collaborate with the Centre for Geodesy and Geodynamics, Toro, Bauchi state under National Space Research and Development Agency (NASRDA) mandated with this responsibility, for continuous monitoring of this phenomena for the safety of lives and properties.

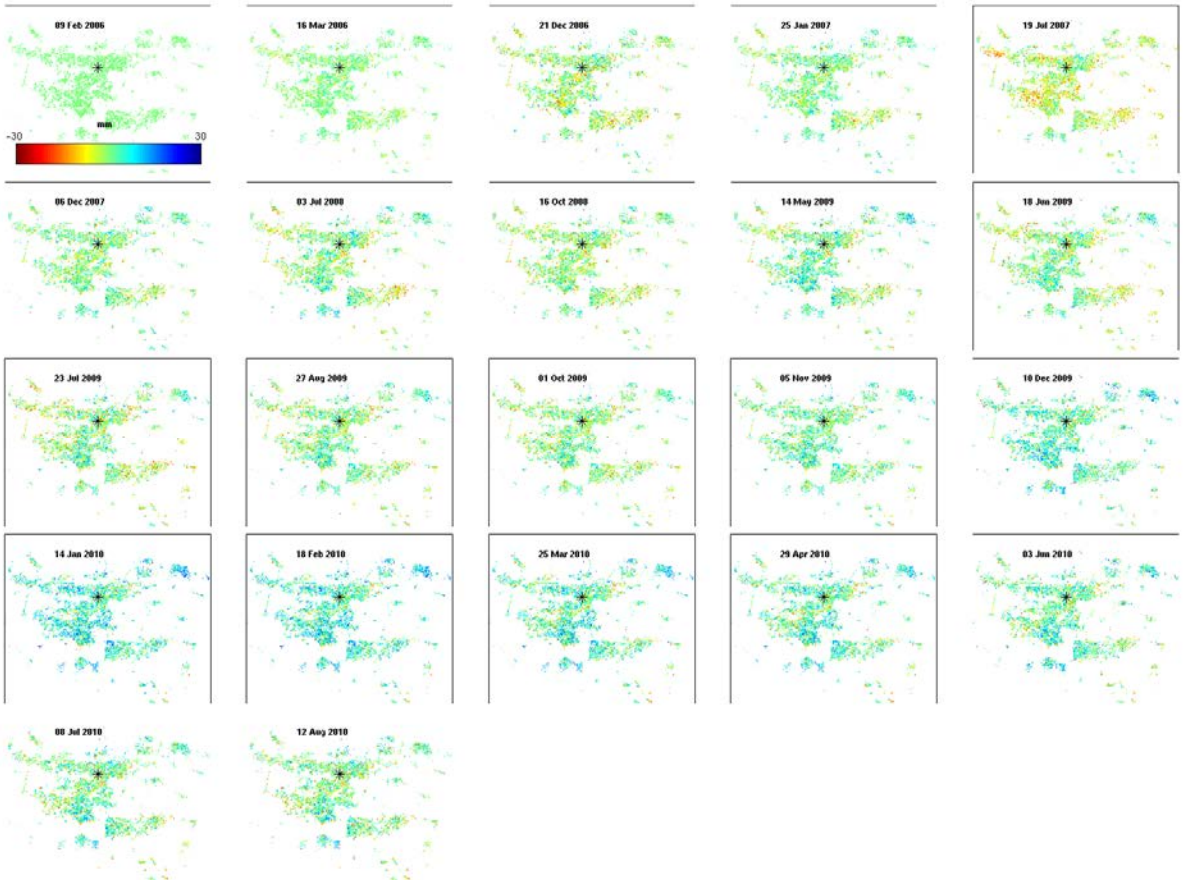

Fig. 5. Unwrapped phase for the combined processing (PS+SBAS) of Warri metropolis referred to the first data. All the single master interferograms are ordered by dates from left to right and up to bottom. The unwrapped phase is represented in millimeters.

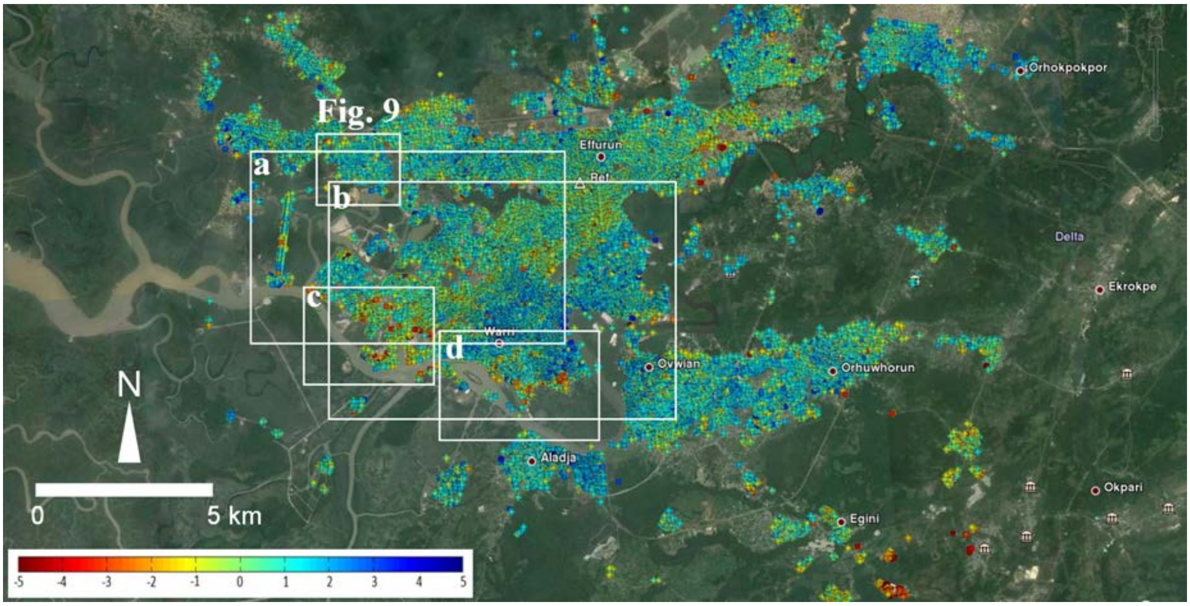

Fig. 6. Geocoded radar mean LOS velocity in mm/yr, assuming a linear deformation rate, superimposed over a Google Earth image. The white triangle indicates the reference area for phase unwrapping and the white rectangles denote the areas enlarged in Fig. 7.

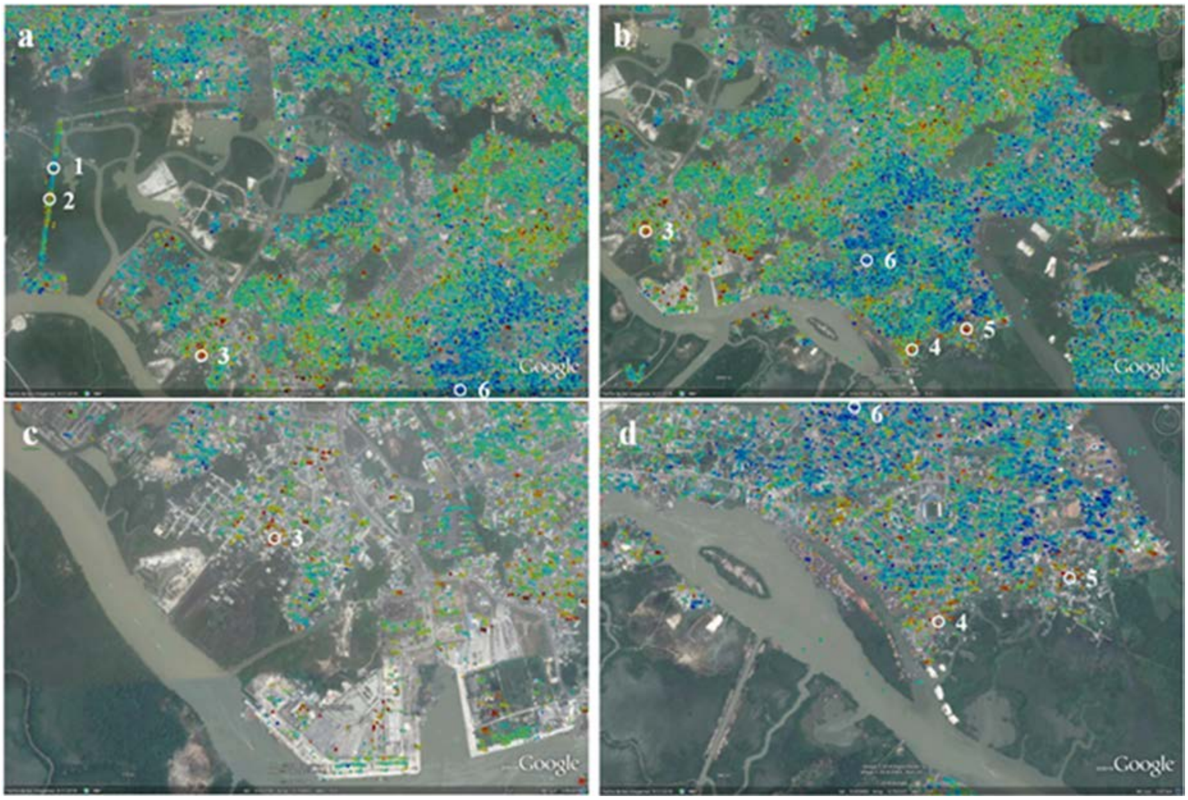

Fig. 7. Geocoded radar mean LOS velocity of the four areas (a, b, c and d) shown in Fig. 6.

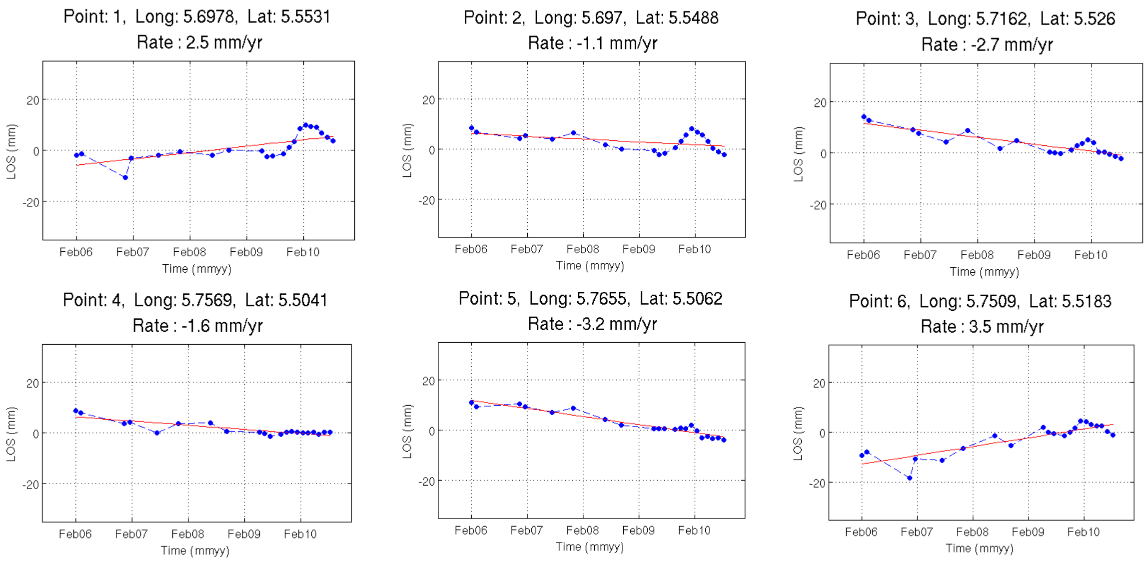

Fig. 8. Deformation time-series PS points 1 to 6 located in Fig. 7.

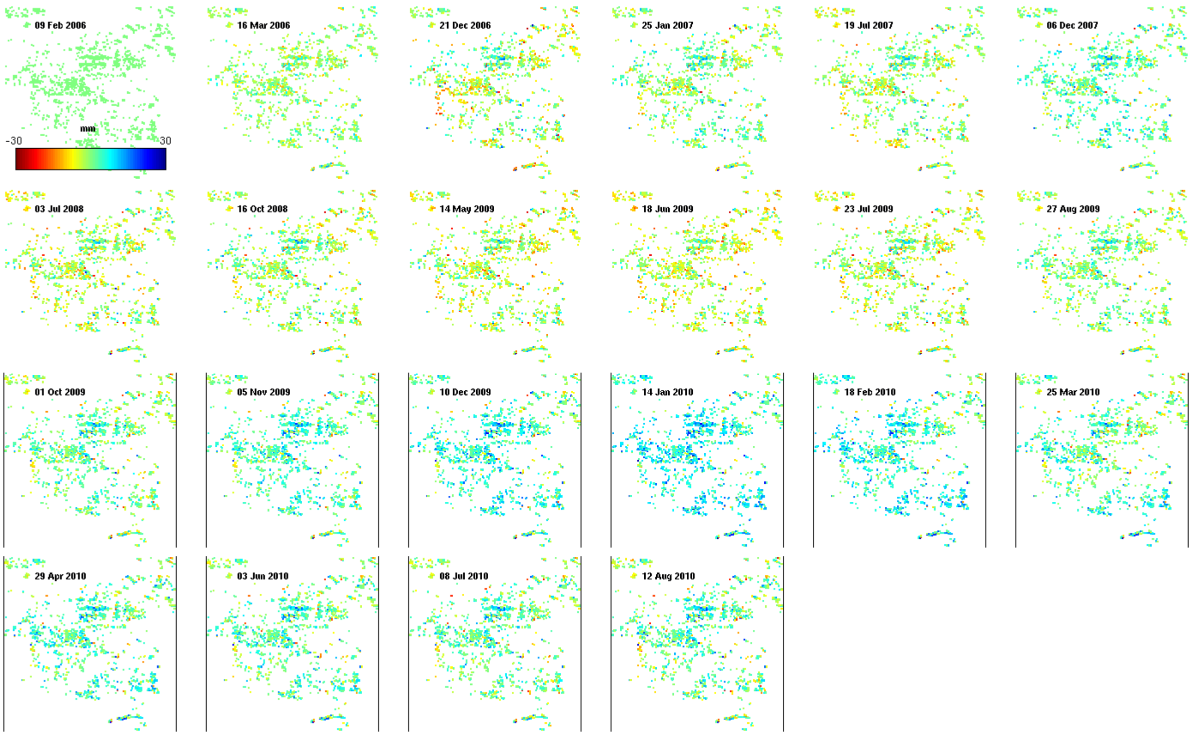

Fig. 9. Unwrapped phase for the combined processing (PS+SBAS) of the refinery (NW Warri, Fig. 6) referred to the first data. All the single master interferograms are ordered by dates from left to right and up to bottom. The unwrapped phase is represented in millimeters.

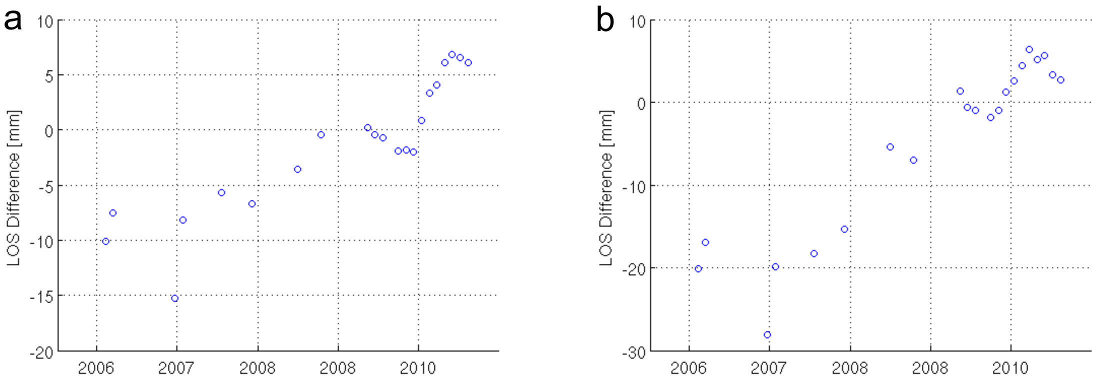

Fig. 10. Difference between the deformation time-series of points 1 and 2 (a), and 6 and 5 (b).

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References

1. Putra DPE, Setianto A, Keokhampui K, Fukuoka H. Land Subsidence Risk Assessment Case Study: Rongkop, Gunung Kidul, Yogyakarta – Indonesia, *The 4th AUN/ SEED Net Regional Conference on Geo Disaster Mitigation in ASEAN*, The Royal Paradise Hotel & Spa, Phuket, Thailand, October 25 26; 2011.
2. Cooks RU, Doornkamp CJ. *Geomorphology and Environmental Management: An Introduction*, Clarendum, press, Oxford; 1974.
3. Folagbe SO. Structural in Domestic Buildings In Nigeria: Causes and Remedies. In: *Proceedings of a National Symposium on Journal of Emerging Trends in Economics and Management Sciences* (JETEMS) 3 (2):123130 (ISSN: 2141-7024). 1997.
4. Oteri AU. Delineation of Sea water Intrusion in a Coastal Beach Ridge of Forcados. *Journ. of Mining and Geol* 1990; 26(2):225-229.
5. National Population Commission; 2006.
6. Mode *et.al.* Intergrating geographic information system (GIS) and hydrochemistry for heavy metal pollution studies: The case of Ubeji and Omadino areas of Delta State, Southern Nigeria. *Journal of Geology and Mining Research* 2010; 2(7):184-185.
7. Hooper A, Segall P, Zebker H. Persistent scatterer InSAR for crustal deformation analysis, with application to Volcán Alcedo, Galápagos. *J Geophys Res* 2007;112:B07407. doi:10.1029/2006JB004763.
8. Hooper A. A multi-temporal InSAR method incorporating both persistent scatterer and small baseline approaches. *Geophys Res Lett* 2008;35:L16302. doi:10.1029/2008GL034654.
9. Hooper A, Zebker H, Segall, P, Kampes B. A new method for measuring deformation on volcanoes and other natural terrains using In-SAR persistent scatterers, Geophys Res Lett 2004;31(23), doi:10.1029/2004GL021737.
10. Ferretti A, Prati C, Rocca F. Permanent Scatters in SAR Interferometry. *IEEE Trans-actions on Geoscience and Remote Sensing* 2001;39(1): 8-20.
11. Kampes BM. Displacement Parameter Estimation using Permanent Scatterer Interferometry, PhD Thesis, Delft University of Technology; 2005.
12. Berardino P, Fornaro G, Lanari R, Sansosti E. A new algorithm for surface deformation monitoring based on small baseline differential SAR interferograms. *IEEE Transactions on Geoscience and Remote Sensing* 2002;40(11):2375–83.