# Assessment of Land Subsidence Pattern in Pokhara Valley Using Sentinel-1 InSAR Processing

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## Abstract

This research examines the use of Sentinel-1's enhanced remote method and Interferometric Synthetic Aperture Radar (InSAR) processing to monitor ground subsidence in Pokhara Valley City, Nepal. It aims to comprehend the reciprocal effects of land sinking on environmental sustainability, infrastructure stability, and urban growth. The methodology encompasses the acquisition and processing of Sentinel-1 SAR data, along with rigorous interferometric analysis to detect and quantify ground deformation. Spanning from 2019 to 2022 AD and, -analyzing annual displacement trends, initially, a subsiding trend was observed in 2019-20 AD with an average rate of 0.037 m/year followed by 0.072 m/year in 2020-21 AD, and then escalating to 0.165 m/year in 2021-22 AD. These fluctuations in rates illustrate the intricate interplay of urbanization and geological dynamics affecting land stability in the region. The implications of this study extend to urban planning and infrastructure management, emphasizing the necessity of integrating land subsidence monitoring into the developmental policies and strategies of Pokhara Valley. Additionally, the potential of Sentinel-1 InSAR as a valuable tool for geotechnical investigations offers a non-invasive, cost-effective means to assess and monitor ground deformation risks. By leveraging the capabilities of Sentinel-1 InSAR, the study contributes to the body of knowledge in geotechnical and civil engineering fields, particularly within the context of sustainable urban planning and disaster risk reduction.

***Keywords:*** *Land subsidence, Sentinel-1, InSAR, Infrastructure Management, Sustainable Development*

## Introduction

Land subsidence can take the form of slow down warping or the rapid sinking of distinct parts of the ground surface. Movement is primarily downward, although the concomitant horizontal distortion frequently has considerable detrimental effects (Galloway & Burbey, 2011). Underground utilities connection breaking, intrusion from seawater, and building and civil infrastructure settlements are all examples of this phenomenon (Hu et al., 2004). It occurs when sediments consolidate due to an increase in effective stress (Ma et al., 2018) and causes infrastructure damage contributing to changes in topographic gradients, reduces the capacity of the aquifer system to store groundwater, and increases the cases of flooding; subsequently posing a threat to humans and the economy (Holzer & Galloway, 2007). Such disasters are geological phenomenon, especially in fast-growing urban regions (Ahmad et al., 2022). The primary reasons include subsurface fluid withdrawal, drainage of organic soils, sinkholes, mining underground, hydro compaction, permafrost thawing, and inevitable compaction (Council, 1991). It has become a significant issue in major cities like Jakarta, Mexico City, and Shanghai which have experienced rapid population growth. A study done by Strozzi & Wegmuller (n.d.) found a subsidence velocity of up to 30 cm/year in some areas of Mexico. In the past, when water was pumped out to an extreme extent, the ground sank at a rate of up to 12 centimeters per year in Thailand (Aobpaet et al., 2013).

For detecting land subsidence Fergason et al. (2015) suggested several traditional techniques include instrumented in-ground sensing systems, repeat optical leveling and navigational system (GPS) surveys, ground inspection, photo-geological examination, groundwater monitoring, and tape-extensometers. However, these methods seem costlier and outdated also, are time-consuming. Modern approaches include analyzing and interpreting differential interferograms of repeat-pass, satellite-based synthetic aperture radar data (InSAR), borehole tiltmeters, micro-seismic arrays, dredging of monitoring trenches, and time-domain reflectometry (TDR) (Fergason et al., 2015). Hu et al. (2004) recommended implementation of advanced techniques to continuously assess and monitor changes in the land surface to prevent serious damages. Satellite image data has been used for various studies. Xavier et al.(2021) investigated on Daily Average and Extreme Rainfall in the Mearim River Drainage Basin, Peng et al., (2015) studied soil moisture downscaling using remote sensing techniques and satellite images. There is various mode of satellite images that are accessible for researches. The major type of satellite images, sentinel data are Sentinel-1 GRD, Sentinel-2 L1C, Sentinel-2 L2A, Sentinel-3 OLCI L1B, Sentinel-3 SLSTR L1B, and Sentinel-5P L2 (Data, n.d.). The Sentinel-1 imagery is from two polar-orbiting satellites that work day and night. They use radar imaging and can get images in all weather conditions. They are used for many things like tracking sea ice, oil spills, and marine conditions. It can also monitor land changes and respond to emergencies like floods and earthquakes.

Sentinel-1 provides radar images for various uses. SAR images effectively track land subsidence and structural damage. They help detect and monitor ground movement caused by natural events like earthquakes, landslides, and volcanic uplift. These images are valuable for urban planners and crucial for observing and analyzing changes in the environment (S1 Applications, n.d.). A SAR signal contains data on both amplitude and phase. The strength of the radar response is represented by amplitude, whereas phase is the proportion of one complete cycle of a sine wave (corresponding to a single SAR wavelength). The distance between the satellite antenna and the ground targets is the key variable influencing the phase of the SAR image (Braun & Veci, 2021). InSAR is a widely used method as it is a powerful tool that provides millimeter-level precision in the regions of deformation in the land (Yang et al., 2016). Using this tool, subsidence was studied by Bokhari et al. (2023) in Gwadar City, in Kathmandu Valley by Bhattarai et al. (2017), and Cormick (2019) researched in Australia. Land subsidence in urban areas is typically caused by a combination of factors, including excessive extraction of groundwater, the natural consolidation of alluvial soil, the load from constructions (such as the settlement of highly compressible soil), and occasionally tectonic activities (Abidin et al., 2015). The study conducted by Council (1991) reckoned flooding and damage to structure caused by ground subsidence are estimated to cost more than $125 million each year in the United States. Reliable information on land subsidence is crucial for urban development and risk assessment. It helps regulate groundwater extraction, control floods, and seawater intrusion, protect the environment, plan infrastructures and utilities, and develop urban areas (Abidin et al., 2015). This shows a need for quantifying the land subsidence effect to be studied in urban areas and planning should be done accordingly.

Study done by Bhattarai et al. (2017) using Differential Interferometric Synthetic Aperture Radar (DInSAR) technique showed Kathmandu Valley is sinking with rate ranging from 1.1 cm/year to 4.8 cm/year because of extensive water extraction and hybrid development in center areas. One of the most governing factors for land subsidence is urbanization and land use pattern. Nepal's urbanization is centered in Kathmandu valley, followed by Pokhara (Joshi, 2023; Rimal, 2012) clarifiers requirement of study of phenomenon like subsidence in Pokhara Valley. Sinkholes have been discovered and reported in the Armala area of Pokhara Valley (northeast of the study area). Dynamic Cone Penetration Test (DCPT) conducted by Bhandari et al. (2021) suggested that the cave has begun to form beneath the gravel layer of the sink hole that increases the cavity size and driving the loose upper layer to collapse, contributing to the Pokhara Valley's peculiar geology, which also includes several extant and new sink hole concerns in other areas. Authorities, and engineering geologists continue to face difficult challenges in avoiding and alleviating land subsidence (Hu et al., 2004). Hence, proper investigation of land subsidence in urban cities is necessary to detect the subsidence pattern and accordingly carrying urban planning. Through examination and analysis, this study aims to deepen our understanding of land subsidence processes and contribute to the formulation of effective mitigation strategies for sustainable land management in Pokhara Valley and analogous regions. The objective of this study is to identify and analyze the main factors responsible for the land subsidence in the central Pokhara valley, as well as to examine their correlation with the subsidence pattern. Additionally, the effectiveness of remote sensing methods such as Interferometric Synthetic Aperture Radar (InSAR) is assessed. The study emphasizes the significance of comprehending the effects of land subsidence on urban infrastructure and planning, and aims to formulate efficient measures to alleviate and forestall subsidence-related harm, thereby ensuring sustainable urban development.

## Methodology

### *Study Area and Data*

The research is centered on the Pokhara Valley within Nepal's Gandaki province, spanning from 28°09'04" N to 28°16'23" N latitude and 83°56'45" E to 84°02'37" E longitude. This area, approximately 200 kilometers west of Kathmandu, covers about 55 square kilometers. In Figure 1, highlighted in red, the study area, Pokhara Valley, is depicted. Geologically, the Pokhara Valley comprises a diverse composition, including metasedimentary rocks such as schists and quartzites, intrusive formations like granite and gneiss, alluvial deposits, glacial moraines, and sporadic limestone formations. These formations, sculpted over millions of years by tectonic activity, erosion, and glaciation, define the distinct topography of the valley. Situated in a seismic zone, the Pokhara Valley region is prone to geological hazards like landslides and earthquakes. Moreover, rapid urbanization, infrastructure development, and changes in land use have significantly altered its natural landscape and hydrogeological conditions.

Pokhara Valley's selection as this research focus stems from several factors. Firstly, its susceptibility to geological hazards, exacerbated by rapid population growth and urbanization, and rainfall pattern. An average annual rainfall in Nepal is 1900 mm (Climate Risk and Adaptation Country Profile, 2011) and Pokhara is Nepal's most precipitous area (U. Paudel, 2020) with the yearly precipitation value up to 3514 mm (S. Paudel & Dawadi, 2022). Such excess of rainfall, increase in runoff behavior due to repaid urbanization, decrease in infiltration in the urban area and increase in groundwater extraction may cause the secondary effect in the Pokhara valley.

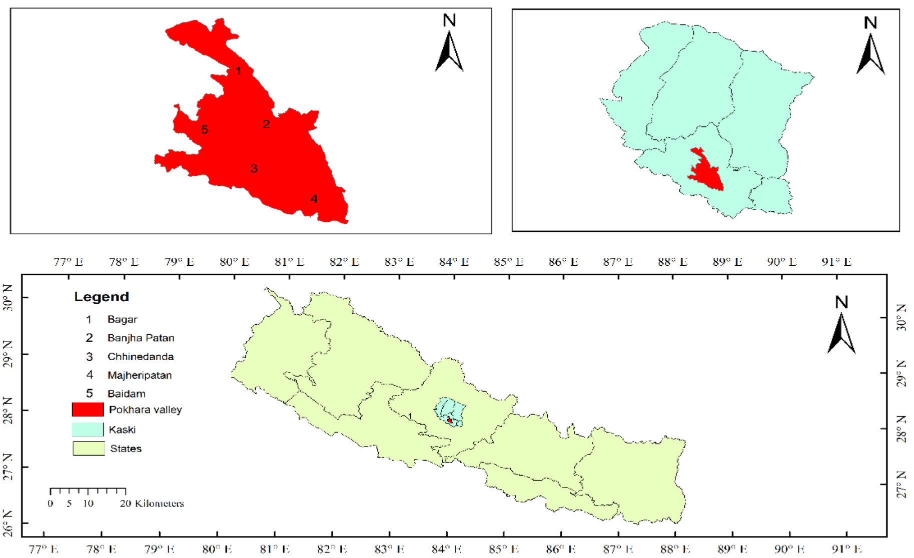



*Figure 1. Location map of study area*

Moreover, Pokhara Valley's role as a tourism hub and economic center underscores the necessity of understanding and addressing land subsidence risks for the region's sustainable development and resilience. In summary, the Pokhara Valley region is an ideal setting for investigating land subsidence due to its geological diversity, vulnerability to natural hazards, and socio-economic significance.

*Table 1: Data obtained through Alaska Satellite Facility (ASF)*

| S.N. | Key | Value |
|---|---|---|
| 1 | Sensing Period | From 2019/06/04 to 2022/05/19 |
| 2 | Check Mission | Sentinel-1A |

| | | |
|---|---|---|
| 3 | Satellite Platform | S1A |
| 4 | Product Type | SLC |
| 5 | Sensor Mode | IW |

***Methods***

The methodology aims to investigate land subsidence patterns in Pokhara Valley using Sentinel-1 Interferometric Synthetic Aperture Radar (InSAR) processing. With rapid urbanization and infrastructure development in Pokhara Valley, understanding and monitoring land subsidence are crucial for sustainable land management and disaster risk reduction. This methodology outlines the research design, data acquisition, processing techniques, and analysis procedures employed in this study. This study adopts a remote sensing approach utilizing Sentinel-1 satellite data for InSAR analysis. The research design involves multi-temporal and spatial analysis of Sentinel-1 Synthetic Aperture Radar (SAR) images to detect and monitor land subsidence over time. Table 1 below enlightens the nature of data obtained from the Alaska Satellite Facility (ASF) and its characteristics.

Figure 2 describes flow charts for the analysis of land subsidence using the InSAR technique. Sentinel-1 Synthetic Aperture Radar (SAR) data will be sourced from the Alaska Satellite Facility (ASF) and processed in the Sentinel Application Platform (SNAP) tool. Additionally, a Geographic Information System (GIS) is used to assist in image interpretation. Synthetic Aperture Radar (SAR) is a technology capable of producing detailed, high-resolution images over large geographic areas. Typically mounted on orbital or airborne platforms, SAR can also be deployed on the ground. Two Sentinel-1 scenes are extracted from the Alaska Satellite Facility using the online interface to study each year's subsidence pattern.

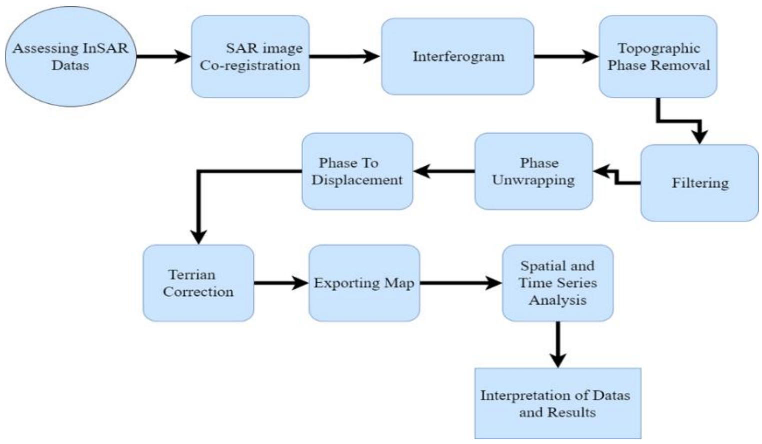



*Figure 2. Flowchart for the analysis of land subsidence*

***Data Pre-processing***

The initial crucial phase in the analysis of land subsidence using Sentinel-1 SAR data involves pre-processing the raw data to ensure its suitability for subsequent interferometric processing and land subsidence detection. The primary pre-processing steps undertaken in this study are outlined as follows:

Acquisition and Import: Sentinel-1 SAR data, sourced from the Alaska Satellite Facility, was imported into the Sentinel Application Platform (SNAP) software. This entailed locating and selecting the appropriate data files, whether in zip format or as a folder, for importation.

Orbit Correction: To enhance the geolocation accuracy of the Sentinel-1 data, precise orbit information was applied. Apply Orbit File function is used, facilitating the download and application of precise orbit data to the SAR images.

By meticulously implementing these pre-processing steps, the Sentinel-1 SAR data was effectively prepared for further analysis, ensuring accurate and reliable outcomes in the investigation of land subsidence dynamics.

***Co-Registration***

The co-registration of Sentinel-1 SAR images represents a pivotal pre-processing step aimed at achieving precise spatial alignment of the data—a fundamental prerequisite for subsequent interferometric processing and land subsidence detection. Utilizing sophisticated algorithms within the Sentinel Application Platform (SNAP) software, the co-registration of two InSAR images from which land subsidence is to be detected was accomplished. These algorithms adeptly identified common ground control points between the images and implemented geometric transformations to minimize spatial misalignment, ensuring pixel correspondence across all images. This step orchestrated the requisite computations to precisely co-register the images, meticulously considering factors such as satellite orbit information and terrain characteristics. By systematically executing these co-registration protocols, the study guaranteed the accurate alignment of Sentinel-1 SAR images, thereby laying a robust foundation for subsequent analyses of land subsidence detection and interferometric processing.

***Interferometric processing***

Interferometric processing of co-registered Sentinel-1 SAR images constitutes a pivotal stage in the land subsidence detection workflow, encompassing the generation of interferograms and subsequent extraction of ground displacement information. Utilizing the co-registered Sentinel-1 SAR images, the phase difference between each pair of image acquisitions was computed to generate interferograms. These interferograms encapsulate surface displacement information alongside contributions from Earth's curvature and the satellite's orbit. The displacement is calculated by analyzing the interferogram fringes using the color cycle. The interferogram fringe is a cycle of color range, with each cycle defined by the $2\pi$ cycle of phase change.

***Topographic Phase Removal***

Utilizing the available reference digital elevation model (DEM) and precise orbit data, the topographic phase removal procedure was executed that undertook requisite computations to estimate and subtract phase contributions attributable to Earth's curvature and terrain, leveraging the reference DEM and precise orbit information. This rigorous topographic phase removal methodology, integrated within the SNAP software, served as a crucial processing step in isolating the land subsidence signal from Sentinel-1 SAR interferograms. This, in turn, facilitated subsequent analysis and interpretation of ground deformation patterns.

***Filtering***

Goldstein filter, renowned for its efficacy in minimizing noise and enhancing the discernibility of surface deformation patterns in InSAR data, was employed. The aim was to augment the signal-to-noise ratio and enhance the interpretability of the Sentinel-1 SAR interferograms.

***Phase Unwrapping***

The phase unwrapping process stands as a pivotal phase in the interferometric processing of Sentinel-1 SAR data, converting wrapped interferometric phase values to continuous, absolute phase differences crucial for land subsidence detection and analysis. In this study, phase unwrapping was executed using the Statistical-cost, Network-flow Algorithm for Phase Unwrapping (SNAPHU) integrated into the Sentinel Application Platform (SNAP) software.

The interferogram, after being flattened and filtered in the previous processing stage, consistently shows a phase value ranging from 0 to $2\pi$. This means that whenever the phase change surpasses $2\pi$, the phase value resets to 0 and the cycle begins anew. This phenomenon is known as $2\pi$ ambiguity and phase unwrapping is the method used to address this issue.

***Phase to Displacement Conversion***

The final step involved converting unwrapped interferometric phase values to ground displacement measurements, crucial for quantifying land subsidence patterns observed in Sentinel-1 SAR data. This conversion relied on known Sentinel-1 SAR sensor characteristics and principles of interferometric synthetic aperture radar (InSAR) measurements.

Sentinel-1 SAR Wavelength: The sensor's C-band operating frequency (approximately 5.405 GHz) corresponded to a wavelength (λ) of approximately 5.6 cm, a vital parameter for the phase-to-displacement conversion.

Line-of-Sight (LOS) displacement calculation could be using equation (i).

$$\Delta LOS = \frac{\Delta\Phi \times \lambda}{4\pi \cos\, \theta} \quad \text{......................} \text{ (i)}$$

where ΔΦ represents unwrapped interferometric phase difference (in radians), λ denotes Sentinel-1 SAR wavelength, and θ signifies the local incidence angle of the Sentinel-1 SAR beam. The local incidence angle (θ) was determined using precise orbital information and the reference Digital Elevation Model (DEM) integrated into SNAP.

***Terrain Correction***

Geometric distortions induced by terrain variations were mitigated through Range Doppler Terrain Correction. This step, accessed via the Terrain Correction option, utilized a digital elevation model (DEM) to rectify spatial and positional inaccuracies in the SAR data.

***Output Displacement Maps***

The outcome of the phase-to-displacement conversion yielded a collection of displacement maps, with each pixel denoting the line-of-sight ground displacement observed between the two Sentinel-1 SAR acquisitions. These displacement maps served as the principal output of the interferometric processing workflow and constituted crucial data for subsequent endeavors in land subsidence detection, analysis, and interpretation.

## Results and Discussion

This section discusses the InSAR analysis from 2019 to 2022, at intervals of every year. These analyses were processed in Sentinel Application Platform (SNAP) software and mapped using GIS tools. InSAR analysis of Pokhara was done every one year from June 2019 to May 2022 from ascending and descending tracts. A total of 3 images were used at a year interval. The results show the deformation scale in meters.

***Land Subsidence Pattern***

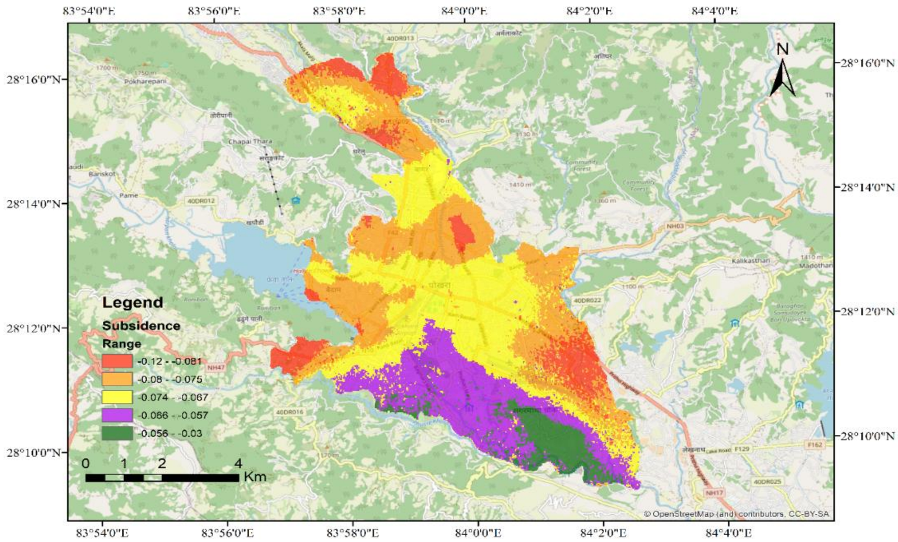
The results of land subsidence are obtained and further processed to determine the precise subsidence rates. The data obtained after Range-Doppler Terrain Correction are exported in tiff format and analyzed with GIS application. The subsidence point’s data is divided according to the Jenks natural break optimization, the method that selects the best arrangement for the data cluster.

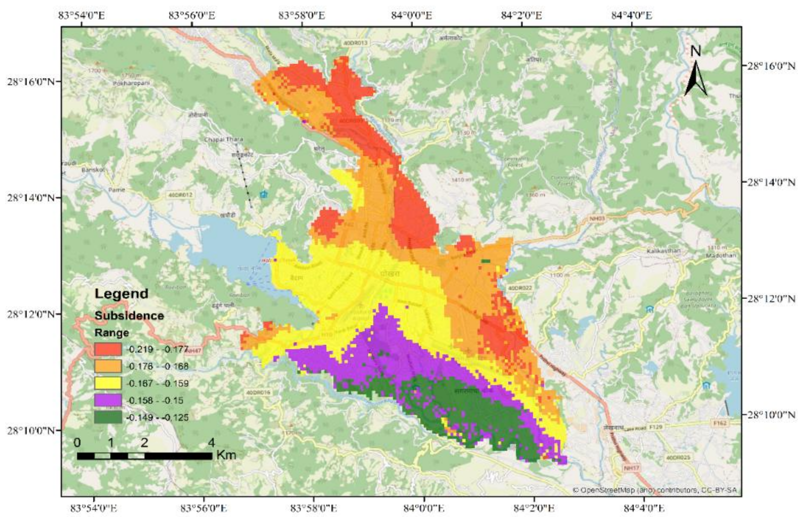
Between June 2019 and May 2020, the Pokhara bounded region was observed to be sub-siding at an average annual rate of 0.037 m. It is determined that there is a minimum subsidence of 0.02 meters and a maximum subsidence of 0.054 m at that period. The study region was shown to be subsiding at an average rate of 0.072 m/year between July 2020 and July 2021 and is discovered that there is a minimum subsidence of 0.030 meters and a greatest subsidence of 0.119 m. There is a 0.166 m/year average sinking from July 2021 to July 2022 provided that subsidence ranges from 0.125-0.218 m/year (Figures 3). According to this data, the Pokhara Valley's overall subsidence rate is approximately 0.091 meters per year, which appears to be a noteworthy finding. summarise the maps generated above, the subsidence pattern of five distinct Pokhara areas throughout the corresponding time periods has been established in table 2 and the trend of subsiding is shown in Figure 4.

*Table 2: Subsidence pattern in different location*

| Duration | Bagar | Banjha Patan | Chhinedanda | Majheripatan | Baidam |
|---|---|---|---|---|---|
| 2019-2020 | -0.037 | -0.042 | -0.039 | -0.041 | -0.029 |
| 2020-2021 | -0.08 | -0.071 | -0.062 | -0.048 | -0.076 |
| 2021-2022 | -0.176 | -0.173 | -0.154 | -0.145 | -0.164 |

The Sentinel-1 InSAR analysis conducted over Pokhara City indicates a complex interplay of natural and anthropogenic factors impacting land subsidence patterns. The findings suggest that areas such as Mahendra Cave, Bat Cave, Baidam, Bagar, Banjha Patan, and Jumleti Khola are highly susceptible to land subsidence. The most significant sinking pattern was found to be Bagar followed by Banjha Patan where popultaion density is relatively higher. The verification of the obtained results could be done manually by using conventional methods and past data.



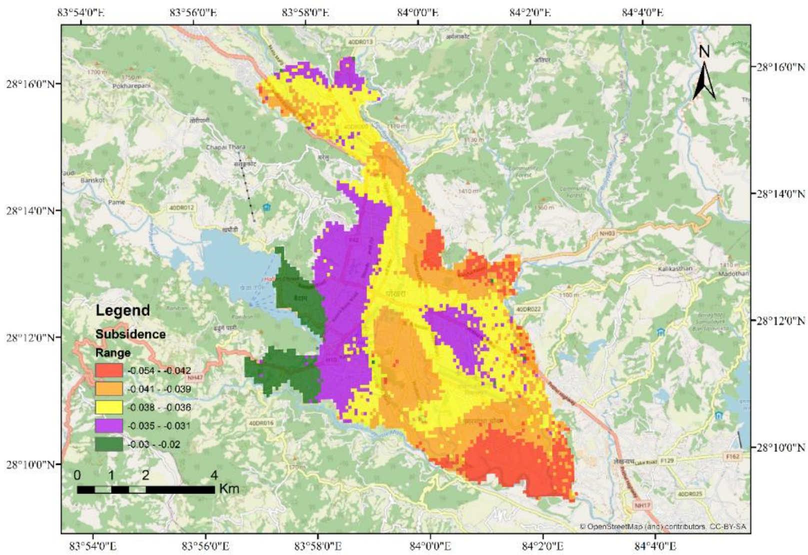



*Figure 3: Land subsidence pattern from a) 2019 -20, b) 2020 –21, c) 2021 - 22*

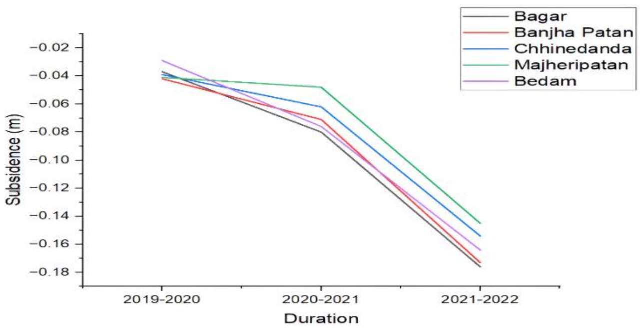



*Figure 4: Trend of subsidence in five different locations of Pokhara*

The three subsidence maps spanning from 2019 to 2022 were temporally stacked using the raster calculator function of a GIS tool, employing equation (ii) to produce the average subsidence map. Subsequently, the resulting map was divided into four distinct sections and the various pattern of land subsidence formed and their profile was plotted and presented in figure 5.

$$Avg\ Subsidence = (\text{"}Subsidence1.tif\text{"} + \text{"}Subsidence2.tif\text{"} + \text{"}Subsidence3.tif\text{"}) / 3 \quad \ldots\ (ii)$$

The curves display notable discrepancies in subsidence levels. Peaks and valleys in the graph signify regions with elevated and reduced subsidence, respectively. This implies that subsidence does not occur uniformly across the four sections, with certain areas undergoing more significant sinking than others. The curve derived from section 1-1 (Bagar to Rithepani) and 2-2 (Baidam to Furse Khola) illustrates substantial variations in subsidence within Pokhara over short distances, whereas the curve from section 3-3 and 4-4 demonstrates a smoother trend compared to the previous sections.

The resemblances in fluctuations and the presence of peaks and troughs suggest shared influencing factors, while differences in intensity and complexity underscore the diverse nature of subsidence across distinct areas. The prominent peaks and troughs indicate that geological aspects, groundwater extraction, or human interventions may impact these disparities. Areas exhibiting higher subsidence levels (peaks in the graphs) necessitate enhanced monitoring and potential remedial actions to safeguard infrastructure and mitigate risks for residents.

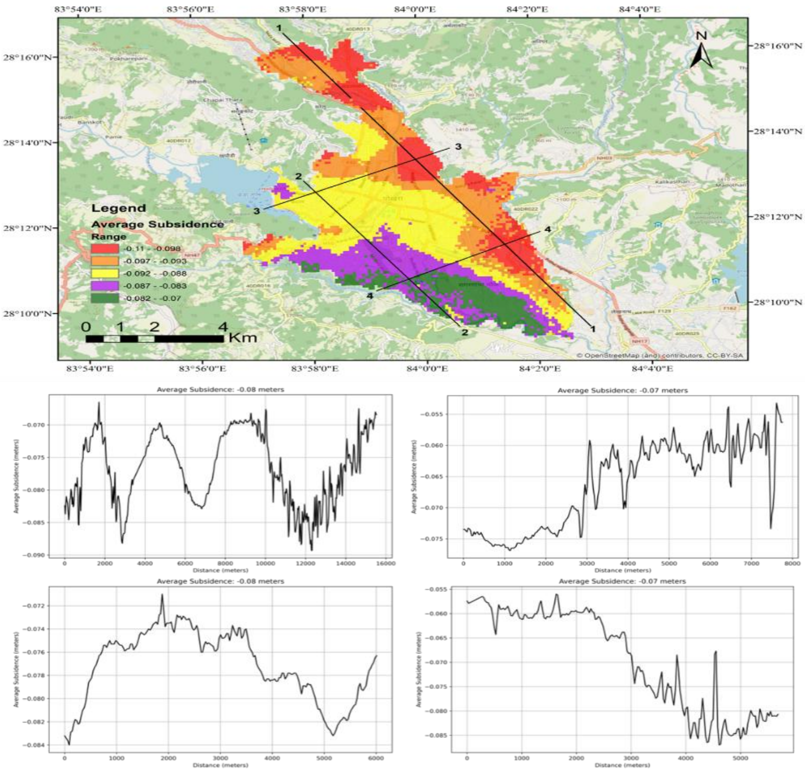



*Figure 5. a. Average subsidence pattern map, b. Profile of section 1-1, c. Profile of section 2-2, d. Profile of section 3-3, e.Profile of section 4-4*

Over 6.3 million square kilometers of the Earth's surface, which accounts for approximately 5% of the total global land area, is considered to be at risk of subsidence rates exceeding 5 mm per year, necessitating the implementation of mitigation measures to prevent damage. This finding is a result of previous research indicating that 12 million square kilometers of land surface were affected by subsidence rates of 430 mm per year. Within the more than 6.3 million square kilometers identified, 231,000 square kilometers were located in urban areas, where the population density indicates that around 2 billion people, constituting 25% of the global population, reside in these high-risk zones (Davydzenka et al., 2024). The pattern generated from this paper shows , pokhara valley is one of the among high-risk zones for subsidence, as the variation of subsidence is unregulated throughtout the regions.

Contributing factor to this subsidence is the narrow, deep channel of the Seti River, which has likely affected the river corridor area. Pokhara Vallley is an intermontane fluvial area that surrounds the middle section of the Seti River in Nepal's Lesser Himalaya. It is covered with a vast volume of layered Quaternary clastic deposits (gravel, silt, and clay) delivered from the Annapurna mountain range, most likely by a number of disastrous debris flows and the debris flows are caused by unstable geology, intensive habitation with weak structures in communities, unstable steep slopes and deep gorges, and excessive rainfall (Yamanaka et al., 1982). Precipitation is highest in Pokhara and during the rainfall because of this steep slopes the gorges are formed that contibutes the erosion, followed by debris flows could be potential reason for subsidence phenomenon.

Few sections of Pokhara are made up of laterally continuous, several meter-thick, poorly sorted, clast-supported conglomerates with no current features, which are thought to be deposits that settled quickly during fully turbulent, sediment-laden flow (Schwanghart et al., 2016). During heavy rainfall, water easily get infiltrate due to this type of soil property and geology. At the evaporation process the calcarious part of soil get dissovled, causing the sinking, could be the another possiblities of the land subsidence. The presence of pots and sinkholes, particularly in the Armala area (northeast of the study area), provides further evidence of the subsidence observed.

The variability in subsidence rates across different locals highlights the impact of urbanization, like infrastructure development, on subsurface stability, and land use. As urban area in Pokhara is growing with rate of 13.2% (Raut et al., 2020) . The demand for water is increasing, which leads to the extraction of water via deep tubewells. Bhattarai et al. (2017) discovered that the number of wells is denser in the central section of Kathmandu, where subsidence is greatest that indicates the higher subsidence is likely to be occurred in urbanized area of Pokhara.

However, the exact causes of land subsidence in Pokhara Valley require further detailed investigation due to the complexity of the influencing factors. The accuracy of the results, derived from the reliable InSAR technique, can be further validated through land measurement data, field surveys, leveling exercises, and by examining existing literature on similar phenomena. This validation is crucial for the results to be effectively utilized in urban and infrastructure planning within Pokhara City.

While the subsidence patterns observed in areas with sinkholes, such as Armala, seem justifiable, it is important to note that the results have not undergone thorough validation. Errors from topographic phase removal may accumulate, potentially exaggerating the subsidence patterns. Therefore, further validation is required to ensure the practical applicability of the results, as unsubstantiated data may not reflect the actual conditions on the ground. The significance of these findings for urban planning and infrastructure management cannot be overstated, necessitating targeted interventions to mitigate risks to Pokhara City's built environment.

## Conclusion

In this study, a detailed analysis of land subsidence and uplift in Pokhara City from 2019 to 2022 using Interferometric Synthetic Aperture Radar (InSAR) techniques has been presented. The InSAR analysis, conducted at yearly intervals using the Sentinel Application Platform (SNAP) GIS platform, provided valuable insights into the changing topography of the region. The results revealed significant variations in subsidence rates over the study period. The average average rate of subsidence was found to be 0.091 m/year. The analysis also identified locations within Pokhara City that are highly susceptible to land subsidence, including Mahendra Cave, Bat Cave, Bagar, and Jumleti Khola. The subsidence results were not validated due to the lack of previous land subsidence measurement data and the difficulty in obtaining GPS data. Validation of the InSAR results through additional methods such as field surveys, land measurement data, and literature review is essential to ensure their accuracy and reliability. As the conventional way of performing an interferometric SAR is widely used worldwide, result should be acceptable. Nevertheless, due to limits in Phase decorrelation, processing Phase unwrapping error, and atmospheric aberrations, various new SAR algorithms have been created that provide higher accuracy and fewer analyzing errors.

This research, due to its limited number of studies in Nepal, could serve as a foundation for future research on Land Subsidence, its effects and planning for the mitigation. Urbanization and infrastructure development were found to exacerbate subsidence, highlighting the need for careful urban planning and management strategies to mitigate risks associated with land instability. By integrating these findings into planning processes and adopting proactive measures, stakeholders can work towards ensuring the resilience and sustainability of the city's infrastructure and environment in the face of ongoing environmental changes.

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