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Analysis of Vertical Land Displacement using Permanent Scatterer Interferometry (PSI)

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Abstract:- In steep mountainous areas, landslides are a widespread geological hazard that endangers people's lives as well as infrastructure and the environment. Ground deformation measurement has changed as a result of advancements in monitoring techniques, notably with regard to InSAR approaches and conventional to contemporary satellite systems. With its advantages of high precision and dynamic real-time monitoring, InSAR makes use of radar interferometry for economical and wide-ranging coverage. InSAR technology, has shown promise in tracking risk scenarios. Operating in TOPS mode, the Sentinel-1 satellite system is selected because to its extensive coverage, frequent acquisitions (12-day return intervals), and open data policy.

Based on 47 Sentinel-1A SAR acquisitions from 2021-01-12 to 2022-12-21 for PSI, the study applied PS technique and found out that the average displacement in the region to be ranged from -179.46 to 159.64 over the research duration. Comparing our result with the stable point on ongoing tunnel project the R square value was found to be 0.867 with standard error of 0.008.

Keywords:- *In SAR, Persistent Scatter(PS), Landslide.*

I. INTRODUCTION

Landslides, prevalent in hilly and mountainous areas, pose a significant geological risk, threatening human life, infrastructure, and the environment[1]. They contribute to substantial economic losses and fatalities. Spaceborne Synthetic Aperture Radar (SAR) emerges as a crucial tool for continuous Earth surface monitoring, overcoming weather constraints. SAR, offering efficient results with cost and time savings, is instrumental in studying tectonics, volcanoes, and subsidence[2]. SAR images, complex arrays of pixel elements, provide information on backscattering amplitudes related to surface characteristics[3]. Interferometric SAR (InSAR) enables millimeter-precision ground deformation studies through radar signal backscattering. Differential InSAR (DInSAR) enhances surface deformation monitoring, addressing issues like temporal and spatial decorrelation. Despite challenges, InSAR's accuracy is leveraged for various applications, supported by advancements in satellite technology, including Sentinel-1A/B, RadarSat-2, ALOS-2, and Gaofen-3. These satellites contribute significantly to SAR and InSAR capabilities, promising a future of expanded applications[4].Differential Interferometric SAR is improved version of the SAR interferometry and commonly known for the generation of interferograms from which topographic contribution become removed. The purpose of the DInSAR is to obtain the precise measurement of the deformation by removing all of other contributors to the interferometric phase other than displacement. So for that, interferogram flattening and topographic phase removal is done[5]. So due to it, DInSAR usually limit itself by temporal and geometrical decorrelation and atmospheric delay anomalies and only are suitable for the areas where there is high coherence because less coherence can cause unreliable difference values[6]. Forest or vegetated areas, snow and surfaces near moisture can also cause of loss of coherence[7] but studies shows that its effectiveness towards landslides is really good[8].

II. STUDY AREA

The Sidhababa landslide region is a geologically unstable[9]area located in the foothills of the Himalayas, specifically in the vicinity of Sidhababa Temple in Nepal. This regionhas been subject to frequent landslides, posing significant risks to the local population, infrastructure, and natural resources. The study area lies in Tinau Rural Municipality of Palpa district in the western region of Nepal. It is about 3 km away to the north of Butwal and lies between 27°43'34"N - 27°44'15"N latitude and 83°28'02" E- 83°28'19"E longitude.

The landslide of this area has been a major concern for government for more than a decade. This site is located in the bank of Tinau River. Recently the landslide obstructed the highway transportation[10].During the study period also the landslide occurred in the region[11]. In past too this landslide has caused barrier in transportation [12][13]however fatality number is very few as it doesn’t lie in the settlement area.

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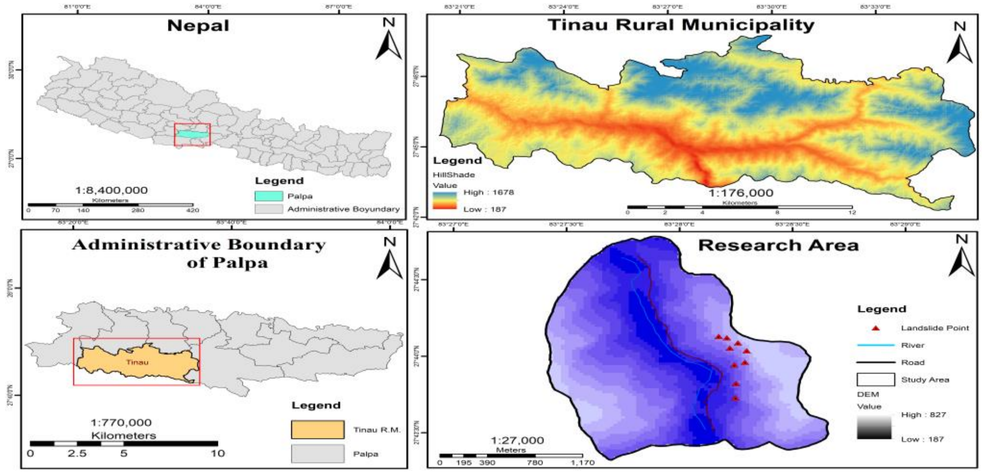

Fig. 1: Location Map of Siddhababa Landslide Area Methodology

A. Data Used

47 Sentinel 1 SLC Sar images was acquired in ascending mode from 2021/01/12 to 2022/12/21. The images were downloaded from Sentinel-1 Scientific Data Hub. All the images used are in VV polarization mode.

Table 1: Summary of Sentinel Data Used

Specification	Detail
Number of scenes	47
Acquisition period	01/12/2021 - 12/21/2022
Beam mode	IW
Product level	SLC
Flight Direction	Ascending
Polarization	VV

B. Software Used

- SARPROZ
- QGIS
- MS office Package
- Google Collab

C. Description

PSI has well known for its vast use and its mm level accuracy. SARPROZ is used for the processing of this technique. While processing, up to the deformation estimation different steps were being carried out. The PSI Processing involves Data preparation, Preliminary Analysis, APS Estimation and MultiImage PS processing.

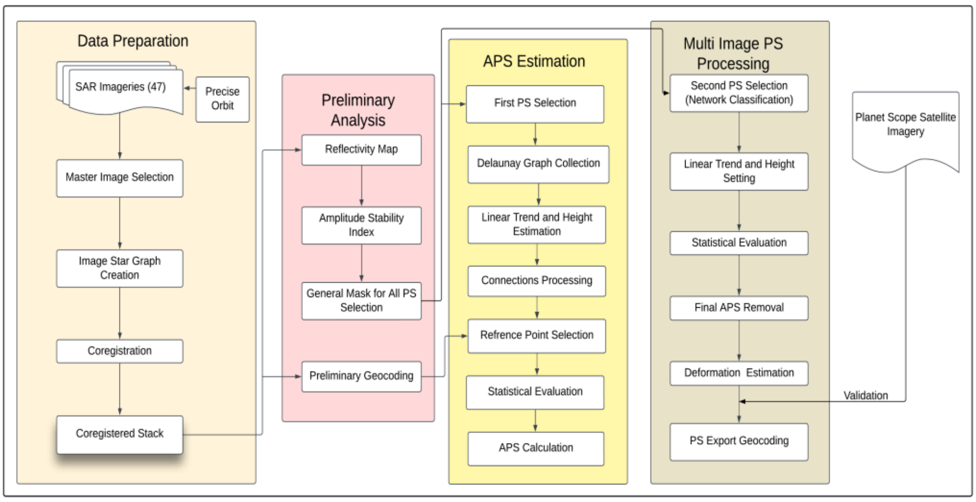

Fig. 2: Simplified processing of PSI in SARPROZ

The Interferometric phase consists of composite of several components related to earth's topography, and changes in the topography plays its role in the change in the information in the signal. The whole interferometric phase consists of following components as mentioned in the equation (1).

$$\emptyset = \emptyset^{flat} + \emptyset^{topo} + \emptyset^{disp} + \emptyset^{atm} + \emptyset^{orbit} + \emptyset^{noise} \quad (1)$$

where, $\emptyset^{flat}$ is the flat Earth phase, $\emptyset^{topo}$ is the topographic phase, $\emptyset^{disp}$ is the displacement between two images, $\emptyset^{atm}$ is the contribution of the atmosphere to the phase of the signal while $\emptyset^{orbit}$ is the contribution due to errors in the estimation of the platform's orbits, and $\emptyset^{noise}$ is the phase noise[14].

One SAR image is referred to as the Master image in Permanent Scatterer interferometry (PSI), which removes the effects of topography, atmosphere, and signal noise in order to assess ground surface deformation. Only coherent pixels with steady phase or amplitude are processed using this method. Because of all the artificial scatterers, there can be fewer points in the more vegetated areas and more in the metropolitan area[8]. In PSI, it is necessary to choose a single reference point and measure the movement of all other points with respect to it. As a result, this reference point needs to be extremely stable.

- *Preliminary Analysis:*

The Reflectivity map and Amplitude Stability Index are used in the preliminary analysis. Sparse point selection and masking are then carried out, leading to the external DEM selection. Typically, SRTM is used as the external DEM since it offers a resolution of 30 m and eliminates topographic error from the differential interferograms. In SAR coordinates, the Ground Control Point comes before the External DEM and Synthetic Amplitude. In order to prevent geo location mistakes from changing the PS point's position, this phase compiles the SAR coordinates with an external DEM.

- *APS estimation:*

APS Estimation is done with the STAR, 1 sensor Image Combination with Amp. Stab, Index 1- sigma/Mu and threshold that is used is different in the different times from 0 to 1 to get better results with variety of PS points. The threshold closer to 1 means to get better temporal coherence and higher temporal coherence mean better connections of PS points in the map. In urban areas, better temporal coherence is necessary because of higher number of PS Points but in the non-urban areas, it's not very easy to access the high temporal coherence, so it can reduce to get more PS points to estimate the displacement. Delaunay graph is produced to connect different PS points. Height and Linear trend are also been selected which are necessary to estimation of the displacement with better accuracy. Usually, height parameter is selected on the base of the estimated heights of the buildings or the height of the area and can be different in different areas. Linear trend is the approximate range in between linear movement can be observed. After selection of these parameters, processing continues and then Reference point has been selected, that is very important because with this reference point, the movement of the other PS points can be calculated, so for that, it has to be stable. Later, atmosphere can be monitored to find the error in the different images and finally Temporal coherence is estimated to look on the PS points that are fit to the graph, indirect way of finding the spatial coherence in the whole processing which is necessary for the estimation of deformation. Here the final step has been taken to calculate the APS.

- *Multi image sparse point processing*

Multi-image sparse point processing is further step to get more stable points with reduction of restrictions for the temporal coherence estimation. Same parameters other than threshold value are being used in this step and finally it is considered as one more step for the final estimation of the APS, and displacement map has been generated with the export of geocoded PS points.

D. Methodology PSI

47 Ascending track SAR acquisitions of Sentinel-1A from 2021-01-12 to 2022-12-21 were used. Sentinel-1A can provide single acquisition with area coverage of 250 km. Single acquisition is divided in to 3 sub swaths when we get it in IW Swath with TOPS mode.

In this study case, sub swath 2 is selected with VV polarization. The images with the same orbit track with least difference of slant range have been selected so errors in measurement can be reduced later. Master image of the date 20 November 2021 was being selected and the rest are considered as the secondary images. The master area is being selected with the Latitude of 27.734 and longitude of 83.47 with radius of 20 km and samples size 12720 and line 3320. The master area consists of lower hills and urban area of Butwal.

The extraction of master and secondary image was being done and finally all secondary images were co registered with Master Image. After the coregistration, Preliminary Analysis in which Reflectivity map and Amplitude Stability Index and Mask of Sparse point selection is conducted. Firstly, I generated the Reflectivity Map to get the temporal average of all images of the dataset and for that temporal Standard Deviation has been processed.

Mask creation was done in which mask has been created for the sparse point selection and this mask is applied in all functions in the PSI and QPS processing. Local maxima extraction is the selected parameter that used reflectivity map for the mask creation.

In the preliminary Analysis, Preliminary geocoding has been conducted which includes following steps.

- *External DEM Selection:*

The External DEM Selection was conducted to obtain digital elevation model of the study area and for that Shuttle Radar Topography data was used.

- *GCP Selection:*

Ground Control Point selection is done to geocoded the dataset through the SRTM.

- *External DEM in SAR co-ordinates:*

For the further processing, it was important to analyze the External DEM and Synthetic Amplitude in SAR Co-ordinates to reduce the errors. APS was done for InSAR techniques. We used STAR, 1 Sensor image Combination for the PSI. On the selection of Sparse Points Selection Parameter Threshold "Amplitude stability Index 1-Sigma/Mu" with threshold value of 0.6, down sample (DS) of 15 and down line (DL) 0 was selected.

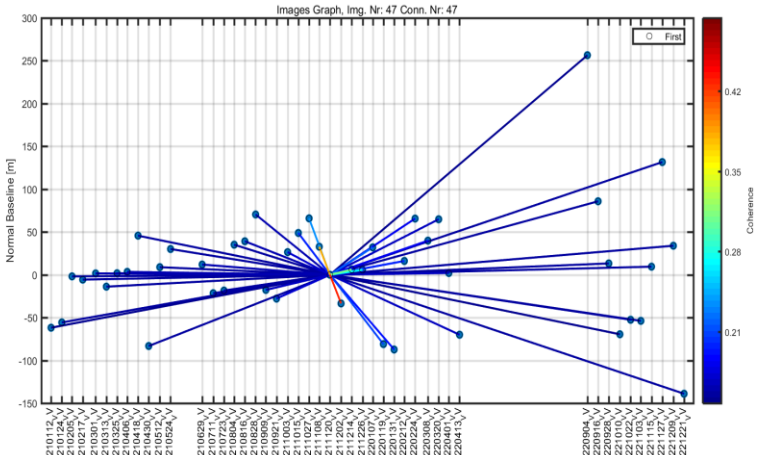

Fig. 3: Star 1 Image Graph for the APS estimation connection showing normal baseline vs Coherence.

Graph has been created to make a connection between different PSC. For PSI, Delaunay Graph has been used to make connection between the PS points.

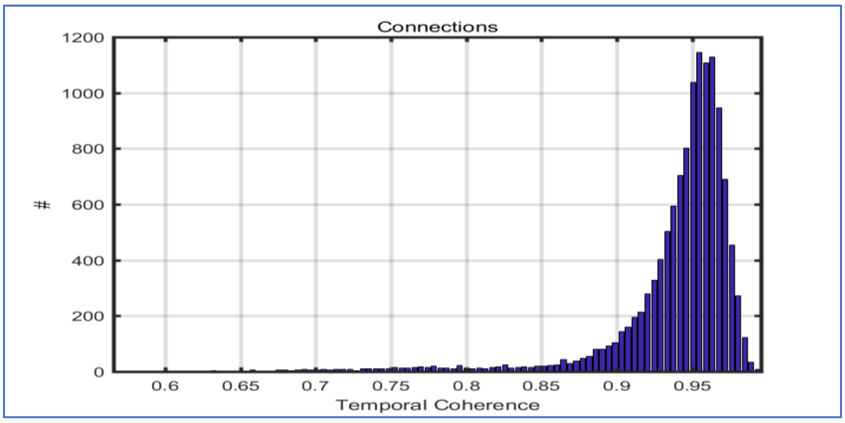

Fig. 4: The temporal coherence vs connection graph of PSI

In the processing steps parameters for the height and linear trend need to be set for the estimation of deformation, Linear trend from -120 to 120 has been selected for the estimated deformation rate in the study area while height parameter from -200 to 200 has been considered for the average height of the study area to approximate calculation.External DEM has been extracted in the case of Permanent Scatterer Inter ferometry.

After the Connection processing with the following values, Temporal Coherence was estimated in the form of Histogram, which indirectly shows the better fit of the PS points to our model for the progress of our process for the PSI. The histogram ranges from 0 to 1, where 0 shows less effectiveness while 1 shows maximum productivity of the function.

After it, reference point for connecting PS points has been evaluated. The most stable point in the whole function has been considered as the reference point, from which other PS points are being connected to estimate the deformation rate. There are different parameters that need to be evaluated before selection of reference point.

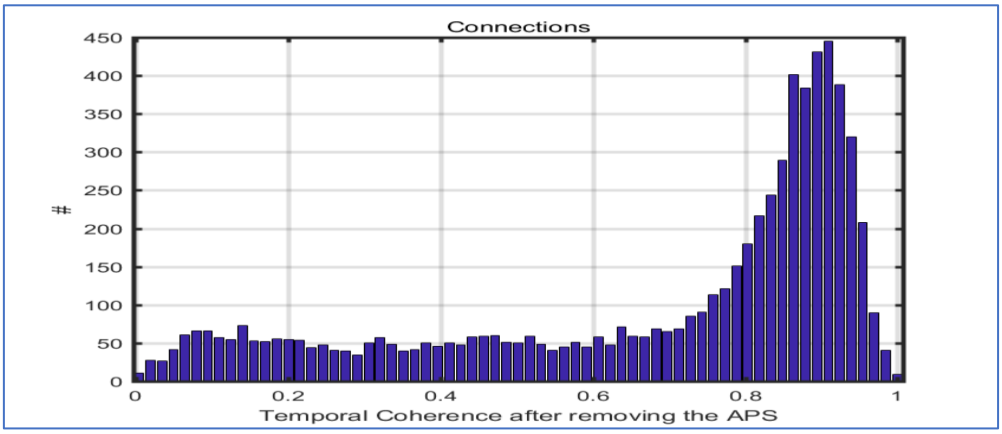

Fig. 5: The temporal coherence vs connection graph of PSI after removal of APS

First parameter for selection of the reference point is the minimization of Integrated Velocity, cumulative displacement, Integrated Height, Residual Height where these parameters are. The other factors of the PS points should be zero or near to zero which shows that the point is stable and can be considered as reference point. If this PS point will move, then there is no way to measure deformation rate. So, this is considered as very important step.

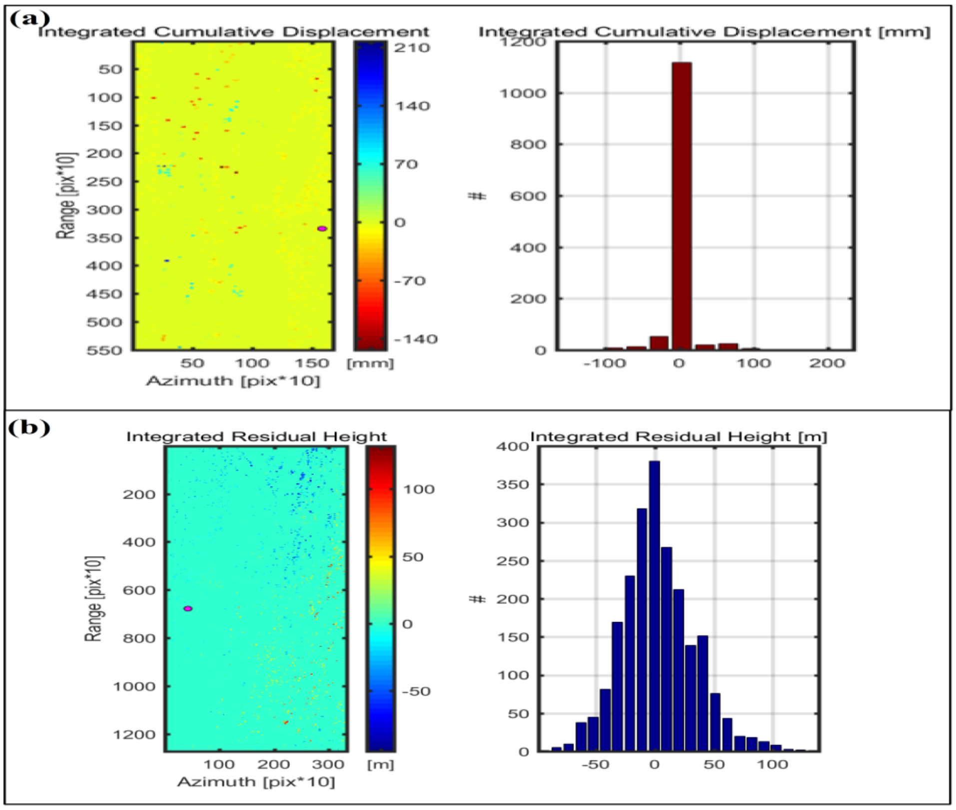

Fig. 6: The integrated cumulative displacement graph and Integrated Residual Height graph of the selected Reference PS point

Integrated cumulative displacement and integrated residual height are 2 important parameters that we can use to monitor or to estimate the stability value of our reference PS point which is important to estimate the movement of the PS points in the study area.The peak of the Integrated Cumulative displacement on the histogram is zero and it concludes that the velocity of the mostof the PS point reference to the selected reference point is zero because most of the PS points should have zero velocity.

The second parameter, integrated height less the external DEM is known as the integrated residual height. The integrated residual height histogram's peak is almost at zero. This indicates that when compared to the reference point, the bulk of locations have 0 relative height. Given that most points should be on the ground, this indicates that the reference point is on the ground.

III. RESULT AND DISCUSSION

A. Reflectance Map

During this research InSAR based techniques namely Persistent Scatterer (PS), was used to process the Sentinel imageries. These methods resulted in the reflectivity maps presented in the Figure 7. The surface characteristics of the region under observation, such as the type of terrain, amount of vegetation, and roughness of the surface, all affect the intensity of radar backscatter.

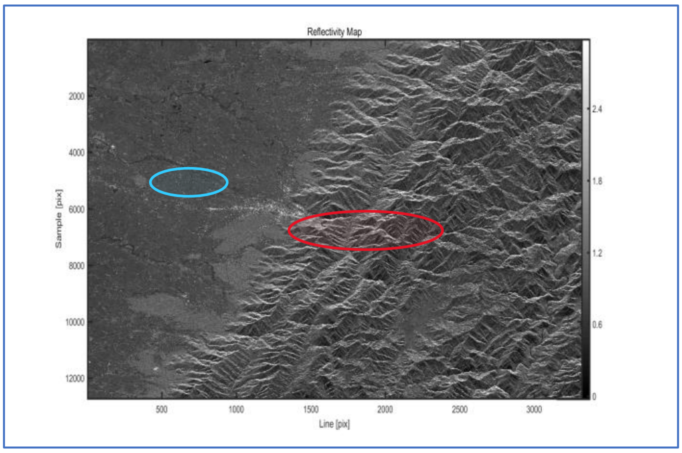

Fig. 7: Reflectance Map generated from processing sentinel 1 image using PS

The areas highlighted by red ellipse shows the areas with higher reflectivity resulted by the semi urban areas present in our area as those areas are rough in nature hence scatter the signal in all direction. Likewise area highlighted with blue ellipse has very few or zero reflectivity resulted by the water body as it reflects away the signal from the satellite because of it smooth surface.

B. PS-InSAR based land deformation

The cumulative displacement of PS points produced using the PSI approach is shown in the graph below. The x-axis in this image represents the points that have been chosen at intervals of 3, and the y-axis displays the corresponding displacement of each point.

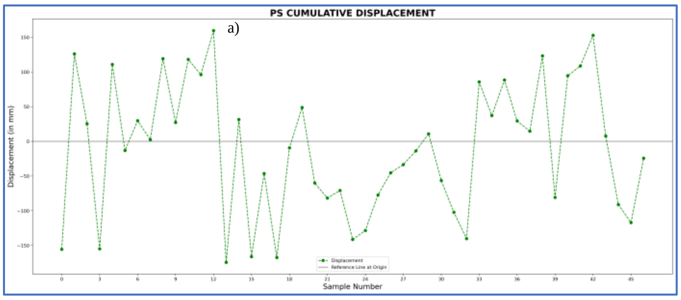

Fig. 8: Graph representing Cumulative Displacement of deformation points in study area by PSI method

Processing using Persistent Scatterer Interferometric Synthetic Aperture Radar (PS-InSAR) yielded a total displacement in the range -179.46 mm to 159.64mm over the research duration. The average displacement was found to be -48.01 mm/year.

Year wise displacement analysis of the same data was done and their monthly average displacement were calculated as per the number of imagery available on the particular month to prepare the graph shown in Figure 9.

In the year 2021 average monthly displacement ranged from -89.96mm to +73.38mm. Figure 9(a) shows the average monthly displacement of the year 2021 while Figure 9(b)shows the average monthly displacement of the year 2022. In the year 2022 average monthly displacement was found to be-171.35mm to 127.65mm. Maximum displacement was found to be in the month of July and August in 2021 and in the month of June and July in the year 2022. These are the months where we expect maximum rain and that may result in landslide. Analyzing the past events of this region we can say that the moths of rainy season are more probable time to occur landslide.

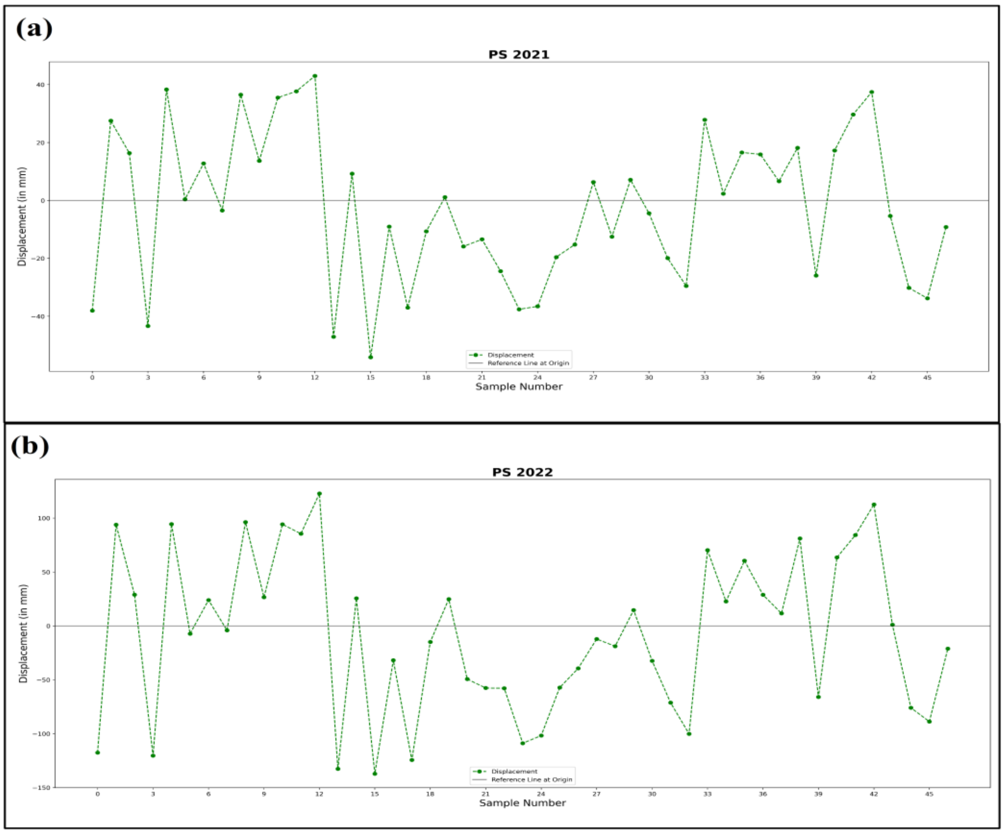

Fig. 9: Year-wise monthly average displacement in PS processing

C. Validation

To validate the result of this research high resolution satellite imagery (resolution of 3-5m) of two different time were used so as to detect the landslide activity during the research period. The first image was downloaded of 10th January 1010January 2021 just before of our research period and the next was of 9th January 2023 just after the end of our research time.

Few landslide activities were found while analyzing these two-satellite imagery of different time periods. The sample points were taken from results generated by PS, and were plotted in the satellite imagery as a base map and found that the point lied on the landslide area. Graph of the monthly average displacement against the month were plotted and has been added in the image as shown in the Figure 10. All thesample points graph shows the negative displacement that means the ground surface is sliding downwards. As they lie on the landslide area the results seem validated.

Linear regression was done with the available tunnel starting point where sample from each process was compared with the Reduce level (R.L) of tunnel starting point. Figure 10(d) shows the statistical relationship generated by regression technique. The R square value was found to be 0.867 with standard error of 0.008. This shows that the results are reliable. Figure 11 shows the normal probability plot generated during regression.

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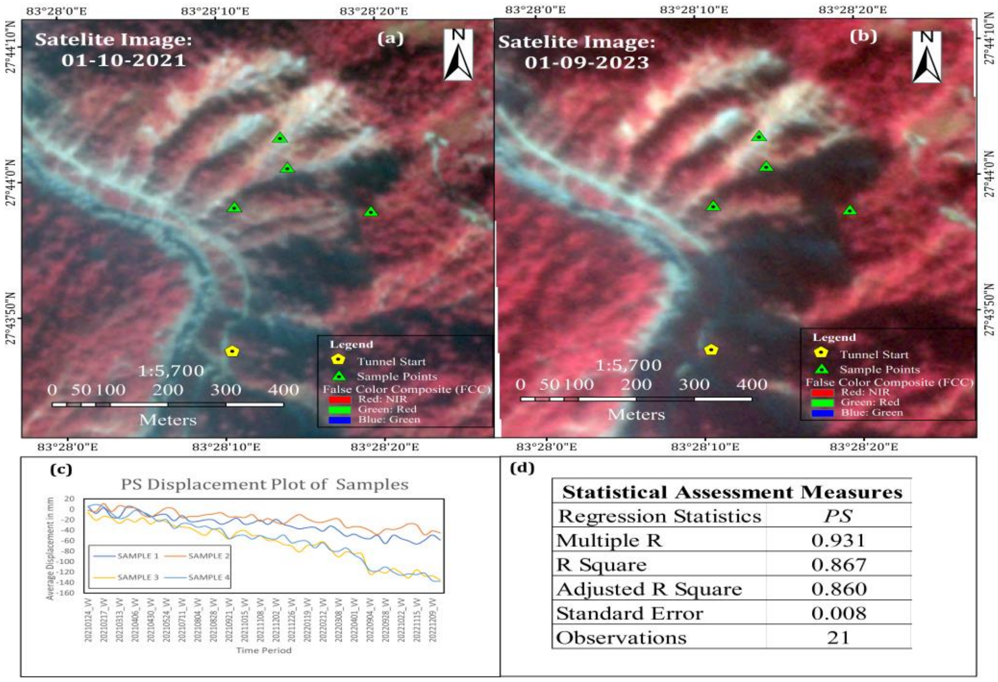

Statistical Assessment Measures	
Regression Statistics	*PS*
Multiple R	0.931
R Square	0.867
Adjusted R Square	0.860
Standard Error	0.008
Observations	21

Fig. 10: Deformation points with high resolution satellite imagery of two different years along with their displacement plots from PS and the statistical assessment measures.

Figure 10(a) and Figure 10(b) shows the satellite imagery of two different dates marked 10th January 2021 in (a) and 9th January 2023. Figure 10(c) shows the graph generated by plotting the average displacements of sample points.

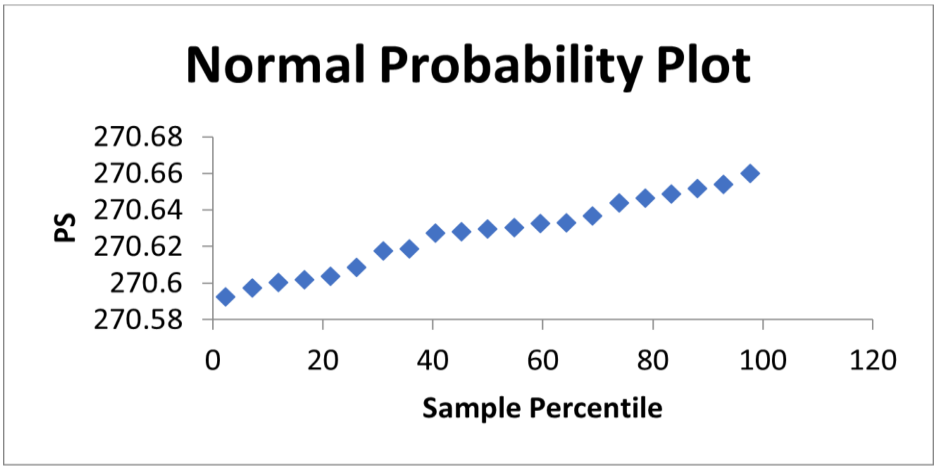

Fig. 11: Normal Probability Plot of PS Method

Figure 11 shows that the plot of our calculate data vs refrence station data which seems to shows that much value lies on the straight line meaning the values seems to be distributed normally.

D. Discussion

This research tried to apply InSAR techniques named PSI to determine the monthly displacement pattern and over all cumulative displacement pattern of the region. We found out higher value of average monthly displacements were in the months of July and August in year 2021 and in the months of June and July in 2022. All these months lies in the rainy season. Naturally it is dominant that landslide occurs mainly in rainy season.Our results generated also follow the trend.The average displacement was found to be -48.01mm/year. The value is abit high because most of the points lie in the landslide prone areas where various landslide event had occurred[15]. The PS technique seems quite effective in monitoring landslide in the area same as of our study area. The StaMPS PS-InSAR approach has been used to study the landslide activity in the Bolshoy Sochi (Big Sochi) region, which is located on the Black Sea coast of the Great Caucasus. Based on satellite data, areas with significant surface displacement rates have been identified; these areas align closely with regions experiencing high landslide activity, as confirmed by ground observations[16]. In our study also we found out the similar conclusion.

IV. CONCLUSION AND RECOMMENDATION

A. Conclusion

Landslides at study area were found by analyzing publicly accessible spaceborne radar data of the Sentinel-1 system with the PSI technique of InSAR. Giving exact forecasts of failure events was not feasible, though. However, there are a number of significant drawbacks, including the research site's location that don't have any level network available nearer, which may hinder application in the first place, the high level of specialized knowledge regarding the processing chain that is needed, and the choice and accessibility of the most suitable technique. By using PSI,we can now detect and locate nearby landslides. Selection of imagery is also a challenging step in this process as it might affect the result severely. Imageries with very few differences in base line and with high temporal coherence are required to get better results, which can be a challenging job. This research concluded that the PS techniques can be used to understand the deformation pattern of the landslide area.

Following that, the findings may be used to recommend when to apply PSI to identify and track landslides that could endanger lives or destroy infrastructure. In this study, we employed established techniques from many fields of expertise to identify landslides, enabling the extraction of information from partly coherent targets through the use of spaceborne Synthetic Aperture Radar data.

B. Recommendations

In light of the research's findings, I would like to suggest the following:

- Use of DEM of higher resolution during the processing might result in higher accurate results and analysis.
- Regular monitoring of landslide prone area with ground-based signal receivers and using those data for validation of result processed from PS, will help to minimize the damage that may be resulted by severe landslide.
- The low density of PSs in non-urban (rural) areas, which are characterized by vegetated or low reflectivity homogeneous zones, is significant constraint of PSI which might be addressed by Small Baseline Subset (SBAS) technique.
- Quasi PS (QPS) technique might be more effective in semi urban and vegetative areas as it employs a multi-master network to restrict the baseline decorrelation.

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