AWS GRANT APPLICATION 2019

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TITLE OF PROPOSED PROJECT

Development of a large scale, operational monitoring system of ground deformations in Nigeria through advanced DInSAR processing of times series Sentinel-1 data

KEY WORDS:
Sentinel-1, Synthetic Aperture Radar (SAR), DInSAR, SqueeSAR, Surface Deformation, Times Series

Collaborators:
The collaborating Institution is the University of Nigeria. Professors and other academic staff involved in the collaboration are:

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EXECUTIVE SUMMARY

Land deformation is well known for their devastating impact on human life, economy and environment. Though, it is almost impossible to completely neutralize the damage due to these disasters, it is possible to minimize the potential risks by developing comprehensive disaster early warning strategies and prepare developmental plans to provide resilience to such disasters.

Various parts of Nigeria suffer from continued land deformation as evidenced by ground fissures, landslides, subsidence and seismic hazards. Land deformation has occurred in Nigeria in response to various natural and anthropogenic factors, such as: Earth movement, indiscriminate withdrawal of fluid, including oil and gas exploration and excessive withdrawal of ground water. This is most prevalent in major coastal mega cities, like Lagos, Port Harcourt, Warri, Yenegoa with high population and large number of industries

Again, Nigeria was not known to be seismogenic in the past and because of this, most people tend to believe that seismic activities are confined to North Africa and the surrounding areas of the rift valley system in East Africa (Onuoha, 1988).

But recent findings have shown that Nigeria may not be completely free from earthquakes (Adepelumi, 2009; Akpan and Yakubu, 2010). It has been shown that Nigeria has witnessed several minor tremors in some parts of the country in 1933, 1939, 1964, 1984, 1990, 1994, 1997, 2000 and 2006 (Akpan and Yakubu, 2010). The intensities of these events ranged from III to VI based on the modified Mercalli Intensity Scale. Of these events, only the 1984, 1990, 1994 and 2000 events were instrumentally recorded. They had magnitudes ranging from 4.3 to 4.5 (Akpan and Yakubu, 2010).

On the other hand, there have been numerous cases of buildings collapses that occurred mostly in coastal mega cities like Lagos, Port Harcourt, Warri and other major cities and State capitals.

Till date, a comprehensive attention has not been given to land deformation hazard monitoring system which can to evolve to early warning land deformation scheme for Nigeria. In fact, there is no record of a comprehensive, nationwide land deformation hazard studies in Nigeria to help in the sitting of critical facilities like nuclear power plants for electricity generation, dams, rail lines, high rise buildings, roads, etc. There is therefore need to develop procedures for monitoring these land deformations with the aim of establishing a nationwide operational land deformation early warning system. These gaps could be resolved by using advanced interferometric processing of large Sentinel-1 multi-temporal SAR datasets, aimed at analyzing Earth surface deformation phenomena at wide spatial scale following the development in Federico Raspini *et al* (2018). To achieve these, the Niger Delta Region of Nigeria, covering an area of about 70,000 km^2 and making up of up to 7.5% of Nigeria's land mass is chosen as a case study. This region is host to all the oil and gas explorations and exploitations in Nigeria. The Niger Delta region also contains majority of the coastal mega cities in Nigeria liable to coastal subsidence.

The launch of the Sentinel-1 sensors opened new possibilities for Interferometric SAR (InSAR) applications. Developed within the ESA Copernicus initiative, the Sentinel-1 mission is a constellation of two twin satellites, Sentinel-1A and Sentinel-1B. Launched in April 2014 and in April 2016, respectively, they share the same orbital plane and offer an effective revisiting time of 6 days (12 days for each single sensor), which is extremely suitable for interferometric applications. With respect to previous SAR satellites, Sentinel-1 data exhibit some favorable characteristics: regional-scale mapping capability systematic and regular SAR observations and rapid product delivery (typically in less than 3 hours from data acquisition). Sentinel-1 SAR products are freely accessible, thus providing the scientific community, as well as public and private companies, with consistent archives of openly available radar data, suitable for deformation monitoring applications.

Differential Synthetic Aperture Radar Interferometry (DInSAR) is regarded as one of the key Earth Observation (EO) methods for its ability to investigate surface displacements affecting large areas of the Earth with centimeter to millimeter level accuracy The DInSAR methodology has been originally applied to analyze single deformation episodes such as earthquakes and volcanic unrests. However, thanks to the availability of long SAR data time series, it is also possible to study the temporal evolution of the detected surface deformations. This is carried out through the exploitation of the so-called advanced DInSAR techniques, which properly combine the information available from a set of multi-temporal interferograms relevant to an area of interest, in order to compute the deformation time series Among several advanced DInSAR algorithms, a widely used approach is the SqueeSAR algorithm (Ferreti et al (2011)) which is the algorithm to be used in this proposed project

The anticipated impact of the proposed project will be the development of land deformation monitoring system, a dynamic system to be updated on a regular basis, which will be capable of providing information to the Nigerian authorities on when, where and how fast the ground is moving in any part of Nigeria in order to prioritize and mitigate hazards deemed to be most urgent. The development of land deformation monitoring system is in line with the Sendai Framework for Disaster Risk Reduction (SFDRR) 2015–2030, with four priorities in disaster risk reduction. The fourth priority emphasizes the improvement of preparedness to respond effectively to a disaster by implementing a simple, low-cost early warning system and improving the dissemination of information about early warning signs of natural disasters at local and national levels

Specifically, the proposed project directly and indirectly addresses the seven targets of the Sendai Framework for Disaster Risk Reduction (SFDRR) 2015–2030. These are:

(a) Substantially reduce global disaster mortality by 2030, aiming to lower average per 100,000 global mortality rate in the decade 2020-2030 compared to the period 2005-2015.
(b) Substantially reduce the number of affected people globally by 2030, aiming to lower average global figure per 100,000 in the decade 2020 -2030 compared to the period 2005-2015.
(c) Reduce direct disaster economic loss in relation to global gross domestic product (GDP) by 2030.
(d) Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030.
(e) Substantially increase the number of countries with national and local disaster risk reduction strategies by 2020.
(f) Substantially enhance international cooperation to developing countries through adequate and sustainable support to complement their national actions for implementation of this Framework by 2030.
(g) Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to the people by 2030.

PROJECT PLAN

AIM AND OBJECTIVES

The aim of this proposal is to develop a comprehensive nationwide land deformation monitoring system for Nigeria using Sentinel-1 data within the Amazon Web Service (AWS) environment

Specific objectives to this study will be to:

(i) Acquire the entire Sentinel -1 and Sentinel 2 and Landsat archived images of the Niger Delta Area of Nigeria

(ii) Process the archived Sentinel-1 images using **the** SqueeSAR technique. SqueeSAR is an advanced InSAR algorithm specifically designed to analyse long temporal series of SAR scenes. SqueeSAR developed by Ferreti A. *et al* (2011), is designed to identify a sparse grid of measurement points (MP) for which it is possible to estimate, with millimetric accuracy the mean yearly velocity (in mm/yr) and displacement time series (TS) along the satellite line of sight (LOS).

(iii) Design a high performance processing chain to automatically download Sentinel-1 image covering the area of interest as soon as a new data is available and process using the SqueeSAR algorithm properly parallelized and optimized to strongly reduce the processing time, and subsequently update the existing database of displacement data.

(iv) Analyze new time series data with time series analysis tool capable of highlighting any changes in trends, steps or accelerations.

(v) Analyze displacement Times Series for each measurement to identify any change in the deformation pattern over the last few months in order to identify anomalous points

(vi) Classify anomalies with the support of thematic information (*i.e.*, topographic, geomorphologic, geological and land use and coverage maps), multi-temporal optical images (Sentinel-2) and other information such as landslide inventory maps, location of mining activities, catalogues of oil and gas extraction and database of elements at risk. Subsequently assign driving forces (*i.e.*, slope instability, oil and gas activities, uplift and subsidence, seismic activities) to the anomalies.

(vii) Develop a smart interactive Web based application to host the database and extracted information and to implement the monitoring system within the Amazon Web Service

METHODOLOGY

The methodology to be adopted in this project will be inter disciplinary in nature and is illustrated in Fig.1. It will be developed in four different phases as follows:

(i) Generation of ground deformation data based on archive Sentinel-1 data and new Sentinel-1 acquisition. This is to be carried out by experts in Geoinformatics and Surveying)

(ii) Generation of anomalous points based on analysis of time series deformation data This is to be carried out by experts in Geoinformatics and Surveying)

(iii) Interpretation and classification of anomalies based on auxiliary information from geological maps, land use and land cover maps generated from sentinel-2 data, land slide and land deformation information. This interpretation would be carried out by specialists in geology (physical Sciences), geography (social sciences), urban and regional planning (economics and social sciences). It will include traditional geomorphological thematic information (topographic, geomorphologic, geological and land use land cover maps), multispectral and multi-temporal images (mostly from LandSat and Sentinel 2 data) and, finally, *in situ* data investigations. Visual *in situ* inspections for land deformation during the period of research will be performed to integrate InSAR measurements with further information and possible evidences of ground/building movement (ground surface fractures and building cracks). Catalogues of oil and gas extraction areas and database of elements at risk will be used in the interpretation and classification of anomalies. Also, *in situ* soil tests where necessary and geological investigation will be carried out in order to enhance the chances of finding possible correlation of any land deformation to a driving force (i.e. manmade or natural causes).

(iv) Web based information and monitoring system

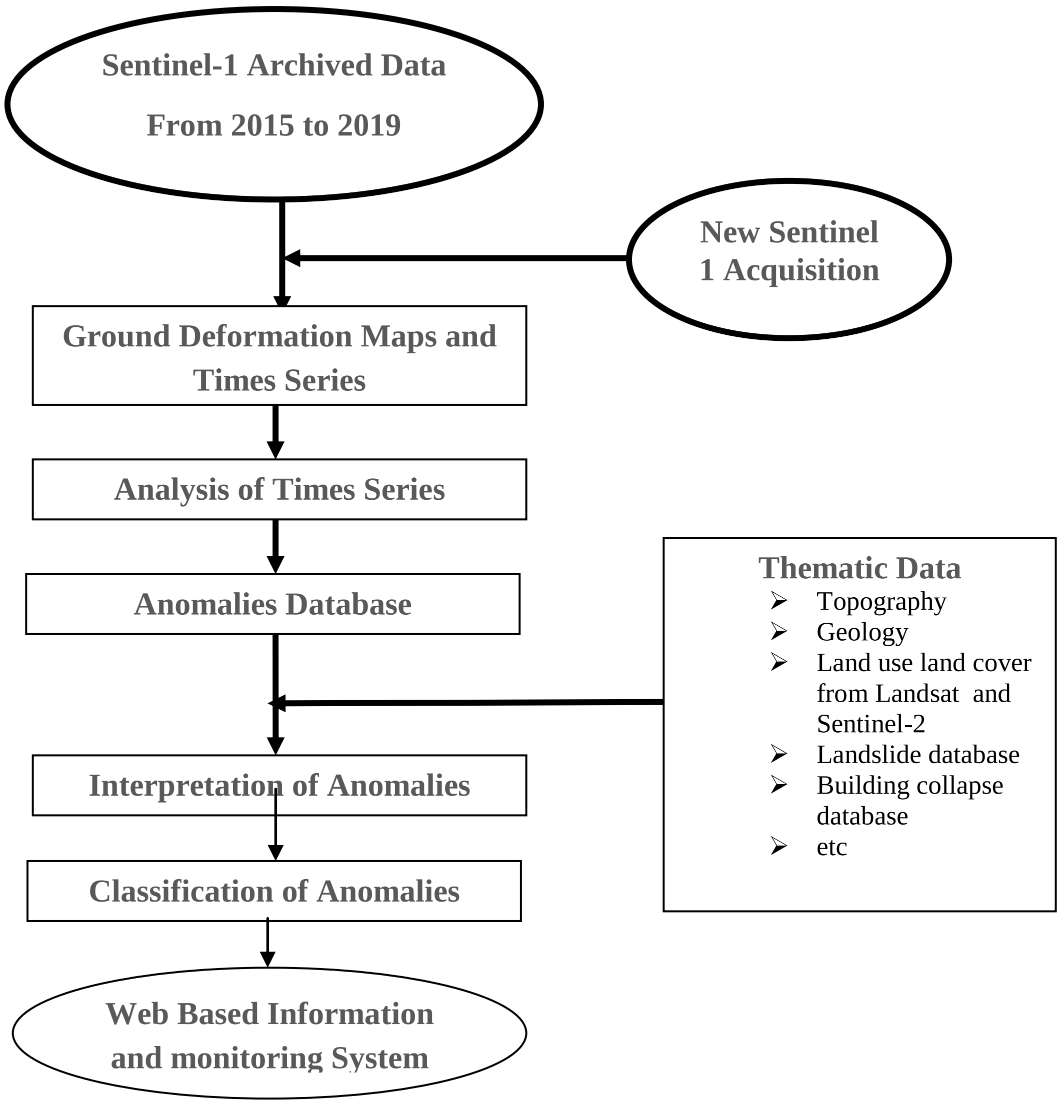

Fig. 1: Flow chart of Methodology (modified from Federico Raspini *et al* (2018)

EARTH OBSERVATION REQUIREMENTS

The project will require the use of Earth observation Satellite data. Specifically the project will require Copernicus Sentinel 1 and 2 , and Landsat data sets. Sentinel 1 dat will be used for developing the land deformation monitoring model, while Sentinel 2 and Landsat data will be used for generating land use land cover (LULC) maps over the study area. The period of Sentinel 1 data acquisition would be from March 2015 to April 2018. Three quarter of the data will be used for the model development while one quarter of the total data will be used for model validation. This means that we would use the Sentinel 1 data from March 2015 to February 2017 for model development and March 2017 to April 2019 and up to the end of the project for model validation and adjustment. Sentinel 2 data sets will be used for LULC change detection analysis over the period of investigation.

AREA OF INTEREST

The area of interest will be the Niger Delta area of Nigeria which extends from longitude 3.5E to 8.45E and latitude 4.5N to 5.65N and covers an area of approximately 70,000km2 (i.e. about 7.5% of Nigeria) and is third largest Delta in the world (Kogbe 1989). The region is of great socio-economic importance to Nigeria because of enormous reserves of petroleum of various types of civil engineering infrastructure. The area of interest is shown in Fig.2.

Fig. 2: Map of the Niger Delta region of Nigeria.

CLOUD COMPUTING CREDITS

To cover the whole area of interest, it is anticipated that an average of 35,000 scenes of Sentinel-1 data would be required. Each scene has 4GB file size. We intend to choose the AWS Elastic Cloud Compute (EC2) environment that is one of the most relevant players in the market. We intend to use the Sentinel Hub. We would require the $600 credit for a period of three years. We intend to opt of splitting the parallel processes of the SqueeSAR processing of each Sentinel-1 slice on different CPUs and exploiting the SSD shared storage able to sustain the I/O workload of the several processes reading and writing concurrently. This choice would allow us to exploit multiple nodes to carry out the processing of more Sentinel-1 slices in parallel, thus significantly speeding up the whole processing. In particular, we intend to exploit the SqueeSAR processing of each Sentinel-1 slice the i3.16xlarge instance, which is equipped with 64 v CPUs, 488 GB of RAM and 8 SSD disks that we will put into a RAID 0 configuration for a total of 15.2 TB of storage with an extremely high I/O bandwidth. For each step of the SqueeSAR processing chain we would defined the number of threads to be launched in parallel according to their average RAM and CPU exploitation in order to optimize the usage of the available CPUs.

TIMELINE AND KEY MILESTONES

The archived data will be downloaded within the first few weeks of the commencement of the project. These will be used for the development of the displacement time series and the deformation monitoring model. New data sets will be downloaded as they become available for the rest of the project period. These new data sets will be used to update the displacement time series map and to identify any change in the deformation pattern and to highlight anomalous points. The time line and key miles stones are described in Fig. 3.

		Years		
S/N°	Activity	1	2	3
1	Acquisition of Archived and new Sentinel 1, 2, and LandSat data sets			
2	Model Development using SqueeSAR algorithm and identification of anomalies			
3	Interpretation of Anomalies			
4	Classification of Anomalies			
5	Validation of the Model			
6	Development of Web Based Information and Monitoring System			
7	Implementation of developed model for new Sentinel 1 data sets			

Fig. 3: Time line and Key Milestones

DELIVERABLES AND USERS

Deliverables will be land deformation maps of the study area and Web-based land deformation information and monitoring system. The system will be capable of being extended to cover the whole of Nigeria

It is our intension to share all the data generated during the project period to all interested stakeholders and the scientific communities in general. Also, the outcome of the research will be demonstrated to the Nigerian Geological Survey Agency (NGSA), specifically, the Nigerian National Geo-hazards Monitoring Centre (NGMC), Awka, Anambra State as well as the Nigerian Emergency Management Agency (NEMA), National Space Research and Development Agency (NASRDA) and the Centre for Geodesy and Geodynamics, Toro, Bauchi State Nigeria. The Nigerian National Geo-hazard Monitoring Centre (NGMC) will be responsible for the implementation and maintenance of the developed monitoring system.

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