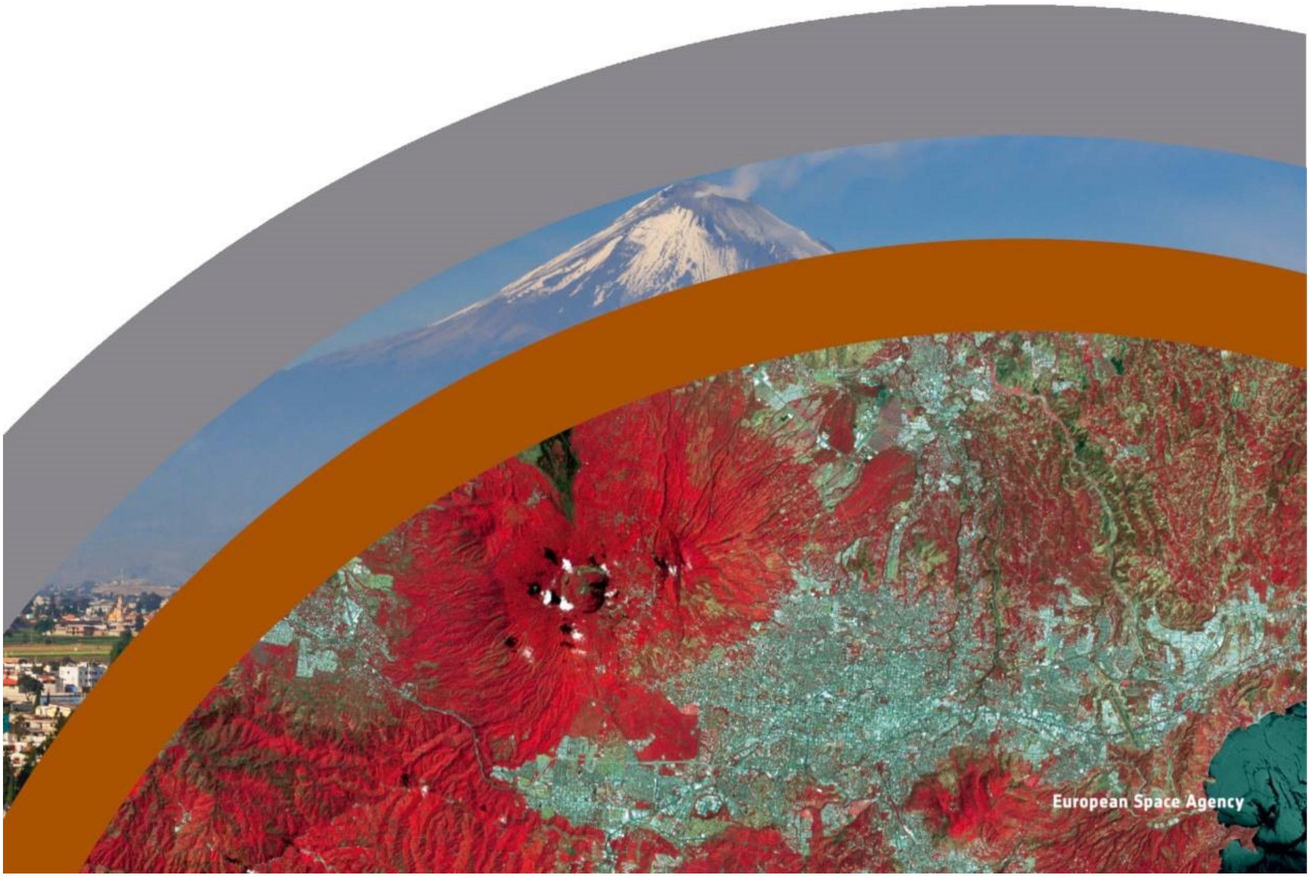
→ EO4SD - EARTH OBSERVATION FOR SUSTAINABLE DEVELOPMENT

Disaster Risk Reduction

City Resilience Program (CRP): Terrain Deformation in urban areas

disaster risk reduction
eo4sd



ESA´s EO4SD Disaster Risk Reduction

Earth Observation for Sustainable Development Disaster Risk Reduction (EO4SD DRR) is an activity initiated by European Space Agency (ESA) in the framework of its collaboration with International Financing Institutions (IFI´s) to support a greater use of satellite Earth Observation (EO) in applications related to the management of natural and man-made hazards and risks.

Disasters cause human suffering, environmental harm, and economic loss; investing in its prevention and reduction will diminish people's vulnerability, saving lives and reducing economical damage.

The impact of disasters on lives and economy are of prime importance to society, especially for developing countries, where the mortality and economic losses are disproportionately high and where development achievements can be threatened. Many types of natural disasters can affect the humankind worldwide: Geo-hazards like earthquakes and volcanoes; hydro-meteorological hazards like floods, hurricanes, tropical storms and storm surges; climatological events like droughts, heatwaves and wildfires among others. There is the need of addressing the impact of these events not only by reacting after episodes but also by enhancing prevention and preparedness. Earth Observation can contribute to tackling most of these natural hazard types efficiently by providing hazard mapping, supporting services for the assessment of exposure, vulnerability and risk and reconstruction monitoring.

Since 2008 ESA has worked closely with Multilateral Development Banks (MDBs) and their Client States to harness the benefits of Earth Observation in global sustainable development increasing the uptake of EO-based information in regular development operations at national and international level.

ESA´s funded EO4SD Disaster Risk Reduction project aims to promote the adoption of Earth Observation-based products and services mainstreamed into the working processes of IFIs funded projects that seek to prevent or mitigate the adverse impacts of natural disasters in developing countries. Earth Observation applied to disasters is evolving quickly and has proven to be effective in all phases of the disaster risk management cycle such as prevention/ preparedness, early warning, post event recovery and reconstruction activities.

The authors of this information include the production, coordination and supervision teams from Planetek Italia, Gisat, BRGM, Indra and ESA.

Terrain Deformation in urban areas

Urban expansion, vulnerabilities and how to contribute to an increased resilience

The rapid urbanization of the world is inducing population to live in urban areas, thus, 55% of the world´s population currently live in cities[1]. It is expected that 90 % of the urban expansion will just happen in a few countries and 35% of the growth will take place in developing countries, much of it occurring near potential hazardous areas like rivers and coastlines, as well as through informal and unplanned, more vulnerable, settlements[1].

The greater concentration of people and assets means that the impact of natural disasters and climate change can be devastating, both in terms of human lives lost and economic livelihoods destroyed. Lack of adequate infrastructure, land use planning and building codes increases the risks to which urban dwellers are exposed.

Preparing cities for disaster and climate risks and strengthening its resilience is a critical point to move towards achieving the development goals, however, there is the inexorable challenge of building more resilient cities as they generally lack both funding and technical expertise to create and follow an integrated investment program aimed at creating a more resilient future[2].

Main identified issues

Unstoppable urban expansion and high rates of population in specific locations

Cities generally lack financial sources, technical expertise and affordable data

The City Resilience Program (CRP) is aimed at empowering cities to pursue a more resilient future supporting investment programs aimed at strengthening resilience, and facilitating the access to a broader range of financing options. CRP has means to use geospatial information for addressing hazards, as a matter of fact, flood hazard is already being assessed with global datasets or standard algorithms but subsidence is not provided systematically at global level yet.

EO4SD-DRR has collaborated with CRP throughout a demonstration on how the Geohazards Exploitation Platform (GEP) can be used in the provision of systematic terrain deformation analysis over several cities in a short period of time feeding the CRP's City Scan process. After a high level analysis and hotspot detection, a high precision terrain deformation analysis can be a valuable tool for the cities to take decisions in prioritizing of investments.

Aim of the collaboration

To inform timely City Resilience Program about hazards for cities to guide their investment plans in resilience

The Area of Interest (AOI) comprises 8.659,31 Km2 within the cities of Banjul (911,57 Km2), Barishal (310,83 Km2), Beira (573,80 Km2), Cap Haitien (333,68 Km2), Georgetown (1.081,56 Km2), Khulna (359,17 Km2), Paramaribo (1.217,97 Km2), Vinh Long (337,22 Km2) and Yangon (3.533,51 Km2).

[1] Desa, U. (2018). 2018 Revision of World Urbanization Prospects. May, 16, 2018.

[2] City Resilience Program. Annual Report. 2018.
https://www.gfdrr.org/sites/default/files/City%20Resilience%20Program_Annual%20Report.pdf

Identification of hotspots of terrain deformation in highly populated urban areas

Research on land subsidence is a frequently addressed issue in environmental research, as its impacts are observed in many countries including Bangladesh, The Gambia and Haiti between others. The need for identifying hotspots is increasingly necessary as they allow the identification of potential hazardous phenomena, constituting a first step towards a future possible management.

Throughout this Demonstration Exercise, the EO4SD-DRR has aimed at demonstrating advanced terrain deformation products obtained via operational InSAR services running on ESA´s Geohazards Exploitation Platform (GEP) and other proprietary platforms in order to support the World Bank (WB) City Resilience Program (CRP). The collaboration aims to support the CRP's City Scan process by the provision of systematic terrain deformation analysis over several cities. Moreover, full resolution terrain deformation assessment has been provided for two of the nine cities, demonstrating how precise and operational can be space technology to understand subsidence phenomena and their impact in the urban environment.

To meet WB CRP requirements the EO4SD DRR team run nine EO-based analysis concerning medium resolution data using the P-SBAS on-demand processing service on the Geohazards Exploitation Platform (GEP - https://geohazards-tep.eu). The P-SBAS algorithm has gone through several years of validation using various independent geodetic measurements (in-situ and spaceborne) to ensure the final quality of the product.

For a common period of observation (approx. 2017-2019) it was possible to extract accurate terrain deformation estimates over the nine selected cities using an automated on-demand InSAR service already operational on the GEP.

Histograms showing the distribution of terrain deformation among the various examined cities and the part of the histogram referring to subsidence (negative values) for the period 2017-2019 (**Figure 1**). It is shown that Vinh Long (Vietnam) and Yangon (Myanmar) are the cities more affected by subsidence phenomena. Note: displacement rates (cm/yr) in x-axis and percentage of pixels in y-axis.

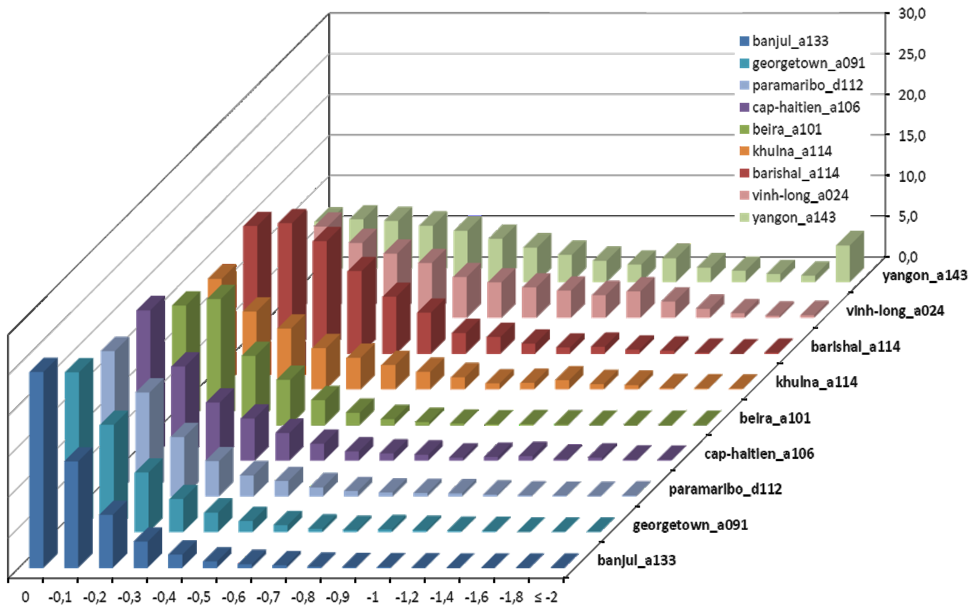


Figure 1 Histogram referring to subsidence for 9 cities (negative values)

Data from the Copernicus Sentinel-1 mission were used by the CNR-IREA P-SBAS algorithm for the generation of mean velocity maps and deformation time series.

Both original GEP InSAR processing results as well as after ingestion to a geographic information system (including production of relevant maps) were disseminated for further utilization and interpretation by thematic experts and local authorities of the various cities.

The obtained results highlight the status of each city concerning subsidence by delineating regions affected by such phenomena. It appears that the cities Vinh Long (Vietnam) and Yangon (Mynamar) are among the ones more affected. Localized patterns of lower displacement rates are recognized in several other cities, such as Barishal (Bangladesh), Cap-Haitien (Haiti) and Khulna (Bangladesh).

While the generated mean velocity maps provide the overall terrain deformation during the observation period, the full time series offer additional information to inspect the temporal behaviour of each area undergoing subsidence, allowing the recognition of increasing or decreasing trends, periodic signals or more complex temporal motion patterns. For such analysis, proper handling of the InSAR time series by an EO export is required.

Sentinel-1 P-SBAS LoS displacement time series showing the evolution of terrain deformation for selected measurement points at **Figure 2** and **Figure 3**) Yangon (point IDs 21145 & 49162, respectively). For the examined points displacement seems to follow a linear trend in time; however, more complex temporal patterns might exist, especially in agricultural lands.

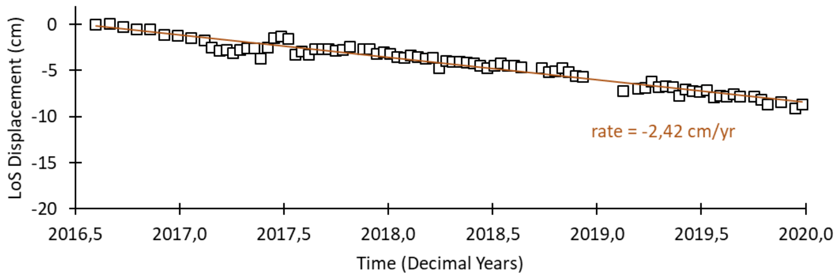


Figure 2 P-SBAS LoS displacement time series. Yangon (point ID: 21145)

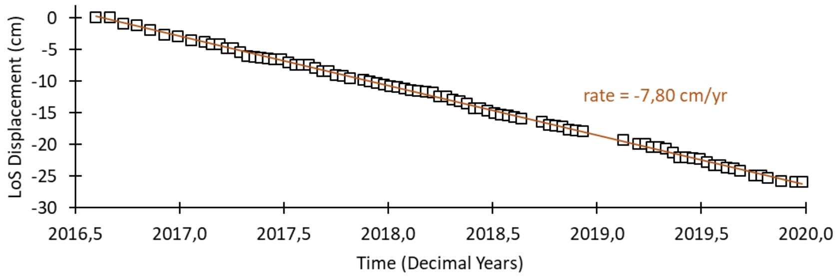
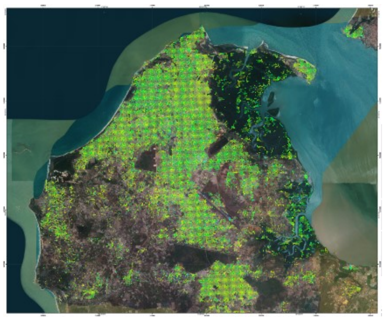


Figure 3 P-SBAS LoS displacement time series. Yangon (point ID: 49162)

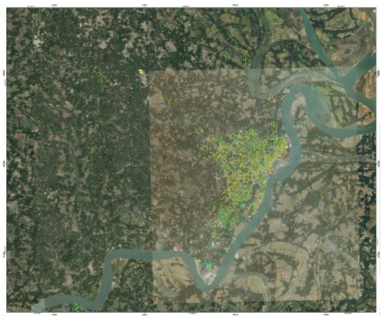
The support of the EO4SD DDR to the CRP via the utilization of GEP involved the demonstration of operational services for the quick and low cost investigation of terrain deformation over cities, allowing the identification of related hazardous phenomena.

Such demonstration combined with tailored capacity building activities pave the ground for the use of platform-based InSAR solution directly by EO practitioners inside the WB for the monitoring purposes of cities.

The current activity also support the decision on whether it is appropriate or not to proceed with more detailed and customized services; results of higher spatial resolution, based either on Copernicus Sentinel-1 mission or other very high resolution EO missions such as COSMO-SkyMed or TerraSAR-X.



Terrain deformation overview of Banjul (The Gambia).

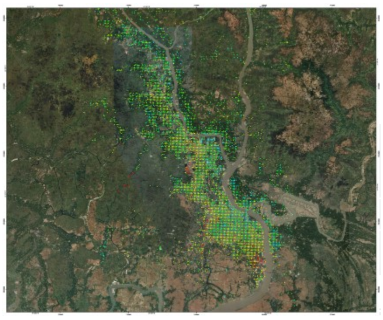


Terrain deformation overview of Barishal (Bangladesh).

Terrain deformation overview of Beira (Mozambique).

Terrain deformation overview of Cap-Haitien (Haiti).

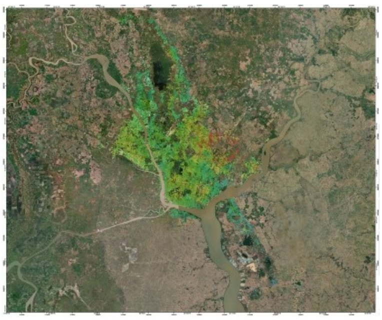
Terrain deformation overview of Georgetown (Guyana).



Terrain deformation overview of Khulna (Bangladesh).

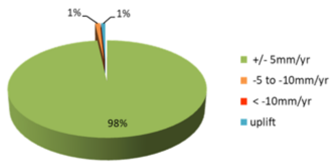
Terrain deformation overview of Paramaribo (Suriname).

Terrain deformation overview of Vinh Long (Vietnam).

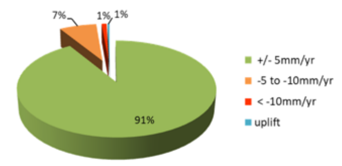


Terrain deformation overview of Yangon (Myanmar).

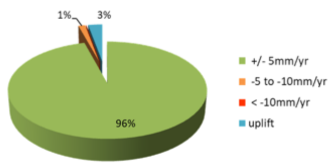
Figure 4 Ground displacements based on InSAR processing of Copernicus Sentinel-1 mission data using the P-SBAS on-demand service on GEP.



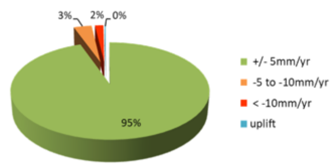
Banjul (The Gambia). Sentinel-1 InSAR LoS displacement rates for the period 02/2017-12/2019.



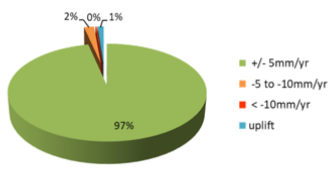
Barishal (Bangladesh). Sentinel-1 InSAR LoS displacement rates for the period 01/2017-12/2019



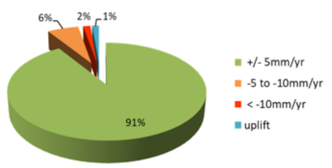
Beira (Mozambique). Sentinel-1 InSAR LoS displacement rates for the period 10/2016-12/2019



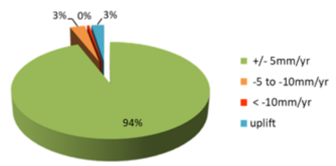
Cap-Haitien (Haiti). Sentinel-1 InSAR LoS displacement rates for the period 01/2017-12/2019.



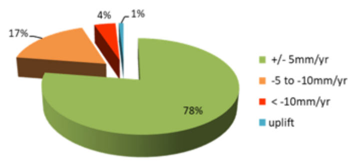
Georgetown (Guyana). Sentinel-1 InSAR LoS displacement rates for the period 09/2016-12/2019



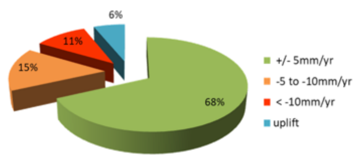
Khulna (Bangladesh). Sentinel-1 InSAR LoS displacement rates for the period 02/2017-12/2019.



Paramaribo (Suriname). Sentinel-1 InSAR LoS displacement rates for the period 02/2017-12/2019.



Vinh Long (Vietnam). Sentinel-1 InSAR LoS displacement rates for the period 03/2017-12/2019.



Yangon (Myanmar). Sentinel-1 InSAR LoS displacement rates for the period 08/2016-12/2019.

Figure 5 Pie charts of terrain deformation for each of the nine cities analyzed

Overall stability of the area of interest in Banjul (The Gambia), with 98%, Barishal (Bangladesh), with 96%, and Beira (Mozambique), with 96% of the points exhibiting motion between +/- 5 mm/yr. In Cap Haitien (Haiti) the largest part of the city (95%) appears to be stable with subsidence rates not exceeding -5 mm/yr with a recognizable deformation pattern is observed (about 2% of total area) at the central part of the city (between Mapou River and the coastal zone) with subsidence rates reaching up to -29.8 mm/yr In Georgetown (Guyana) there are limited isolated points with relatively higher subsidence rates compared to the remaining parts of the city which show rates between +/- 5 mm/yr with overall stability along the coastline. In Khulna (Bangladesh) there are several pronounced subsidence patterns mainly along the western and southern margins of the city reaching –16.8 mm/yr (approx. 6-8% of the area). Worth to mention the observed uplift trends at several locations along the river sides. Remaining part of the city (91%) exhibiting motion between +/- 5 mm/yr. There are recognizable subsidence patterns at the north-western and north-eastern parts of the Paramaribo (Georgetown). Local areas of increased displacement rates along the river banks and within the broader Meerzorg region. The largest part of the city (94%) shows subsidence that does not exceed -5 mm/yr In Vinh Long (Vietnam) significant parts of the city undergo relatively high subsidence; about 21% exceed -5 mm/yr of which 4% are larger than -10 mm/yr. Several of these patterns are located in the vicinity of the Co Chien Rriver, whereas a large one also dominates the central part of the city. Finally in Yangon (Myanmar) about 26% of the area shows displacements between -5 and -10 mm/yr (e.g. along the eastern margins of the Hlawga National park). The region mostly shows moderate to high subsidence, whereas only the 68% are within +/- 5 mm/yr.

A *detailed Terrain deformation analysis and exposure map* was carried out over Vinh Long (Vietnam).

Land subsidence in Vinh Long area was detected by persistent scatterers interferometry technique. This method allows detection of subtle surface displacements with up to millimetric accuracy using long time series of radar measurements from satellite-borne sensors. Displacement velocity map shows average annual displacement rate of terrain or assets' instabilities, either of natural or anthropogenic origin. Results bring insight into distribution and intensity of land subsidence patterns. Analysis was carried out using two independent image stacks consisting of measurements from two orbital trajectories of Sentinel-1 satellite constellation: both ascending and descending.

The analysis was carried out on existing satellite measurements from period 2014/2017- beginning of 2020, that were acquired from Sentinel-1 long-term archive hub. As such, it provides insight into distribution and severity of existing deformation patterns and can be, in certain extent, used to extrapolate evolution of terrain deformation trend in near future.

Figure 6 Persistent scatterers displayed in InSARviz

The exposure map shows intensity of exposure of urban blocks and road segments to land subsidence detected by satellite interferometry (**Figure 7**).

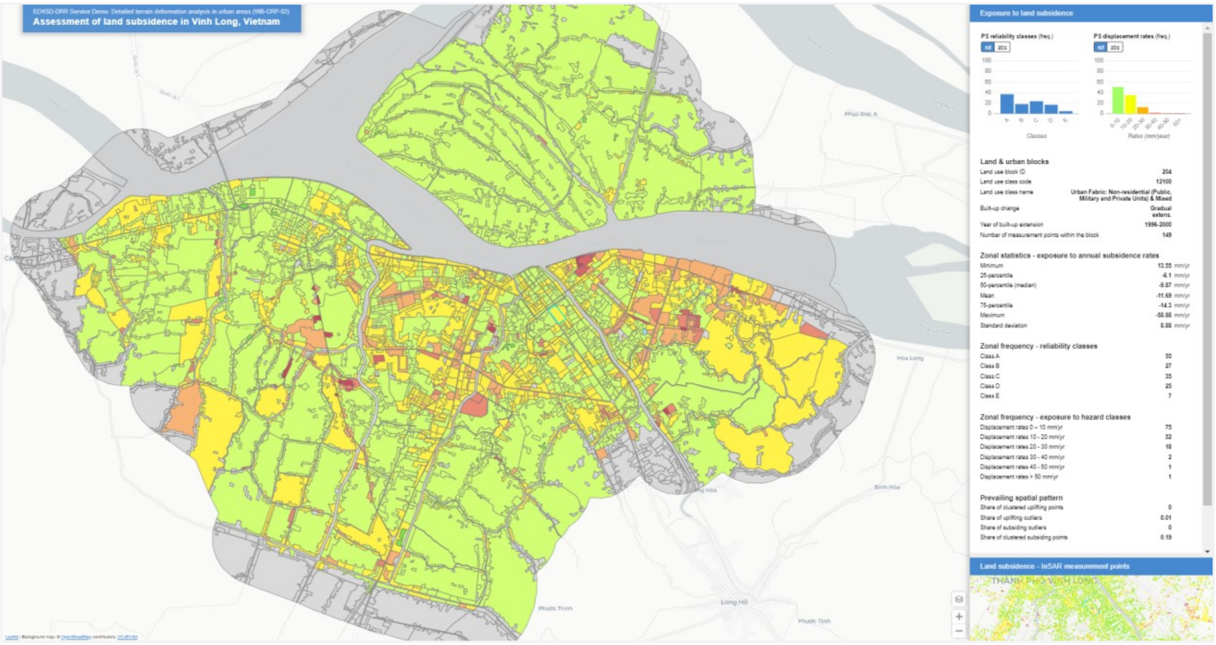


Figure 7 Exposure of urban blocks to land subsidence in InSARviz

A detailed *Terrain deformation analysis over the Greater Banjul* area was produced by the Rheticus® platform and delivered under the name of Rheticus® Displacement service. The service implements the SPINUA algorithm, that is the state-of-the-art algorithm for the InSAR time-series analysis (PSI) and produces a dense map of measurement points (Persistent Scatterers and Distributed Scatterers, PS/DS) representing terrain motion, and providing a quantitative assessment of ground motion through the time series of displacement (mm) and the average velocity (mm/year) for each measured point.

The PSI analysis has been performed by processing the 65 SAR COSMO-SkyMed images provided by the World Bank and acquired from 2011/05/31 to 2018/09/07.

The ground motion is measured with a precision up to 1,5 mm/year along the satellite's line of sight for coherent targets (buildings, roads, bridges, pillars, exposed rocks, bare soil, etc). The accuracy of the measures is guaranteed by a high level of error compensation of the PSI technique that allows the generation of time series analysis highlighting displacement trends over time.

The results (**Figure 8** and **Figure 9**) reveal general stability of the Greater Banjul Area and a subsidence motion hotspot up to 18.5 mm/year in the harbour area of Banjul. All the ground motion measurements can be exploited through the Rheticus® Displacement service World Bank account that is accessible with the provided username and password.

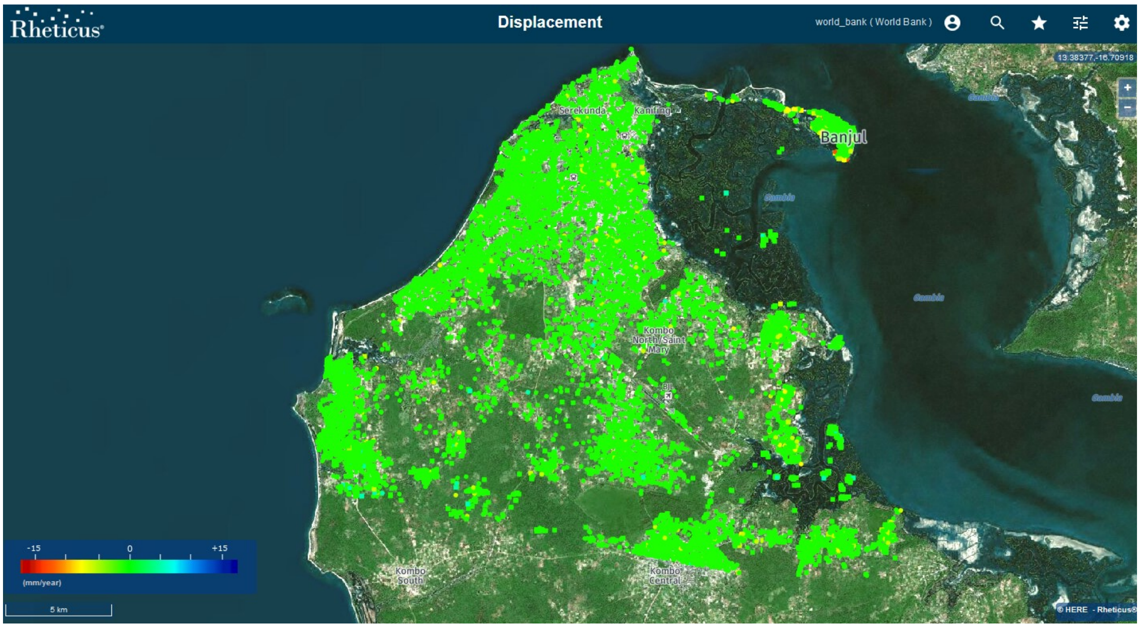


Figure 8 Overview of the full ground motion maps over the Greater Banjul area (The Gambia). It is possible to see how the major part of the area does not present differential motion

Figure 9 Localized ground motion phenomena close to Banjul harbor, with detailed time-series graph of the displacement that shows a total movement of about 140 mm from May '11 to September '18

The results of the study were delivered to the City Resilience Program and to the World Bank urban teams of each of the cities. Moreover, the cluster guided the City Resilience Program through several training sessions in the understanding of the technique, with its benefits, especially the capacity to perform analysis over multiple cities at a relatively low cost in comparison with other methods, and limitations. The World Bank teams of several cities Beira, Khulna, Barishal, Cap Haitian, Vinh Long) received individual targeted capacity building actions for discussing the results over their cities and the applicability of the technique in their practices of improving resilience. In particular the World Bank team of Vinh Long was involved in several in depth sessions due to counting with both medium and full resolution products.

Understanding disaster risk in all its dimensions of vulnerability, exposure of persons and assets, hazard characteristics and the environment is the first priority action of the Sendai Framework for Disaster Risk Reduction (2015-2030).

International Financial Institutions (IFIs) play a significant role as facilitators of funding in developing countries, in direct cooperation with national mandated disaster authorities to prevent and mitigate the adverse effects of natural disasters and foster sustainable development.

The ESA EO4SD Disaster Risk Reduction project aims to promote the adoption of Earth Observation-based products and services mainstreamed into the working processes of IFIs funded projects that seek to prevent or mitigate the adverse impacts of natural disasters in developing countries. Earth Observation applied to disasters is evolving quickly and has proven to be effective in all phases of the disaster risk management cycle such as prevention/ preparedness, early warning, post-event recovery and reconstruction activities.

Consortium partners

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