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Detection of Land Deformation Using Differential Interferometric Synthetic Aperture Radar (DInSAR) Technique Over Part of Kaduna State, Nigeria

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Abstract

Land deformation poses significant threats to infrastructure, environments and human settlements. However, the need to investigate and assess the rate of land displacement will aid in providing best mitigating approach. This study employed Differential Interferometric Synthetic Aperture Radar (DInSAR) technique to detect land deformation over part of Kaduna state, Nigeria. The observation was carried out in North West Nigeria due to the rapid incidents of earth tremor within the early month of September, in the year 2016 and 2018. Sentinel-1 satellite dataset were used to generate deformation maps, revealing area of uplift and subsidence. InSAR was adopted due to its ability to cover large area and its capability to retrieve deformation data up to millimeter accuracy. Observation was carried out within the interval of 12days from August 30th to October 5th, 2018, covering the whole month of September, 2018. The results show some level of uplift in the region. The displacement varies between -0.011m to + 0.035m (-11mm to +35mm) for interval one, –0.024m to +0.012m (-24mm to 12mm) for interval two, and -0.023m to +0.026m (23mm to 26mm) for interval three. The Kurmin Kwara area had the highest uplift levels with a maximum value of 0.035m. The causes of this deformation may be attributed to excessive earth disturbance either as a result of human factors, such as excessive drilling of borehole and other earth works. The research finding recommend the use of high resolution image data such as COSMOS-SkyMed, ALOS-2; PALSAR-2, along with some other better techniques such as Squee InSAR, PSInSAR for the assessment of this deformation within these years and also GNSS stations should be established in these areas for better monitoring.

Keywords: Differential Intereferometric Synthetics Aperture Rader (DInSAR), Displacement Map, Land Deformation, Subsidence and Uplift

1. Introduction

Interferometric Synthetic Aperture Radar (InSAR) is a remote sensing method that offers accurate assessments of land surface deformation across expansive regions and with exceptional spatial detail (Dehghani and Javadi, 2013; Ajayi *et al*., 2023). Land surface deformation occurs as changes in the topography of the ground. Displacement maps, essential for disaster mitigation efforts, are generated by comparing phase measurements obtained from Interferometric Synthetic Aperture Radar (InSAR) images captured from slightly different sensor positions and at different time intervals. This phase contrast, known as an interferometric phase, which facilitates the creation of these maps (Dehghani and Javadi, 2013). Seismic activities can also lead to land deformation. In the year 2016 and 2018, seismic event occurred in parts of North West and North-Central Nigeria around Kwoi, Nok, Sanbang Daji, and Chori Kaduna State and Gwarinpa, Wuse, Mpape, Maitama areas of Abuja. On September 11th & 12th, 2016, earth movement was recorded in Kwoi area of Kaduna State Nigeria. Also on September 7th, 2018, residents of Mpape, a suburb of Abuja, North Central Nigeria, reported experiencing tremors and shaking, prompting widespread concern among the local population (David *et al*., 2022). In addition, mining activities such as exploration of gold and other minerals resources can lead to land deformation (Bako *et al.,* 2020; Etim *et al.*, 2015).

Interferometric Synthetic Aperture Radar (InSAR) technology utilizes radar signals emitted by satellites to measure ground surface displacements with millimeter-scale accuracy. By comparing radar images acquired at different times, Interferometric Synthetic Aperture Radar (InSAR) can detect slight changes in ground elevation, allowing for the detection and assessment of various forms of ground deformations (Coutinho *et al*., 2023). This research aims to explore the application of satellite Remote Sensing techniques, particularly InSAR, for ground deformation detection and assessment in Southern Part of Kaduna, Nigeria. By reviewing existing literature, evaluating the capabilities of InSAR technology, and developing methodologies for processing and analyzing InSAR data, this research seeks to enhance our understanding of ground deformation processes in rural areas and provide valuable insights for hazard assessment and mitigation strategies.

2. Study Area

The study area is located at southern part of Kaduna State. Kaduna State is bounded by latitude 09^0 02'N and 11^0 32'N and between longitude 6^0 15'E and 8^0 38'E. The climate of the study area is tropical dry and wet type, it lies in the tropical climatic belt of Nigeria. The wet season lasts from March/April through mid-October/November with a peak in August, while the dry season extends from November to around mid-March/April of the next year. The annual average rainfall in the state is 25.2 mm. Rainfall reaches its high peak around August of the year Calendar. Temperatures vary between less than 22.9^oC to 23.9^oC around December/January and 28.9^oC in March/April (State, 2015). Vegetation consists of broad-leaved savannah wooded areas. The land is open to the cultivation of vegetables and other food crops as well as for grazing by animals. The topography of the study area is characterized by pen plains with a landscape which is relatively flat and gentle slopes. Residents within this area are predominantly Jaba, Jema'a, Zangon Kataf, Kaura and Riyom their main occupations include farming, cattle rearing and trading across the area. Figure 1 depicts the map of the study area

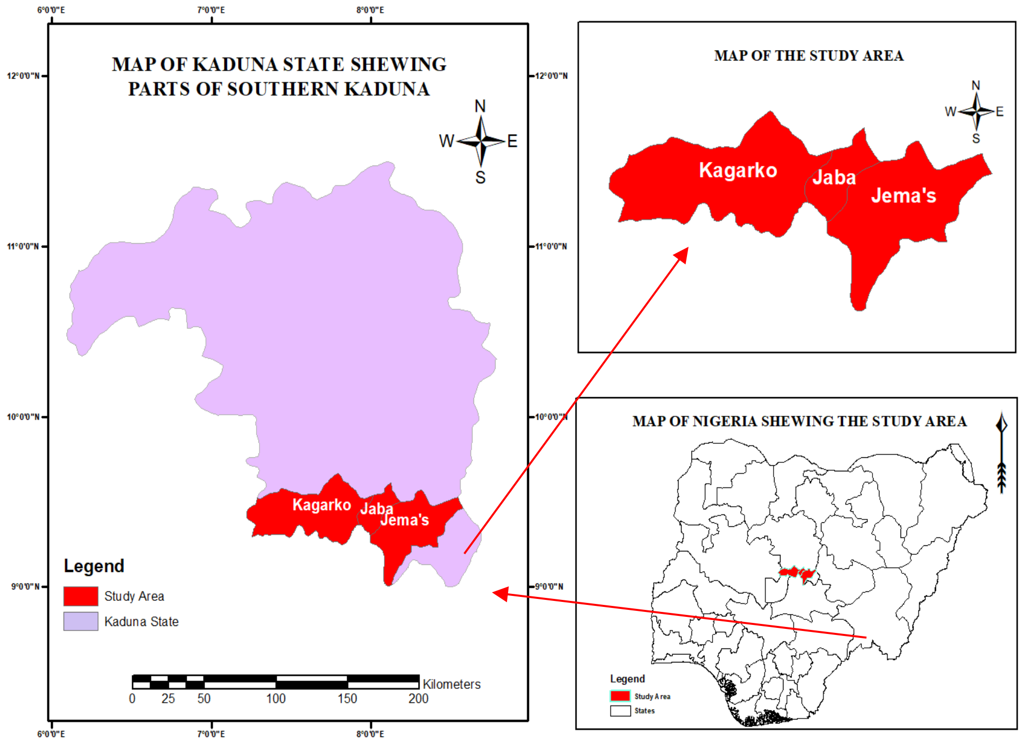


Figure 1: Map of the Study Area

3. Method

3.1 Data Acquisition

Sentinel-1 Interferometric Swath Width (IW) Single Look Complex (SLC) products were acquired from Alaska Satellite Facility https://asf.alaska.edu/ , which contain three sub-swaths labelled IW1, IW2, and IW3. Each sub-swath is for an adjacent acquisition by the TOPS mode. Sentinel-1 images of 12days temporal baseline from 31^{st} of August to 5^{th} of October were utilized in order to detect land deformation level within the month of September 2018. Two images each was used to produce an interferogram. Data of 31^{st} to 11^{th} of September, 11^{th} to 23^{rd} of September, 23^{rd} to 5^{th} of October was used for the processing. Figure 2 depicts the conceptual flow.

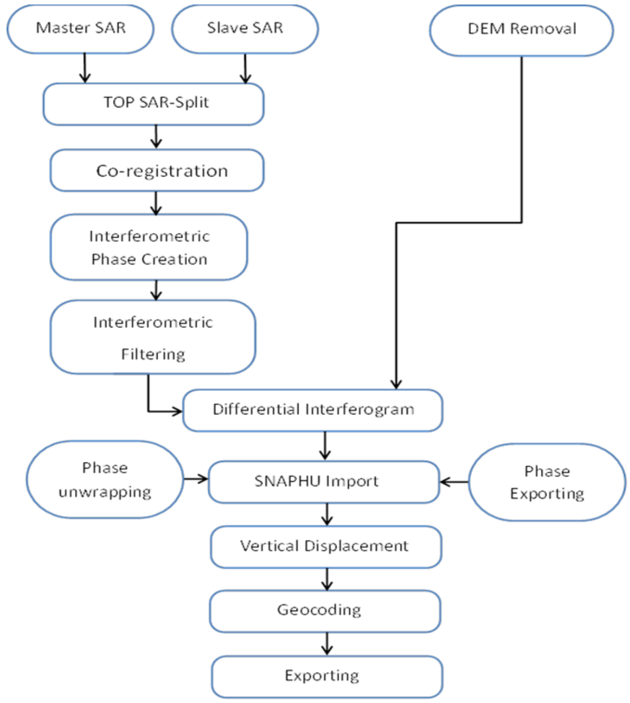


Figure 2: Conceptual Diagram

Importing of the Sentinel images (Slaves and masters images) was done into the product explorer. These images contain some useful information such as Metadata, Vector data, the point grids, overlook and Bands. The focus data is on the product band data, this band contain the main information for the processing, such as Interferometric wide swath (IW1, IW2, IW3) along with Polarization channel (VV, VH, HV, HH), depending on the polarization available when downloading the data. The Image Burst Splitting was carried out using TOPSAR-Split algorithm. This is a crucial preprocessing step in handling Sentinel-1 data. This involved splitting only the bursts containing the area of interest out of whole image in order to isolate and process the specific bursts of interest within the wide swath of a TOPSAR acquisition and by extension, reducing the time of processing**.** Co-registering the Images and Interferogram Formation was achieved by cross-multiplying the image of the first acquisition, known as the master image with the complex conjugate of the second acquisition which is known as the slave image. The amplitude of both images is multiplied while their respective phases are differenced to form the interferogram. The phase difference map, i.e., interferometric phase at each SAR image pixel, depends only on the difference in the travel paths from the SAR sensor to the considered resolution cell during the acquisition of each image. Co-registration procedure is carried out using both the orbital and the topography correction information of the image acquisition and it is very important for the process chain (Zinno *et al.*, 2015). Figure 3. show the field of processing for co-registration of master and slave image data

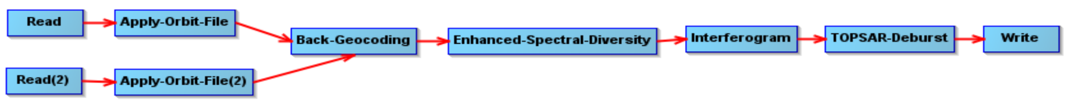


Figure 3: Co-Registration of Master and Slave Image Data

In order to reduce the effect due to temporal decorrelation, geometric decorrelation, volume scattering and processing error on the interferogram, multi-looking and phase filtering correction was applied, Figure 3.1 shows the algorithm application of the correction.

Figure 3.1: Processing Graph Phase Filtering Generation

After obtaining the corrected interferogram phase, the phase differences in wrapped interferograms lie between -π and π (Zhang *et al.*, 2023). Phase unwrapping attempts to assign multiples of 2π to add to each pixel in the interferogram to restrict the number of 2π jumps in the phase to the regions where they may actually occur (Werner *et al.*, 2014). This is done in order resolve phase ambiguities to obtain continuous phase values. This process was done using both notepad and window command software and compared the result to the unwrapping done directly from the SNAP software. Figure below shows the phase unwrapping process.

3.2 Displacement Map Creation

After the phase image has successfully been unwrapped, the unwrapped file was then imported back to the software to create the displacement map. Then the unwrapped phase is then converted to displacement values to create a deformation map.

3.3 Geocoding (Range-Doppler Terrain Correction)

Then the deformation map was converted to geographical coordinates by selecting the preferred coordinate system based on the location of the study area and the topographic phase contribution using a Digital Elevation Model (DEM) was subtracted. Reduction of high resolution Digital Elevation Model must be combined in order to obtain accurate result (Duro *et al.*, 2013).

4. Result and Discussion

Figure 4, below shows the corrected interferogram phase images of each epoch with interval of 12days from August 30th to October 5th, 2018. These interferogram phase images was generated by combining and processing both the masters and slaves images together, the outcome is the deburts interferogram which can later be processes into Differential Interferometric Phase Map.

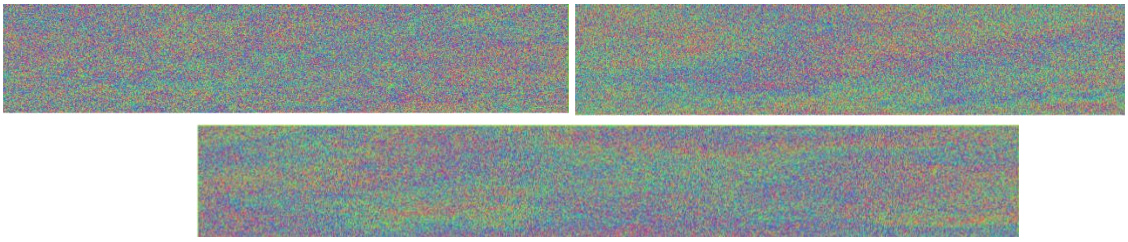
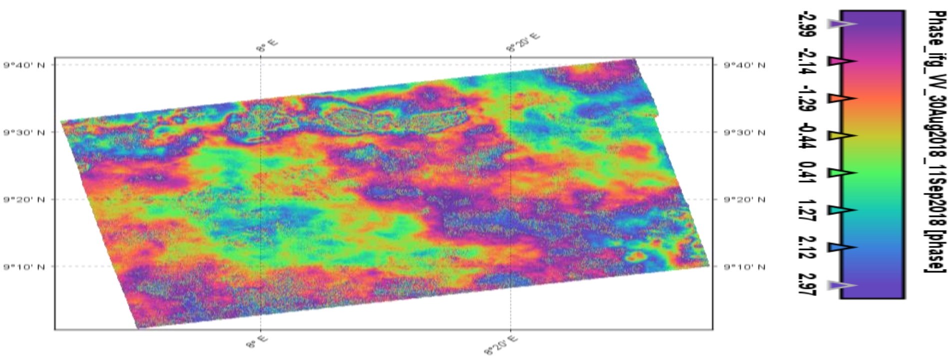


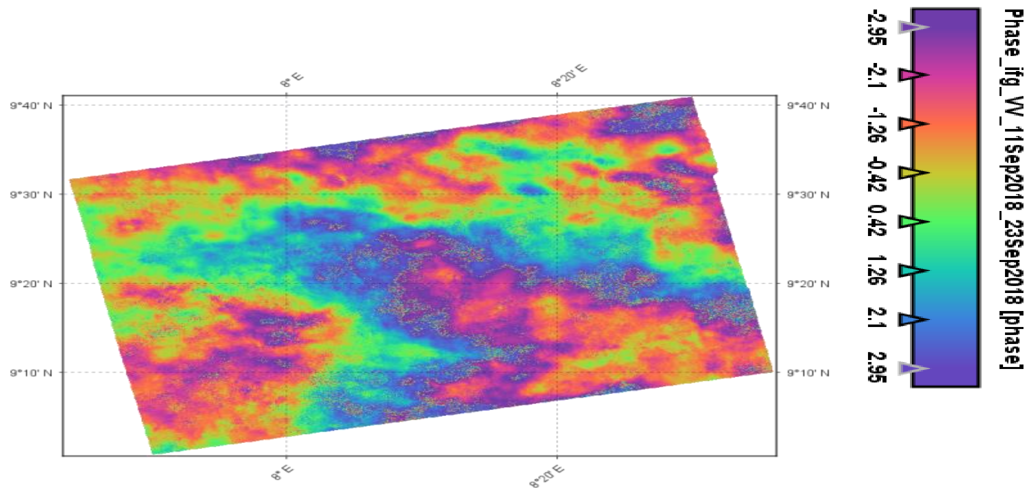
Figure 4: Interferogram Phase Maps for the Three Epochs

4.1 DInSAR Phase Images (Wrapped Phase)

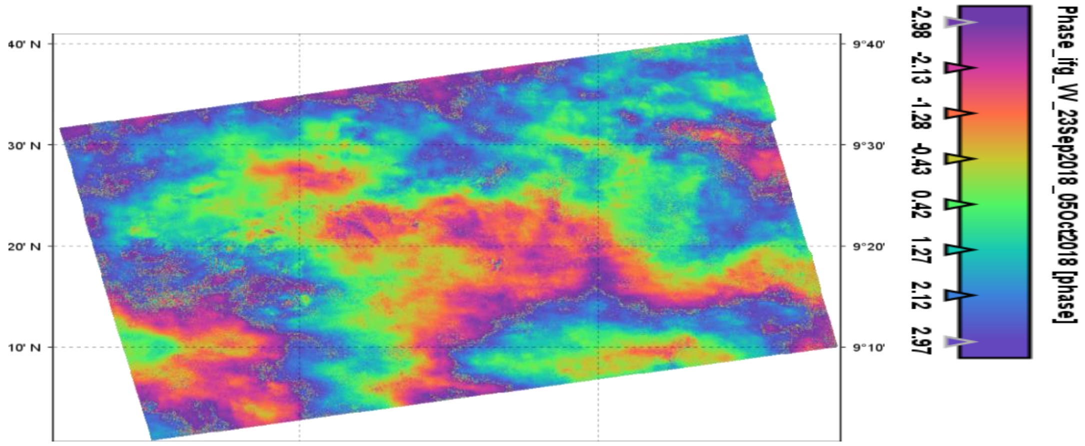
Figure 4.1 shows the DInSAR phase map obtained from the three epochs. Continuous fringes were observed in the first interval interferogram, but no significant continuous fringes were observed in the second and third interval interferogram. However, a scatter pattern of light blue, red to purple was observed in the two other scenes with no fringe patterns, indicating no significant deformation. For the first interferogram image, the ground deformation is clearly seen towards the northern side of the image but for the interferogram of second and third, the colours show no definite fringe pattern, evidence that ground deformation was not significant. According to (Zhou *et al.*, 2009) that one fringe in an interferogram corresponds to the displacement of half the wavelength in the ground displacement in the range direction. Then the images were unwrapped (as shown in Figure. 4.2) in order to be converted into displacement map for proper vertical displacement calculation.



(4.1a)

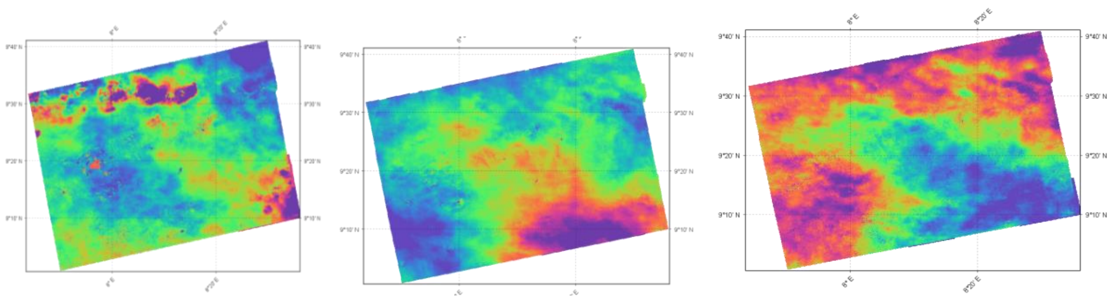


(4.1b)



(4.1c)

Figure 4.14a, b and c: Differential Wrapped Phased Interferograms for the Three Epochs



(4.2a) (4.2b) (4.2c)

Figure 4.2a, b and c: Unwrapped Differential Phase Interferogram

4.2 Displacement Map

The generated differential interferograms were unwrapped and converted to ground displacement images shown in Figure 4.3, 4.4 and 4.5, shows the variation of ground deformation for the other 2 epochs (September 11th, 2018 to October 5th, 2018). It can be observed from the displacement map legend that the estimates of deformation varies between -0.011m to + 0.035m (-11mm to +35mm) for interval one, –0.024m to +0.012m (-24mm to 12mm) for interval two, and -0.023m to +0.026m (23mm to 26mm) for interval three. Negative values indicate subsidence while positive values represent uplift.

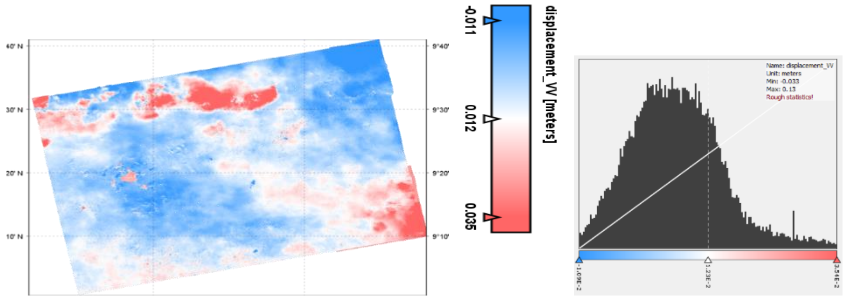


Figure 4.3: Displacement Map of the 1st Epoch

However, a number of pixels revealed high positive displacements particularly in Figure. 4.4, which falls within the region of kurmin Kwara at jaba's local government southern Kaduna of the study area. The first image maximum positive displacement values of up to 0.035m, indicating slightly high ground movements. The Kurmin Kwara area had the highest uplift levels with a maximum value of 0.035m. A number of factors can be attributed to this observed land uplift including both anthropogenic and non-anthropogenic activities. However, absences of reliable ground truth GNSS data made it difficult to assess the height differences for proper causes of the deformation and also lack of seismic ground data within this particular time at this region make it difficult to determine the contribution of tectonic activities on the observed deformation.

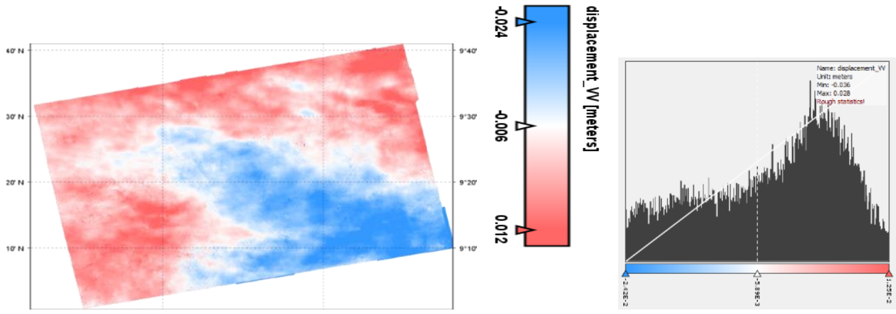


Figure 4.4: Displacement Map of the 2nd Epoch

It can also be observed from the displacement map legend of the second epoch, Figure 4.5, it shows that the estimates of deformation varied between -0.024m to and 0.012m (-24mm to +12mm). This result indicate that there is no significant deformation in our study area, the slightly colour changes is uniform throughout the study area.

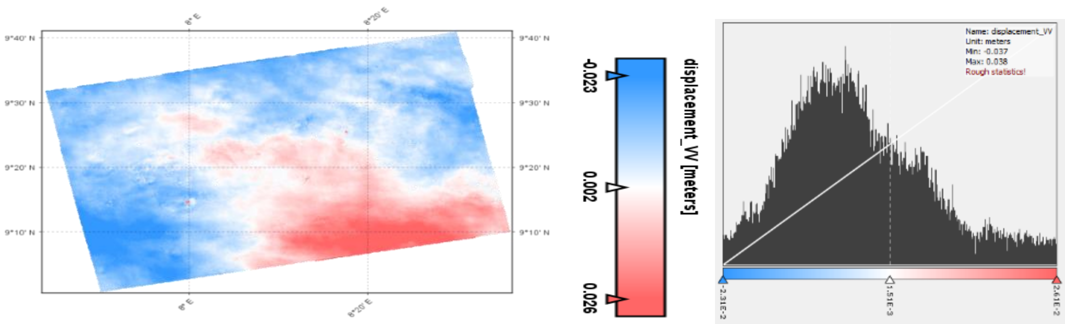
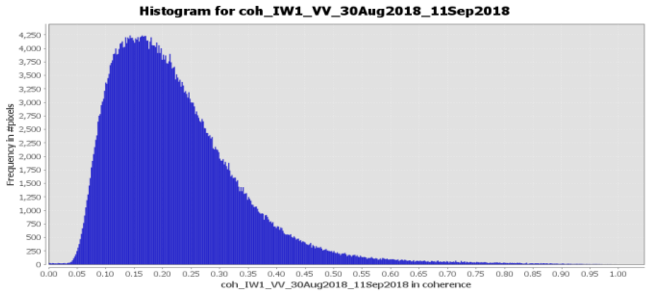
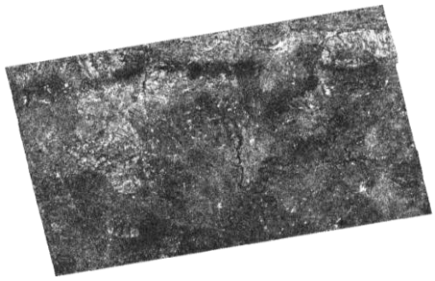


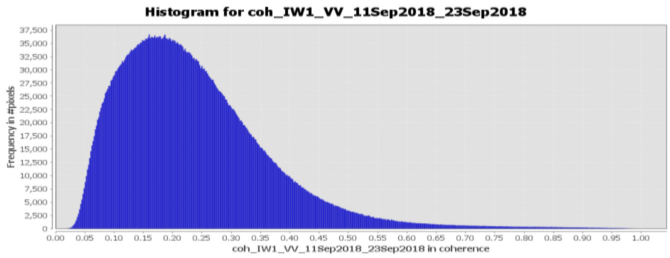
Figure 4.5: Displacement Map of the 3rd Epoch

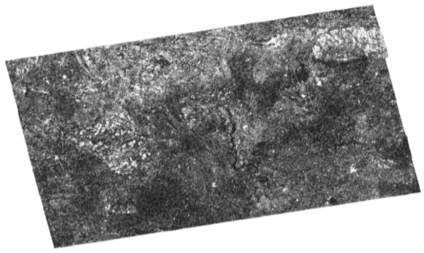
It can also be observed from the displacement map legend of the second epoch, Figure 4.6 depicts the estimate of deformation varies between -0.023m to +0.026m (-23mm to +26mm). This result indicate that there are no significant deformation in our study area, the slightly colour changes is uniform throughout the study area. It has been observed that within the first 12days of September 2016 and 2018, there has been rapid deformation in some part of the North Central Nigeria, mainly the Federal Capital Territory (FCT) and Part of Southern Kaduna state (Adepelumi, 2020; Lar, 2015; Oluwafemi *et al.,* 2018). Based on our result, we observed higher deformation within one of these areas, which is within the first 12days of September 2018. Figure 4.6 depicts the coherence levels of the images data for each epoch.



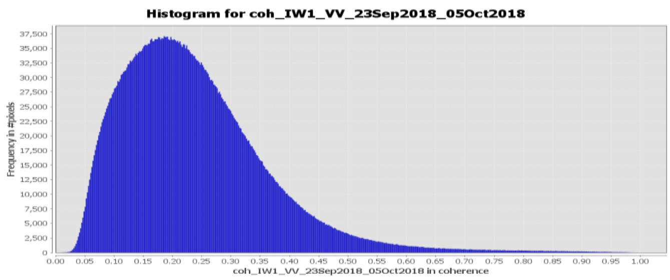


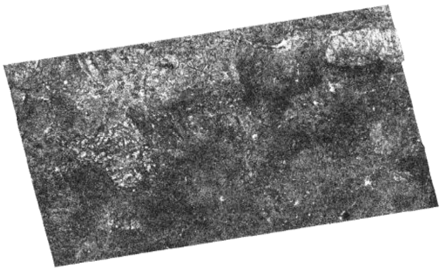
(4.6a)





(4.6b)





(4.6c)

Figure 4.6a, b and c: Coherence Level and the Map for Each Epochs

These graphs show lack of coherence in the radar images. This issue is as a result of temporal and spatial coherence reduction which impacted the phase quality of the interferogram. The lack of coherence can be attributed to several factors such as: Vegetation and land cover changes over the short period of time, these changes reduced the correlation between the SAR images acquired at slightly different times. Also, temporal baseline can also be the issue of this lack of coherence, despite using pairs with 12-days temporal baseline to minimize decorrelation, this can be as a result of rapid weather effects during the imaging periods contributing to the loss of coherence. The images were captured during the month of September which is a period of rainfall, this may be the cause of the decorrelation. Furthermore, topographic effects as a result of terrain variations, particularly in hilly area of the study area can contribute to phase noise, further reducing. Figure 4.7 depicts the bar chat indicating epochs where uplift was recorded

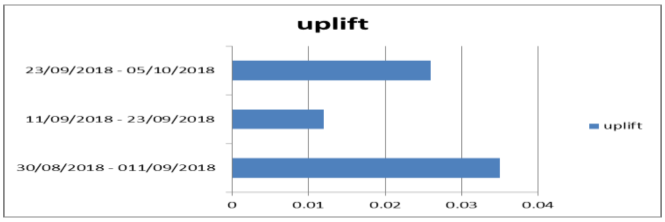


Figure 4.7: Uplift Bar Chart of September 2018

5. Conclusion

The active remote sensing approach was used to detect deformation using Differential Interferometric Synthetic Aperture Radar (DInSAR) technique. Uplift deformation was observed in the first 12days of September, 2018 which is +0.035m (+35mm) with subsidence of -0.011m (-11mm), while no significant deformation was observed in the study area throughout the other days of the month. Furthermore, this study has revealed the strengths and limitations of DInSAR techniques for ground deformation assessment. These must be taken into consideration before employing this technique for deformation assessment.

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