Land Subsidence Mapping with Sentinel-1 Dual-Pol SAR Data

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Research Article

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Abstract

Some areas of Kohima district have been experiencing land deformations as a result of subsidence which has caused landslides, damaging roads and buildings. In this regard, the current attempts to estimates the frequency of subsidence over Kohima district with the help of Copernicus Sentinel-1 SAR datasets for the year 2018 and 2019. The subsidence mapping is carried out with Differential SAR Interferometry (DInSAR) method to give information about the region with a good spatial resolution. DInSAR Interferometry is performed for both VV and VH polarizations to analyse the levels of variations. A lower level of displacement was recorded in VH polarization but a higher level of displacement was recorded in VV polarization. Both polarizations show higher displacement in the Southern and Western parts of Kohima district and lower displacement in the Northern part of Kohima. The rate of occurrence of subsidences was observed higher during 2018. At a broader level, it was observed that the southern and western parts of the Kohima district experienced more subsidence than the northern and eastern parts with a maximum displacement of -0.207 mm in VV polarization for the year 2018. A field survey was also carried out in six locations at the extensively affected areas and it was observed that surface displacement has taken a major toll in the district of Kohima. The maximum rate of displacement for the surveyed locations for the year 2018 shows displacement ranging between − 0.086 to -0.129 metres in VV polarization and between − 0.12 to -0.161 in VH polarization with rainfall of 1684.7 mm in compared to 2019 when displacement ranges between − 0.056 to -0.095 in VV polarization and between − 0.01 to -0.04 metres in VH polarization with rainfall of 1306.8 mm. This analysis reported that the major factors contributing to land subsidence include uncontrolled and random human developmental activities, unplanned urbanization and construction of highways without any technical inputs and occurrence of heavy rainfall.

1. Introduction

Land subsidence occurs as a result of the gradual movement of the earth’s surface from higher to lower surface. This is caused mainly by anthropogenic activities or other natural processes. One of the main challenges faced by the town and city planners nowadays is the difficulty in evaluating the land surface deformations owing to the huge area and continuous change on the ground surface. Thus, the application of SAR plays a vital role in this field. Over the past decade, the use of SAR for this type of studies has also increased leading to the development of innovative and advanced techniques in surface deformation mapping. Multi-temporal analysis for detection of surface subsidence can be mapped using the C-band SAR data (Kumar et al.).

Different InSAR techniques have been developed over the years which have shown significant results in land subsidence and deformation studies (Ferretti et al.; Yang et al.; Amelung et al.; Galloway et al.; Tiwari and Malik). InSAR is extensively used in land subsidence, volcanic deformation, landslide, earthquake, volcanic and glacial studies (Massonnet and Feigl). InSAR technique is also used to monitor the coal mining activity which results in land subsidence ((Mroz and Perski). The phase difference of two SAR images shows the displacement of an area that generates deformation and topographic Interferogram. The topographic information is then removed from the Interferogram to get Differential Interferogram which is used to monitor land subsidence. DInSAR is also used for remotely mapping surface deformations over large areas with millimetre level accuracy and metre level spatial resolution using multiple imageries (Hooper; Sansosti et al.; Rosen et al.). According to (H. Wang et al.), DInSAR is one of the most advance method used in land deformation and subsidence mapping which can be studied from a distance, especially where information on GPS locations are not available or inaccurate. Over the recent years, DInSAR has been extensively used in studying tectonic geomorphology (Lanari et al.; Argus et al.; Wisely and Schmidt), underground mining and oil extraction (Gourmelen et al.), subsidence measurement in groundwater detection (Hoffmann et al.; Schmidt and Bürgmann; Bell et al.) and studies related to sediment compaction (Teatini et al.).

Owing to fast development due to an increase in the rate of urbanization, many of the megacities are facing the problem of land subsidence. (H. Wang et al.) undertook a study using InSAR in the coastal region of Pearl River Delta to gather information on the rate and extent to which land subsidence is occurring, as it is one of the most densely populated and important economic region of China. Results indicated that the areas where rapid urbanization has taken place in recent
years in the coastal region of Shenzhen are affected by subsidence and as a result, this is harming the area as there is a rise in the sea level. These type of researches are therefore important in conducting risk assessment studies.

Copernicus Sentinel-1 data was used in the study of Rome metropolitan for analysing urban features such as bridges, road connectivity and other infrastructures. Results indicated deformation over urban infrastructures, showing a subsidence rate up to -7.8 mm/year along the ring highway which surrounded the city of Rome (Blasco et al.).

A study to analyse the factors contributing to land subsidence along the coastal areas of Java Island in Semarang and Demak was carried out using Sentinel-1A data by the remote sensing technique of Persistent Scatterer Interferometric Synthetic Aperture Radar to extract the deformation signal. (Azeriansyah et al.).

In 2016, (Wallring et al.) carried out a study on geotechnical analysis of Debris Slide which occurred along the National Highway-2 near Secretariat Junction, Kohima. The occurrence of the slide caused a lot of inconvenience to the public as vehicular movement was shut down due to road blockage. Studies undertaken to determine the cause of the slide indicated that the road along NH-2 has been cut through the Disang Group of Eocene rocks and the materials in the slide zone contain soils and crumpled rocks that are saturated with water, particularly during the monsoon. Analysis performed in the slide zone indicated that due to the occurrence of prolonged and heavy rainfall in the region, the soil has become very weak and unstable as the slide zone is saturated with water which causes an alteration in the consistency of the soil structure due to its low liquid limit and high plasticity content. Since Kohima is a hilly terrain so it is widely affected by landslides every year damaging buildings and causing land subsidences. Risk analysis along part of NH-2, North of Kohima Town was also carried out by (Thong). in the year 2014 to determine the causes of the debris slides. Results indicated that NH-2 is being broadened without any mitigation measures and fresh slope cutting of these weak materials during the heavy monsoon season makes this region vulnerable to landslides. Instability of slopes in this region occurs due to heavy rainfall which reduces the shearing strength of the slope materials causing slope deformations. It was also found that rapid urbanization, unplanned developmental activities cutting off roads in unfavourable regions makes the area very prone to slides and subsidence as it disturbs natural slopes and the natural drainage pattern which takes down the portion of hillsides.

Differential Interferometry is one of the most important methods used in observing the changes occurring on the earth's surface. This method involves the process of preparation of master and slave images in which the slave images are co-registered by applying the orbit files about the selected master image. Differential Interferogram was generated by using the (SRTM) DEM having a resolution of 3 arc-second (90 m) by removing the topography from the Interferogram (Veci and March; Fielding and Handwerger; Kumar et al.). Studies on surface deformation have been mostly carried out using cross-polarized (VH) and co-polarized (VV) images (Wegmüller et al.; Ng et al.). The surface deformation of an area can be analysed by comparing the effect of VH and VV polarizations of Sentinel-1 data (Ittycheria et al.).

The objective of this paper is to study the importance of DInSAR in mapping land subsidence using the co-polarized (VV) and cross-polarized (VH) single-look-complex (SLC) images of Sentinel-1A satellite data over the seven administrative blocks of Kohima district and also to monitor the changes which have occurred over two years using temporal Sentinel-1A satellite images.

In the year 2014, the European Space Agency (ESA) launched the Copernicus Sentinel-1 satellite which was mainly designed to observe the changes occurring on the earth's surface (Bischoff et al.). Sentinel-1 data consist of a C-band SAR, which allows us to collect land surface information irrespective of the weather condition including night imagery. There has been an improvement in the Sentinel-1 data as compared to the earlier European C-band SAR mission, European Remote Sensing (ERS) satellites and Environmental Satellite (ENVISAT), as the revisit time of the satellite sensor has been reduced to six days from 35 days, with a large swath coverage thus enabling us in keeping a track over large areas with the much lesser acquisition with the help of two satellite A and B. Moreover, due to the short revisit time of the satellite, the deformation rate of the land surface can also be regularly monitored (Sowter et al.; Blasco et al.).
The European Space Agency (ESA) extends its support to Earth Observation (EO) communities in using the SAR data for land surface studies and also continues to develop appropriate tools for processing the Copernicus Sentinel-1 data. A cost-free tool available for processing Sentinel-1 data named Sentinel Application Platform (SNAP) (Veci and March 2015) was developed by ESA, which can be used for processing SAR and Optical data (Blasco et al.). In this study, an open-source tool of SNAP was used for carrying out the land subsidence mapping of the Kohima district using Sentinel-1 data.

2. Study Area

Kohima, the state capital of Nagaland, India is a hilly district that was earlier named Kewhira, established in the year 1878. It was officially declared the state capital when Nagaland attained statehood from India in the year 1963. Kohima district is located in the foothills of Japfu range with a latitude of 25.67ºN and a longitude of 94.12ºE. It lies at an elevation of 1261 metres (4137 feet). The population of Kohima District stands at 99,039 as per the 2011 census comprising 51,626 males and 47,413 females. Kohima district has seven Administrative blocks namely, Chunlika, Tseminyu, Botsa, Chiephobozou, Kohima Sadar, Sechu (Subza) and Jakhama.

Kohima (as shon in Fig. 1) usually witnesses unfavourable monsoon causing extreme weather events resulting in loss of lives and properties. Moreover, Kohima being a district without proper planning is prone to man-made disasters.

A major risk factor of Kohima district is the increase in the concentration of human population in hazardous areas which poses a serious threat to human life and property. Due to lack of proper town planning and technical experts inputs majority of the infrastructures constructed in Kohima stands on a very high-risk zone as Nagaland state falls under earthquake Zone-V. For any kind of developmental activities planning on Land, development is not taken into account most of the time. Another major hindrance affecting the developmental activities of this region to a large extent is the issue of land ownership as the land and its resources belong to the indigenous inhabitants which are empowered under Art. 371 A of the Indian Constitution. Lastly, many parts of the Kohima district is prone to landslides and land subsidence as most of the surface areas are composed of loose soil and weak rocks.

Kohima, Nagaland is chosen as the study area mainly because of the following factors:

1. Minimal Research studies on land subsidence have been conducted in this region.
2. The study area is prone to landslide & subsidence during monsoon.
3. Commuters and inhabitants (both commercial and private) are affected due to damaged caused by landslide and subsidence.
4. Instances of damage to infrastructures and properties had occurred due to a lack of proper town planning.
5. To facilitate town planning and road connectivity, more research studies need to be conducted in this region.

3. Methodology & Datasets Used

3.1. Satellite Images

This study has been carried out using descending pass images of Sentinel-1A satellite from 17th May 2018 to 9th September 2019 for analysing the land subsidence pattern of Kohima district. The Sentinel-1A data used have an Interferometric Wide Swath mode with a GR Pixel Spacings of 13.97 metres in azimuth and 3.67 metres in range direction respectively.

Three sub swaths are captured by the technique of Terrain Observation with Progressive Scans (TOPS) in Interferometric Wide Swath mode where each sub swath consist of multiple bursts (De Zan and Guarnieri). The European Space Agency (ESA) has made this data accessible to the researchers for free of cost through the Copernicus Open Access Hub. Differential Interferometry was carried out in both co-polarized (VV) and cross-polarised (VH) images of Sentinel-1A data.
using the open-source tool of SNAP. For this work, an image acquired on 17th May 2018 is taken as a master image and an image acquired on 28th July 2018 is taken as a slave image for 2018 analysis. Likewise, an image acquired on 23rd July 2019 is taken as a master image and an image acquired on 9th September 2019 is taken as a slave image for 2019 analysis.

The master image and slave image selection has been done by sorting out the Sentinel-1A Single Look Complex (SLC) data as per the acquisition date, depending on whether the study area is covered in one scene.

<table>
<thead>
<tr>
<th>META-DATA PROPERTIES OF MASTER IMAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite</td>
</tr>
<tr>
<td>Product type</td>
</tr>
<tr>
<td>Acquisition date</td>
</tr>
<tr>
<td>Acquisition mode</td>
</tr>
<tr>
<td>Sub-swath</td>
</tr>
<tr>
<td>Bursts</td>
</tr>
<tr>
<td>Orbit Pass</td>
</tr>
<tr>
<td>Orbit Cycle</td>
</tr>
<tr>
<td>Near incidence angle</td>
</tr>
<tr>
<td>Far Incidence angle</td>
</tr>
<tr>
<td>Polarization</td>
</tr>
</tbody>
</table>

After the selection of the master and slave images, the Region of Interest (ROI) is extracted out by TOPSAR Splitting. Splitting of images is recommended when the analysis is confined only over a particular area and not over the complete scene as it reduces the processing time. As seen in Table 1 and Table 2, an image acquired on 17th May 2018 is taken as a master image and an image acquired on 28th July 2018 is taken as a slave image for both the polarization. Similarly, an image acquired on 23rd July 2019 is taken as a master image and an image acquired on 9th September 2019 is taken as a slave image for both the polarization.
<table>
<thead>
<tr>
<th><strong>META-DATA PROPERTIES OF SLAVE IMAGE</strong></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Satellite</strong></td>
<td>Sentinel-1A</td>
<td>Sentinel-1A</td>
<td>Sentinel-1A</td>
<td>Sentinel-1A</td>
</tr>
<tr>
<td><strong>Product type</strong></td>
<td>SLC</td>
<td>SLC</td>
<td>SLC</td>
<td>SLC</td>
</tr>
<tr>
<td><strong>Acquisition date</strong></td>
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<td>28/7/2018</td>
<td>9/9/2019</td>
<td>9/9/2019</td>
</tr>
<tr>
<td><strong>Acquisition mode</strong></td>
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<td>IW</td>
<td>IW</td>
<td>IW</td>
</tr>
<tr>
<td><strong>Sub-swath</strong></td>
<td>IW2</td>
<td>IW2</td>
<td>IW2</td>
<td>IW2</td>
</tr>
<tr>
<td><strong>Bursts</strong></td>
<td>4,5,6,7,8</td>
<td>4,5,6,7,8</td>
<td>5,6,7</td>
<td>5,6,7</td>
</tr>
<tr>
<td><strong>Orbit Pass</strong></td>
<td>Descending</td>
<td>Descending</td>
<td>Descending</td>
<td>Descending</td>
</tr>
<tr>
<td><strong>Orbit Cycle</strong></td>
<td>146</td>
<td>146</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td><strong>Near incidence angle</strong></td>
<td>36.43°</td>
<td>36.43°</td>
<td>36.40°</td>
<td>36.40°</td>
</tr>
<tr>
<td><strong>Far Incidence angle</strong></td>
<td>42°</td>
<td>42°</td>
<td>42°</td>
<td>42°</td>
</tr>
<tr>
<td><strong>Polarization</strong></td>
<td>VV</td>
<td>VH</td>
<td>VV</td>
<td>VH</td>
</tr>
</tbody>
</table>

### 3.2. Methodology

Generation of Differential Interferogram for this study has been performed using the open-source Graph Builder Tool of European Space Agency (ESA) SNAP. The steps (as shown in Fig. 2) are as follows:

**Step-1: Co-registration & Interferometric SAR Processing**

To begin with the processing, co-registration is performed by applying the orbit files on the selected master and slave images of Sentinel-1A data for getting a precise satellite position and velocity information. The interferogram is produced by the co-registered images after back-geocoding with Enhanced Spectral Diversity.

a) Co-registration confirms that the ground target information of Sentinel-1A images consists of the same pixel in both azimuth and range direction. The slave image is co-registered by the master image.

b) To co-register two split products of the same sub-swath, Back-geocoding is applied by using the orbits of two products and a DEM.

c) Enhanced Spectral Diversity follows Back-geocoding and is a refinement step that performs range and azimuthal correction for every burst.

d) Interferometry gives us the phase difference of master and slave images which also contains height information. While performing Interferogram, we can also have the coherence image estimation from the co-registered complex images.
e) TOPSAR Deburst is performed to produce a continuous coverage of the ground since the image consist of a series of bursts.

This is the processing chain for InSAR analysis and with this, Interferogram containing both topography and deformation is generated.

**Step-2: Generation of Differential SAR Processing**

Differential Interferogram is used to observe the phase changes in master and slave images by removing topography which was generated from the Interferogram. DinSAR contains only the deformation.

a) The topographically induced phase in the Debursted Interferogram is removed by Topographic phase removal.

b) For better image visualization, a Multi-looking step is performed which also reduces speckle noise.

c) Goldstein Phase Filtering is a step used to reduce the phase noise for better image interpretation. It is an interferogram filter was developed by Goldstein and Werner (Baran et al.) which was created by the technique of multiplication of Fourier spectrum $Z(u,v)$ over an interferogram area having an absolute value of $S\{|Z(u,v)|\}$ with a power of exponent $\alpha$.

$$H(u,v) = S\{|Z(u,v)|\}^\alpha Z(u,v)$$

where,

$H(u,v) = $ Filter response ; $S\{|\} =$ Smoothing operator ; $u,v =$ Spatial frequencies and

$\alpha =$ Filter parameter.

According to (Baran et al.), Interferogram areas are a part of interferogram that are coincided to avoid cut-offs at the borders. The filter parameter value is randomly selected between 0 and 1 and has the highest effect on the results generated by the filter. For eg: The multiplication factor becomes one in the case of an area having a value of $\alpha = 0$ and hence no filtering takes place but in the case of an area having greater values of $\alpha$, filtering takes place.

d) Snaphu Export is done to apply Phase Unwrapping.

**Step-3: Phase Unwrapping and Displacement mapping**

a) Snaphu Import operator imports the data from a Snaphu.

b) Phase unwrapping is the method of removal of unwanted atmospheric noises from an image using the algorithm which estimates the phase angles of a sequence of images in which Fourier suppresses the unwanted atmospheric effects of an image (Itoh).

c) After performing Phase Unwrapping, the Displacement map is generated by converting the Phase to Displacement.

d) Radiometric Terrain Geometric correction was then applied in the Coherence and Displacement images using 1-second SRTM Digital Elevation Model (DEM) and Bilinear Interpolation technique for Resampling of DEM and the Image with a GR Pixel Spacings of 13.97 metres in azimuth and 3.67 metres in range direction respectively.

**Step-4: Generation of Displacement Mask**
a) Terrain corrected Coherence and Displacement images were stacked and the following equation was run in the Band Math Expression Editor:

\[
\text{If Coherence } \leq x, \text{ then Displacement mask}
\]

where \( x \) = value of Coherence. This equation was used for the generation of the Displacement mask through which the trend of displacement range was recorded.

b) Upon generation of the Displacement mask, the data was exported as per the desired format for further analysis.

4. Results And Discussion

Sentinel-1A descending pass images were used to analyse and achieve the targeted goal of this research paper. The master images were obtained on 17th May 2018 and 28th July 2019 whereas the slave images were obtained on 28th July 2018 and 9th September 2019. Displacement analysis was performed in both VV and VH polarizations using the selected master and slave images for the year 2018 and 2019. Displacement information of an area is extracted by performing the phase difference of master and slave images. Displacement analysis based on the Differential Interferogram shows noticeable changes in the land subsidence pattern over the seven Administrative blocks of Kohima district. The displacement range obtained in VV Polarization during 2018 was between -0.044 to -0.207 metres and during 2019, it was between -0.031 to -0.132 metres. Likewise, the displacement range obtained in VH Polarization during 2018 was between -0.038 to -0.199 metres and during 2019, it was between -0.052 to -0.066 metres.

Variation in the level of displacement over the seven administrative blocks of Kohima district was also analysed for both years. It was observed that a lower level of displacement was recorded in VH polarization and a higher level of displacement was recorded in VV polarization. This is due to the property of VV polarization in which vertically placed earth objects produces a dual reflection, which in return sends a powerful backscattered signal towards the sensor (Ittycheria et al.). In both cross-polarized (VH) and co-polarized (VV) images, higher subsidence was observed in the Southern and Western parts of Kohima district which comprises the administrative blocks Kohima Sadar, Sechu (Zubza) and Jakhama. Medium and lower subsidence was observed in the Northern part of Kohima comprising of administrative blocks Chunlika, Tseminyu, Botsa and Chiephobozou. The overall displacement trend ranges from -0.038 to -0.207 metres in which the minimum range of -0.038 metres was recorded in the VH Polarization of 2018 and the maximum range of -0.207 was recorded in the VV Polarization of 2019. The displacement trend of occurrence of subsidence with bases on the two time period and mode of polarization can be seen in Fig. 3 (Displacement in VV Polarization 2018), Fig. 4 (Displacement in VV Polarization 2019), Fig. 5 (Displacement in VH Polarization 2018) and in Fig. 6 (Displacement in VH Polarization 2019).

The results based on the land subsidence map generated by DinSAR indicated that during both the year, the Southern and Western regions of Kohima district shows more subsidence as compared to the Northern and Eastern regions. The level of subsidence was recorded highest in the year 2018 with a maximum displacement range of -0.207 metres (-20.7 centimetres).

From this analysis, it is clear that surface displacement has taken a major toll on the district of Kohima. Kohima district, comprising mostly of rocky and mountainous topography is widely affected by a landslide every year. Land subsidence is evident during the monsoon period. During the monsoon season, the regions experiencing higher displacement are slowly and continuouslysubsiding resulting in the development of cracks which increases the risk of landslides in future. Rainfall data received from the Department of Soil & Water Conservation, Govt. of Nagaland shows that during the DinSAR analysis period from May to September, the Rainfall recorded was 1684.7 mm during 2018 and 1306.8 mm during 2019 (as seen in Table 3). Land subsidence takes place as a result of heavy rainfall which reduces the shearing strength of the sloppy terrain as the slope zone is saturated with water which attributes to high-pore water pressure leading to slope material deterioration causing land deformations. Uncontrolled and haphazard human developmental activities, urbanization and construction of
roads without any scientific inputs and heavy rainfall are also the major factors responsible for the initiation of land subsidence in the State Capital (Thong).

Figure 9 shows the displacement map of Kohima district for 2018 in VH Polarization. Deforestation also contributes to the formation of landslides as trees and vegetation control the rate of weathering and erosion of the underlying rocks and soils. When trees are cut down, the slopes destabilise due to the high-pore pressure and this leads to gravitational displacements of rock and soil masses which are responsible for damage to man-made structures and the natural environment (Mountain; Temsulemba Walling, Mehilo Apon, C. Nokendangba Chang, Glenn T. Thong, Supongtemjen Jami). All of these factors including the heavy rainfall which was recorded during the monsoon 2018 i.e. 1684.7 mm attributed to higher subsidence observed in Kohima during the year 2018.

Table 3: Rainfall recorded in Kohima district during monsoon 2018 and 2019 (May to September)

<table>
<thead>
<tr>
<th>Year</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>Total Rain (in mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td>279.2</td>
<td>338.1</td>
<td>568.4</td>
<td>359.4</td>
<td>139.6</td>
<td>1684.7</td>
</tr>
<tr>
<td>2019</td>
<td>175</td>
<td>208.1</td>
<td>1286.4</td>
<td>355.9</td>
<td>281.4</td>
<td>1306.8</td>
</tr>
</tbody>
</table>

(Data Source: Department of Soil & Water Conservation, Govt. of Nagaland)

4.1. Field Survey Analysis

Figure 15 visualises the zoomed portion of displaced area in Tseminyu Block and Fig. 16 illustrates the field survey locations in red squares. For this study, six locations were selected for conducting a field survey which can be seen in Fig. 7. The survey was carried out along the National Highway (NH) -2, New Secretariat Road and towards the Nagaland University Road. These locations were chosen for field survey because these regions are extensively affected by landslides every year during the monsoon season which has caused land subsidence. The survey area covers a part of the administrative block of Kohima Sadar and Chiephobozou.

The field surveyed location stretches along NH-2 that runs through the Disang Group of Eocene Rocks which consist of thick beds of shale mixed with thin beds of flags mudstone, siltstone and sandstone. The NH-2 stretch comprises extremely weak clays and crushed rocks which are saturated with water during the monsoon season and this makes the road that runs through the NH-2 very unstable (Walling et al.). Four locations were covered along the stretch of NH-2 which are namely, A2-Between High Court Junction and Indira Gandhi Stadium (total road length covered during a field survey in this location was 30.6 metres), A3-Below Indira Gandhi Stadium Gate (total road length covered during a field survey in this location was 59.5 metres), A4-Perizie Colony (total area covered during field survey this location was 13,921 square metres) and A6-Between Meirema& High Court Junction (total road length covered during a field survey in this location was 66.7 metres). The fifth location was A1-Sinking zone on the way to Nagaland University and Women Resource Department which is considered to be the lifeline of the residents and students (total road length covered during a field survey in this location was 50.9 metres). And the sixth location was A5-Sanuoru Bridge which connects the road leading to Nagaland Civil Secretariat (total road length covered during a field survey in this location was 227 metres). The field survey photographs of these locations can be seen in Fig. 8.

4.2. Displacement Analysis in Field Survey Locations
Table 4 reports the level of displacement recorded in the field survey locations for 2018 & 2019 in VV Polarization and 2018 & 2019 in VH Polarization. Displacement analysis was done in the location where the field survey was carried to see the changes that occurred during 2018 and 2019. Displacement mask images and the field survey data were overlaid on Google Earth for further validation. Google Earth image was used for validation purpose because the images released from Google Earth are freely available data having high spatial resolution images which provide detailed information about the study area (Hu et al.). Tools for extracting different types of land use/land cover information has also been developed by Google Earth which has been extensively utilized in many areas of study (Y. Wang et al.). The elevation data of the field surveyed locations was also extracted using the Google Earth Elevation profile tool.

<table>
<thead>
<tr>
<th>LOCATION ID</th>
<th>FIELD SURVEY LOCATION DETAILS</th>
<th>GEO-COORDINATES</th>
<th>MEAN ELEVATION</th>
<th>LEVEL OF DISPLACEMENT (In metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2018 VV Polarization</td>
</tr>
<tr>
<td>A1</td>
<td>Way to Nagaland University &amp; Women Resource Department</td>
<td>25°43'25.57&quot;N 94° 5'17.73&quot;E</td>
<td>1353 metres</td>
<td>Between -0.086 to -0.129 metres</td>
</tr>
<tr>
<td>A2</td>
<td>Between High Court Junction &amp; Indira Gandhi Stadium along NH-2</td>
<td>25°42'54.46&quot;N 94° 5'10.14&quot;E</td>
<td>1402.5 metres</td>
<td>-0.129 metres</td>
</tr>
<tr>
<td>A3</td>
<td>Below Indira Gandhi Stadium gate along NH-2</td>
<td>25°42'14.72&quot;N 94° 5'30.75&quot;E</td>
<td>1454.5 metres</td>
<td>-0.129 metres</td>
</tr>
<tr>
<td>A4</td>
<td>Perizie Colony Sinking area along NH-2</td>
<td>25°41'21.70&quot;N 94° 5'47.01&quot;E</td>
<td>1831.5 metres</td>
<td>-0.129 metres</td>
</tr>
<tr>
<td>A5</td>
<td>Sanuoru Bridge</td>
<td>25°41'30.38&quot;N 94° 6'13.43&quot;E</td>
<td>1369 metres</td>
<td>-0.129 metres</td>
</tr>
<tr>
<td>A6</td>
<td>Between Meriema &amp; High Court Junction along NH-2</td>
<td>25°42'59.31&quot;N 94° 5'7.97&quot;E</td>
<td>1373.5 metres</td>
<td>-0.129 metres</td>
</tr>
</tbody>
</table>
Variations in the level of displacement have been recorded for all the locations in both the years and polarization which can be seen in Table 5 and the field photographs of the surveyed locations can be seen in Fig. 8. The subsidence rate for all the surveyed locations was found to be higher in the year 2018 with the displacement ranging between − 0.086 to -0.129 metres in VV Polarization and between − 0.12 to -0.161 metres in the VH Polarization. However, as compared to 2018, the subsidence rate over the surveyed locations was much lower in the year 2019 with the displacement ranging between − 0.056 to -0.095 metres in VV Polarization and between − 0.01 to -0.04 metres in the VH Polarization. Rainfall is one of the probable factors resulting in a higher level of subsidence in the year 2018. As seen in Table 3, the rainfall recorded was 1684.7 mm during 2018 which is higher than in 2019. Heavy rainfall causes displacement of rocks and soil masses which attributes to high-pore water pressure leading to slope material deterioration causing land subsidence.

In 2018, Kohima district witnessed a lot of disasters because of incessant rains which triggered landslides causing land subsidence in different locations. It was reported that on the 22nd of July 2018, the landslide occurred due to heavy rainfall in the Perizie colony (Location ID- A4) destroying 43 houses including 35 mud huts and eight RCC buildings (Source: https://nenow.in/north-east-news/nagaland/landslides-continue-wreak-havoc-nagaland-courtesy-incessant-rain.html). A massive landslide also occurred on the 30th July 2018 along the Sanuoru-Nagaland Civil Secretariat road (Location ID-A5) that took down half of the blacktopped road which sank about 3feet down just below the working women hostel (Source: https://nsdma.nagaland.gov.in/disaster-in-nagaland/). As per the report of the Public Work Department (PWD), Govt. of Nagaland, on the status of the condition of National Highways as of 1st August 2018, it was noted that most of the landslide and subsidence affected areas falls along the stretch of NH-2 which can be seen at Fig. 13.

Rapid urbanization, unplanned human activities, cutting down of trees, unscientific construction of roads and highways are also some of the major contributing factors leading to land subsidence in these regions. Moreover, the Disang Group of Rocks which runs along the NH-2 comprises extremely weak clays and crushed rocks that are saturated with water during the monsoon season and this makes the stretch of road along the NH-2 very unstable (Walling et al.).

<table>
<thead>
<tr>
<th>NAME OF DIVISION</th>
<th>NH NO.</th>
<th>LOCATION AFFECTED BY LANDSLIDE/SUBSIDENCE</th>
<th>NATURE OF DAMAGE</th>
<th>STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kohima Division</td>
<td>NH-29</td>
<td>179/500 Near Avila Petrol Pump</td>
<td>Major Landslide and Subsidence</td>
<td>Open for traffic</td>
</tr>
<tr>
<td></td>
<td>NH-29</td>
<td>180/500 Near Para Medical Junction</td>
<td>Breaching of pavement and subsidence</td>
<td>Road partially restored for the single way traffic</td>
</tr>
<tr>
<td></td>
<td>NH-02</td>
<td>10/900 km Near Tsiesema</td>
<td>Subsidence</td>
<td>Open for traffic</td>
</tr>
<tr>
<td></td>
<td>NH-02</td>
<td>18/500 km Near Nerhema</td>
<td>Subsidence</td>
<td>Road partially restored for the single way traffic</td>
</tr>
<tr>
<td></td>
<td>NH-02</td>
<td>19/600 km Nerhema</td>
<td>Subsidence</td>
<td>Road partially restored for the single way traffic</td>
</tr>
<tr>
<td></td>
<td>NH-02</td>
<td>Various Locations on NH-02</td>
<td>Landslide and subsidence occurred at various locations</td>
<td>Partially/Wholly Restored</td>
</tr>
</tbody>
</table>


4.3. Elevation Profile of the Field Survey Locations

The Elevation profile of the Field Survey Locations was generated using the tools of the Google Earth Imagery. The Elevation range was observed to be highest in the region having Location ID- A3, which is a subsiding zone below Indira Gandhi
Stadium gate having a mean elevation range of 1454.5 metres. Table 6 reports the elevation ranges in the field survey locations.

### Table 6
Table showing the Elevation Range in the Field Survey Locations

<table>
<thead>
<tr>
<th>LOCATION ID</th>
<th>FIELD SURVEY LOCATION DETAILS</th>
<th>ELEVATION RANGE (In metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Way to Nagaland University &amp; Women Resource Department</td>
<td>Between 1350 to 1356 metres</td>
</tr>
<tr>
<td>A2</td>
<td>Between High Court Junction &amp; Indira Gandhi Stadium along NH-2</td>
<td>Between 1401 to 1404 metres</td>
</tr>
<tr>
<td>A3</td>
<td>Below Indira Gandhi Stadium gate along NH-2</td>
<td>Between 1454 to 1455 metres</td>
</tr>
<tr>
<td>A4</td>
<td>Perizie Colony Sinking area along NH-2</td>
<td>Between 1364 to 1399 metres</td>
</tr>
<tr>
<td>A5</td>
<td>Sanuoru Bridge</td>
<td>Between 1361 to 1377 metres</td>
</tr>
<tr>
<td>A6</td>
<td>Between Meriema &amp; High Court Junction along NH-2</td>
<td>Between 1371 to 1376 metres</td>
</tr>
</tbody>
</table>

The level of displacement in this location was found to be higher in 2018 with the displacement in the range of -0.129 metres in VV Polarization and between -0.012 to -0.161 metres in VH Polarization and it was found to be lower during 2019 with the displacement ranging between -0.056 to -0.095 metres in VV Polarization and the displacement in the range of -0.01 metres in VH Polarization. The Elevation range was observed to be the lowest in the region having Location ID- A1, which is a sinking zone on the way to Nagaland University and Women Resource Department having a mean elevation range of 1353 metres. The level of displacement in this location was also found to be higher in 2018 with the displacement ranging between -0.086 to -0.129 metres in VV Polarization and between -0.012 to -0.161 metres VH Polarization and it was found to be lower during 2019 with the displacement ranging between -0.056 to -0.095 metres in VV Polarization and the displacement ranging between -0.0 to -0.04 metres in VH Polarization. The Graph representation under the Location ID can be seen in Fig. 10 and the Field survey location and photographs can be seen in Fig. 7 and Fig. 8. The displacement map and information of the field survey locations can be seen in Table 5 and from Fig. 11–14.

### 5. Conclusion

Land subsidence mapping was carried out for the year 2018 and 2019 to study the variation in the pattern of land deformation over the seven administrative blocks of Kohima district. Land subsidence map was generated by Differential Interferogram using the open-source Graph Builder Tool of ESA SNAP and the free data of Copernicus Sentinel-1A. Results indicated that during both the year, the Southern and Western regions of Kohima district shows more subsidence as compared to the Northern and Eastern regions. Deformation estimation of the subsidence affected zones was also studied in both VV and VH polarizations. The lower level of subsidence are identified in the VH polarization and the subsidence was found to be higher in VV polarization. This is because of the property of VV polarization in which vertically placed earth objects produces a dual reflection, which in return sends a powerful backscattered signal towards the sensor.

The field survey was also carried out in six locations along the National Highway-2, Sanuoru-Secretariat road and on the way to Nagaland University Campus. These selected locations are extensively affected by landslides every year during the monsoon season causing land subsidence. The results depicted that rapid urbanization, unplanned human activities, cutting down of trees, unscientific construction of roads and highways are the contributing factors of land subsidence.

### Declarations

**Author Contributions**
Dr Deepak Kumar conceived and designed the study, and Ms Noyingbeni Kikon performed the research, analyzed the data, and Dr Syed Ashfaq Ahmed also contributed to editorial input.

**Conflicts of Interest**

The authors declare that there is no conflict of interests regarding the publication of this paper.

**Acknowledgements**

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**References**


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**Figures**
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Study area Map of Kohima district showing the boundaries of the seven Administrative Blocks namely, Chunlika, Tseminyu, Biotas, Chiephobozou, Kohima Sadar, Sechu (Subza) and Jakhama.
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Workflow of Methodology used for Land Subsidence Estimation of Kohima district
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Displacement map of Kohima district for 2018 in VV Polarization of Sentinel-1A data
Figure 4

Displacement map of Kohima district for 2019 in VV Polarization of Sentinel-1A data
Figure 5

Displacement map of Kohima district for 2018 in VH Polarization of Sentinel-1A data
Figure 6

Displacement map of Kohima district for 2019 in VH Polarization of Sentinel-1A data
Figure 7

Displacement map of Kohima district for 2019 in VH Polarization of Sentinel-1A data
Figure 8

Displacement map of Kohima district for 2019 in VV Polarization of Sentinel-1A data
Figure 9

Displacement map of Kohima district for 2018 in VH Polarization of Sentinel-1A data
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Displacement map of Kohima district for 2019 in VH Polarization of Sentinel-1A data
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Zoomed in Displacement Map of Ciephobozou Block in Sentinel-1 data
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