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GEOPHYSICS

Monitoring land subsidence in an urban area of Tamilnadu, India using SAR time series data

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ABSTRACT

PS-InSAR (Persistent Scatterer Interferometric Synthetic Aperture Radar) technique is one of the most effective methods for detecting land displacement in selected areas. It combines the advantages of radar interferometry and remote sensing, and it is based on long-term coherent radar measurements collected from the SAR (Synthetic Aperture Radar) images. As for this specific study, 186 Sentinel-1 images were collected in the study area from 2016 to 2022. The authors used well-known SARPROZ software to process PS-InSAR techniques. The measured rate of cumulative displacement in this region was close to -60mm/year. On the contrary, the remaining areas of the study area experienced lower subsidence rates or no subsidence compared to the urbanized part. It demonstrated that high levels of urbanization and industrial activities led to high subsidence in the urban part of the study area, with the rest showing low or no subsidence at all. The results of the research highlight the necessity of planning concerning groundwater management to mitigate the nefarious implications of over-extraction. Sustainable practices can be implemented; however, ensuring stability and sustainability in the face of urbanization and industrial development is the key.

Keywords: SAR, PS-InSAR, Subsidence, SARPROZ

Monitoreo del hundimiento de tierra en una área urbana de Tamilnadu, India, a través de datos temporales del radar de apertura sintética

RESUMEN

El radar de apertura sintética interferométrico de dispersión persistente es uno de los métodos más efectivos para detectar el desplazamiento de tierras en áreas seleccionadas. Este combina las ventajas del radar interferométrico y la detección remota, y se basa en mediciones de radar coherentes a largo plazo recopiladas a partir de imágenes SAR (radar de apertura sintética). Para este trabajo en específico se recolectaron 186 imágenes del satélite Sentinel-1 en el área de estudio entre el 2016 y el 2022. Los autores usaron el software SARPROZ para aplicar el método de radar de apertura sintética interferométrico de dispersión persistente. El ritmo medido de desplazamiento acumulativo en la región fue de -60mm por año. Por el contrario, las áreas de la zona de estudio que no están urbanizadas experimentaron rimos de hundimiento muy bajos o de no hundimiento. Esto demuestra que los altos índices de actividades urbanísticas e industriales conllevan a un alto índice de hundimiento en las zonas urbanas del área de estudio, mientras las otras partes no tienen hundimiento o es muy poco. Los resultados de la investigación resaltan la necesidad de una planeación y administración de las aguas subterráneas para mitigar los efectos de la sobreexplotación. Se pueden implementar prácticas sostenibles; sin embargo, la clave está en asegurar la estabilidad y sostenibilidad en el desarrollo urbanístico e industrial.

Palabras clave: radar de apertura sintética; radar de apertura sintética interferométrico de dispersión persistente; hundimiento; SARPROZ

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1. Introduction

Subsidence, a geological phenomenon in which the ground surface sinks or settles, can have a far-reaching impact on structures, infrastructure and the environment. While typical natural causes such as tectonic plate movement and subsurface cavern erosion contribute, anthropogenic activities such as mining, construction, and groundwater extraction can significantly influence their prevalence. Subsidence is costly, dangerous and damaging, illustrating the value of careful planning and stewardship of natural resources.

In addition, areas of substantial coal, ore, or other mineral extractions are more prone to subsidence (Gupta et al. 2020; Ishwar et al. 2017; Guang et al. 2009; Miao et al. 2008).A prevalent phenomenon of land subsidence is due to a number of underground mining operations including the excessive exploitation of coal, minerals, groundwater, and petroleum products as well as the collapse of existing galleries and the flooding of abandoned ones (Jianjun et al. 2012; Chatterjee et al. 2006). Natural and human activities can both lead to land subsidence. Natural and anthropogenic causes of land subsidence include: urbanisation, construction, earthquakes, volcanic deformation, sediment compression, land subsidence and extraction of ground and surface water. Some soil properties such as organic matter content, soil structure etc. may influence land subsidence (Jalayer et al. 2023; Tariq et al. 2023; Majeed et al. 2023). Pacheco-Martínez et al. (2013) Land subsidence causes destruction of environment urban infrastructure, loss of valuable resources, puts human life and daily activities in danger; causes to the economic crises and road blocking.

Ferretti et al. (2000) introduced the PS-InSAR technique, which is capable of detecting land deformation at a precision level of millimeters. In recent years, as explained by Crosetto et al. (2016), the use of the PS-InSAR technique has successfully eliminated temporal and geometric decorrelation within SAR data with the help of the identification of persistent scatterers having consistent and stable behaviour over the full acquisition time-series, leading to enhanced temporal and geometric coherence PS-InSAR allows for the rejection of atmospheric interference effects by utilizing a multi-temporal time-series of SAR data, which can be seen in papers presented by Ferretti et al. in 2001 and by Davila-Hernandez et al. in 2014 Perissin and Wang (2012) developed an innovative PSI known as modified PS-InSAR incorporating both permanent and partially correlated scatterers. By introducing partially correlated scatterers, they sought to increase the point target density inside the highly sensitive area and decrease the decorrelation effect. Using the C-Band and L-Band SAR data, Gueguen et al. applied the PS-InSAR technique to determine the deformation of the ground in coal bearing regions. (2009), Abdikan et al. (2011; 2014), Jiang et al. (2011), and Thapa et al. (2016). Such results of PS-InSAR are in good agreement with GPS measurements. This would suggest that the two methods are quite similar to each other, C 2018 by Society, when applying to the field of deformation data with PS-InSAR being fairly accurate and out of GPS observations, giving quite an accurate output. This will be beneficial in building confidence in results used in geospatial studies (Dumka et al. 2020). Deformation and crustal strain were estimated using GPS-derived velocities (Dumka et al. 2022). GNSS as a great tool to investigate the deformation pattern in the central mainland Kachchh. It is used to accurately record the soil oscillations and changes so that scientific fraternity can understand the geodynamic processes in the area (Suribabu et al. 2022). Khorrami et al. (2020), Mahmoodinasab et al. (2021) proposed the use of PS-InSAR technology for efficient land subsidence monitoring and directly confirmed the synergy between groundwater extraction and ground subsidence. Xiong et al. (2021) demonstrated PS-InSAR analysis for the displacement measurement of the HZMB based on displacement observations collected by Sentinel-1A. The findings from Bock et al. The PSI technique was also proved to be extremely efficient in estimating the displacement in the study of Liao et al. Bakon et al. (2016) have shown well the useful of sharing multi-sensor data throughout the InSAR technique for land subsidence estimation. Significant procedures utilized for the investigation and checking of progressions on the Earth's surface incorporate SAR, InSAR, PS-InSAR, and D-InSAR (Sahu et al. 2023). The PS-InSAR method generates high-resolution surface displacement maps by using long-term coherent radar measurements from SAR images (Sahu et al. 2025).

According to Dumka et al. (2023), Kachchh earthquake 2001, GPS and InSAR data have a significant contribution toward understanding the underlying tectonic processes. The focus of Tripathi et al. (2022), this has been extended to covering aerial and spaceborne SAR remote sensing modalities on soil health studies adopting multiple monitoring and parameter modeling approaches over various soil classes and subclasses. According to Malik et al. (2019), is a remote sensing technique that facilitates estimating the ground subsidence with a good accuracy and resolution. The need for minute and progressive measurements of ground height variations on a time-scale necessitates the use of a technique that can provide relative and accurate measures on the order of micrometers, and as such is an effective technique to the required measurements. According to Kumar et al. (2020), the efficacy of the modified PSI approach to detect land subsidence in vegetated and rural areas is not yet established. Raju et al. (2022), in of reduced-cost Persistent Scatterer Interferometry to establish the slumping of land that is happening as demand on ground water increases in Lucknow in north India. According to Tripathi et al. (2021), as stated in remotely sensed SAR data is very flexible for flood study because it can penetrate through various barriers and possesses considerable periodic availability of data and resists rain. The study of temporal changes in groundwater levels is straightforward using the Gravity Recovery and Climate Experiment (GRACE) satellite sensor (Tripathi et al. 2022). SAR remote sensing has gradually gained more popularity due to its very reliable means of analyzing different natural and anthropogenic catastrophic events (Tripathi et al. 2023).

Due to the extensive damage to buildings and structures as well as land displacement in Kanchipuram, its ancient temples built on unstable land and the region's flourishing cultural legacy have also been affected. Moreover, over-extraction of groundwater has led to soil subsidence in Chennai, Tamil Nadu, which adjoins Kanchipuram. This study aims to help detect and track ground subsidence along the Tamil Nadu coastal region using InSAR technology. This will provide stakeholders and decision makers with key information they need to manage and protect the coastal ecosystem. The Kanchipuram district has never before seen any research being conducted on ground sinking. Using subsidence analysis, we can effectively control and mitigate the risks associated with land subsidence.

2. Study area

The major river traversing the region of study is derived from the basin of the Palar river. The Palar has two small tributaries called Vegavathi and Cheyyar rivers. Kanchipuram soil type: The soil type available in Kanchipuram include clay, loam, sand, & silt soil. This makeup is an important factor in the land use, agriculture, the region. Located along the western fringes of the dynamic, continually moving Indo-Australian plate edge west as it ascends towards the eastern coastline of India, Kanchipuram sits within the intersection of tectonic destruction and accumulation. And so the region has already had some big quakes like the 2004 Indian Ocean earthquake which was very deadly. This caused widespread ground displacement and considerable damage to infrastructure. One of the potential environmental problem to threaten the Kanchipuram is declining groundwater. The increased use of water for industrial, residential and agricultural purposes has caused a subsequent decline in the groundwater level of the city. Its significant impact on the local ecosystems and population, and dire consequences on the sustainability of its water resources. Kanchipuram is also greatly affected by the increase in groundwater levels due to the monsoon rains. Sufficient monsoon rainfall both replenishes the underground water reservoirs and keeps a proportional water supply available. But, another factor Hamadalavalla said was the erratic nature of rainfall in dry season affected groundwater levels. Implementing sustainable water management principles is an important solution. method of addressing sustainable water management principles_PARAM gregorio water sustainable sustainable water management sustainable water management sustainable sustainable Some of these issues can be resolved by implementing sustainable water management methods. Such as water reuse, efficient irrigation, and rainwater harvesting, which are used to conserve a limited water supply and make the utmost of its use.

In addition, educational programs and awareness campaigns have been initiated to promote water sustainability at the local level. Check the map of the study area in the Fig. 1.

Geology of the study area

The geology of Kanchipuram district shows a wide range of rock formations and soil types (Fig. 2). Geology data of the study area collected from Bhukosh. The district is located on the eastern side of the Archean granitic basement complex of Peninsular India. The dominant rock group in the area is the Charnockite group, which includes granitic gneiss, charnockite, and migmatite. These rock formations have greatly influenced the district's landscape. Besides, Kanchipuram district has many mineral deposits that have contributed to its economic development. Bauxite, a significant mineral used in aluminum production, is found in the villages of Koodalur and Reddipalli. Limestone deposits, which have versatile industrial applications, are located in the villages of Ramasamudram and Sankarapuram. The existence of these mineral deposits has, therefore, encouraged mining activities in the district, making it economically sound.

The diversified and complex geology seen in the Kanchipuram district is adding a major impact on its overall landscape and natural resources. The features of geology have provided fertile land for agriculture hence making the district have a well-settled agricultural industry. Moreover, the presence of these mineral deposits has spurred the mining activities and therefore enhanced the local economy. Regarding the information, it contained, saying Fig. 1B shows a geological map of the study area. Even describing the map and its contents is difficult without access to the actual figure. The map likely illustrates the distribution of various rock formations, mineral deposits, and other geological features within the district, providing valuable insights into its geological composition. Kanchipuram district stands as a testament to the diverse and intricate interplay between geology, landscape, and economic activities. The district's unique geological characteristics have shaped its topography, supported agriculture and mining, and contributed to its overall development.

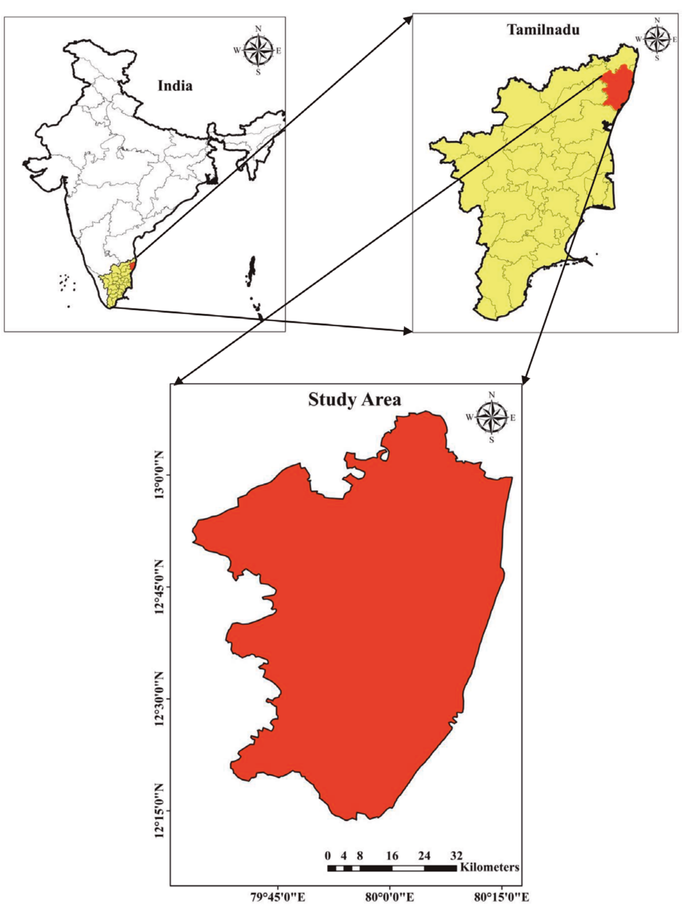


Figure 1. Study Area map

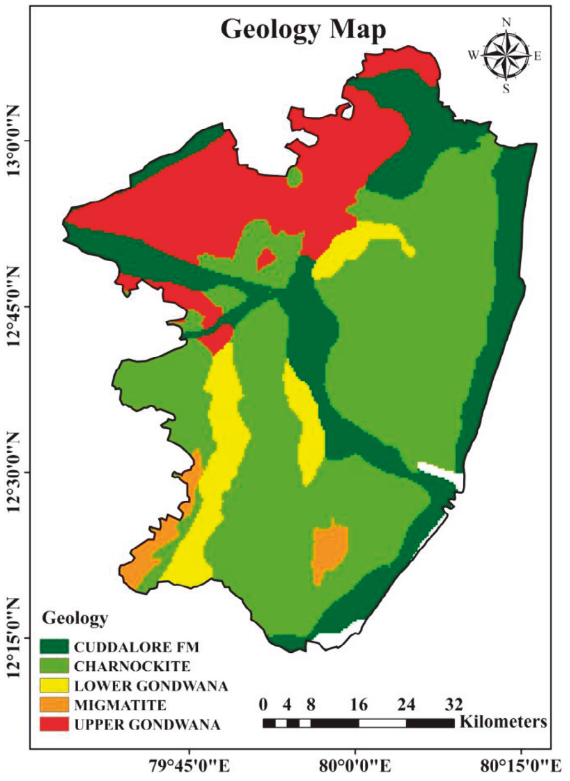


Figure 2. Geology Map of the study area

3. Datasets

The data filters describe the desired parameters for the Sentinel-1A (SA) satellite imagery data that is available. It specifies the file type, which is L1 SLC (single look complex), a format of radar data which, unlike interferometric data, retains both amplitude and phase information. This format is commonly used by applications that need advanced radar. All 186 pictures from 2016–2022 were obtained from the Alaska Satellite facility (ASF-Vertex).

The specification for the beam mode is Interferometric Wide Swath. This mode can provide wide area coverage during data collection, which could be beneficial for applications such as land monitoring, disaster management, and maritime surveillance. Set direction: Descending → This is the orbital direction of the satellite when collecting data, which in our case is descending; set polarization: VV+VH → The data must content both VV (Vertical-Vertical) and VH (Vertical-Horizontal) polarizations. If the flight of the satellite is descending, it is flying from north to south. This orientation should be considered when comparing data from different acquisitions and tracing temporal dynamics. Subtype, frame no of Sentinel-1A dataset (547,548,549 and 550). Table 1 describe the details about datasets.

Table 1. Datasets

Data filters	Details
File type	L1 SLC (Single Look Complex)
Beam mode	IW
Polarization	VV+VH
Direction	Descending
Subtype	Sentinel-1A (SA)

4. Methodology

SARPROZ software uses PS-InSAR techniques to process SAR data. This software can handle large time series data. According to Crosetto et al. (2015), a minimum of 20 SAR images in C-band data is required for PSI techniques in the monitoring process. The selection of a master image is essential for processing the PS-InSAR techniques.

The PS-InSAR processing is carried out in several steps to produce accurate and reliable deformation maps, as shown in Fig.3. Co-registration is the first step, where the SAR images are aligned to a common reference point, allowing for accurate measurements of surface deformation. Then, reflectivity maps, as shown in Fig.4, and amplitude stability index maps are prepared to identify areas with stable radar reflectivity and low noise levels, respectively. Reflectivity Map shows reflectivity values for various regions that indicate surface properties and changes in land cover. This is of significant importance as it gives the spatial distribution of reflectivity, which is an important aspect in determining the underlying surface characteristics. From these maps, PSs are selected based on their coherence and stability characteristics. Multi-image sparse grid phase unwrapping is performed to resolve the phase ambiguity and get accurate deformation measurements. APS analysis and removal are carried out to correct atmospheric disturbances that may affect SAR measurements. Then, PSC phase reading and displacement estimation to calculate the difference in phase for slave and master images and provide an estimate for the deformation map. Spatial-Temporal baseline with respect to master image, Fig.5.

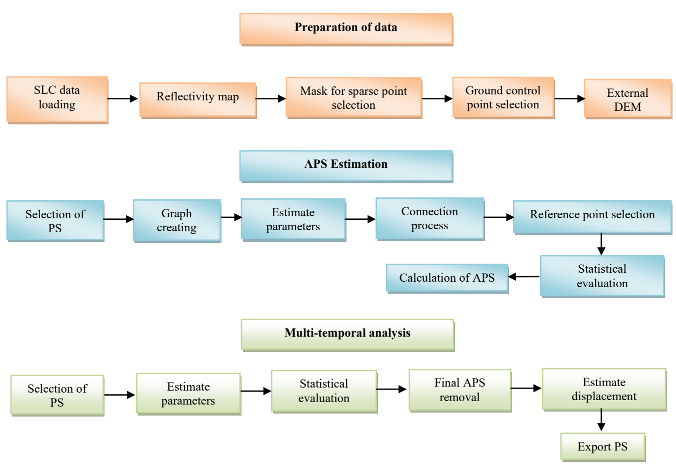


Figure 3 Methodology flow chart of SARPROZ software

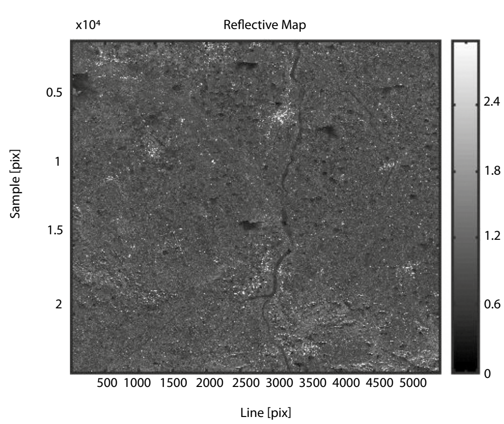


Figure 4 Reflectivity Map

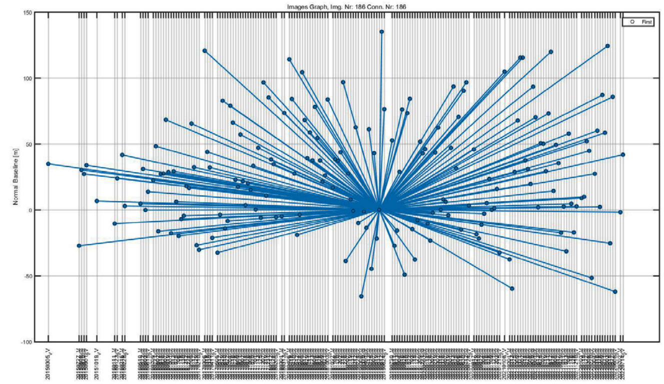


Figure 5 Temporal base line

APS Estimation

APS estimation involves a multi-step process, which accurately estimates the position and properties of sparse points from a dataset. It uses sparse point selection, Delaunay graph connection, connection coherence graph, automatic reference point determination, parameter estimation, connection velocity histogram, connection height assessment, and connection residual height analysis to estimate the parameters. Each of these processes is necessary for accurate and reliable APS estimation.

Sparse point selection plays a primary role in the estimation of APS (Fig. 6A). This means choosing a small segment of points in the dataset that have certain features or characteristics. These selected sites make up the basis for additional estimation and analysis. Once, sparse spots of key points are identified, the Delaunay graph Connection approach is used. (Fig. 6B). By connecting the sparse points, Delaunay triangulation forms a network of interconnected triangles. This relationship allows for a deep understanding of the fundamental framework and lends itself to examining how spaces relate to one another. The connectivity analysis is further teed up by extracting a link coherence graph (Fig. 7). This graph helps you visualize the consistency of connections between nearby points and it is possible to identify potential outliers or wrong connections. Considering the total coherence enhances and stabilizes the APS estimation. Subsequent step is to find automatic reference (Fig. 8). Such a reference point allows for accurately pinpointing the sparse locations in the dataset by serving as a baseline to the estimate procedure. A selection of the automated reference point is made based on predefined standards or algorithms that consider the overall characteristics and distribution of the dataset.

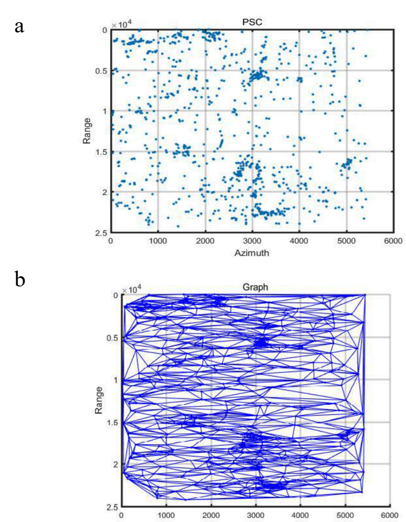


Figure 6. (A) PSC sparse point selection and (B) Delaunay graph connection

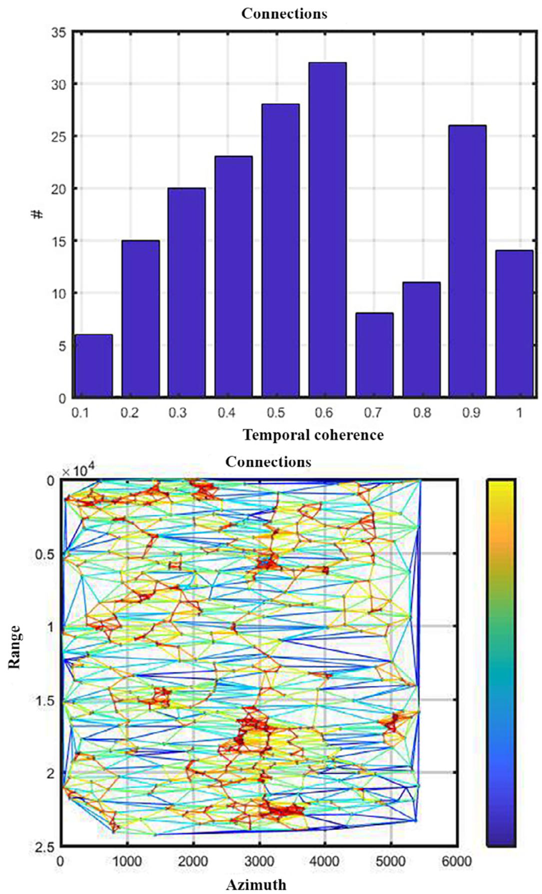


Figure 7. Connection Coherence graph

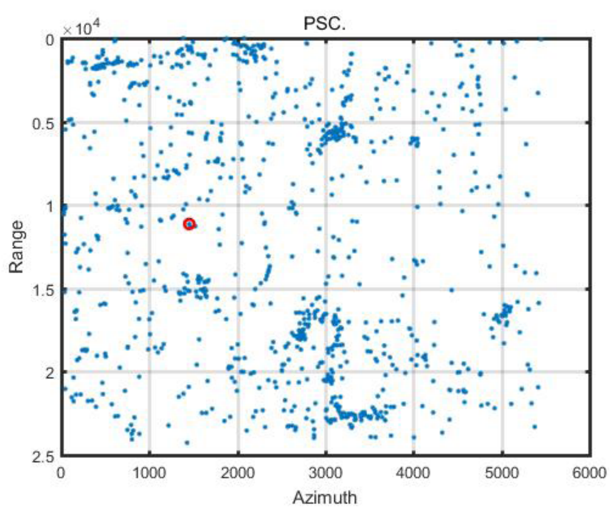


Figure 8. PSC reference point

Once a baseline has been established we can proceed to parameter estimation. This is the step in which it estimates multiple properties of the sparse points, including scale, rotation, and location. These metrics are valuable insights for further analysis and used to characterize fundamental statistics of the dataset. are computed in Figures 9A and 9B and defined for integrated velocity and integrated cumulative displacement, respectively. To examine the connection velocity, a histogram is constructed based on the connections between the sparse locations (Fig. 10). This histogram helps to find trends or patterns in the displacement of the points, visually. It helps to build a more enriched view of the dataset as a whole. Height of Connections assessment (a.k.a. Elevation of links) determines the height or elevation of connections between sparse labels. However, for Applications requiring the bodies of water, earth surface, buildings and etc. like terrain model or geospatial analysis, this method may be a great help as it retains the vertical relationships of the data.

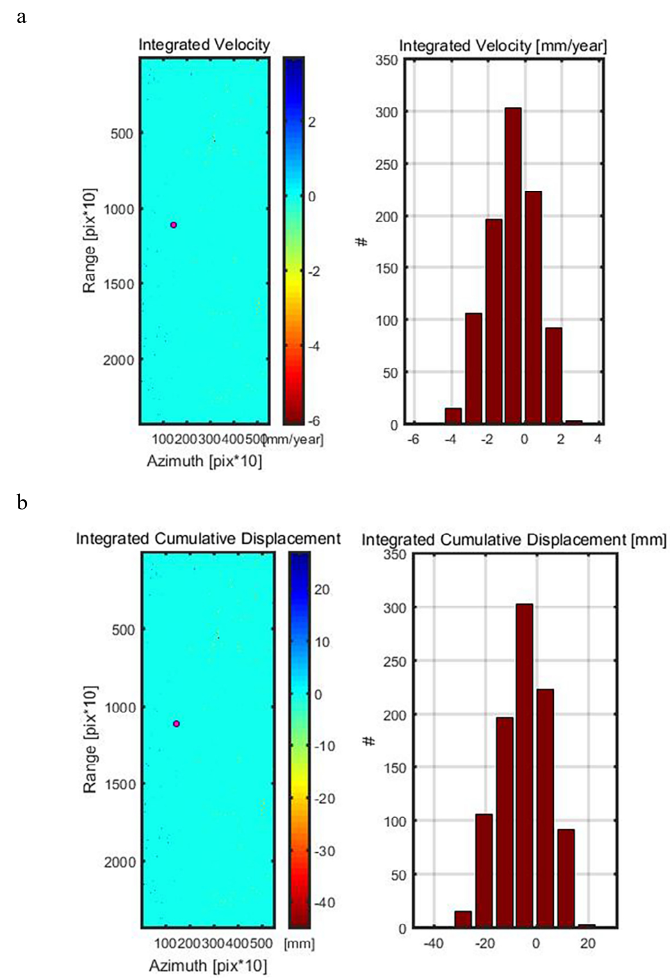


Figure 9 (A) Integrated velocity, (B) Integrated cumulative displacement

Finally, residual height analysis of connections is applied to evaluate the accuracy of the calculated heights (Fig. 11). Residual height is defined as the deviation between the real height of the dataset and its estimated height. The estimation of APS is shaken by the heights of the residues to the lines, which can be evaluated for their quality and reliability, with adjustments if needed.

The coherence for each slave date from its associated master date, once the estimating APS has been removed, is shown in Fig. 12. As shown in Figs. 13A and 13B.

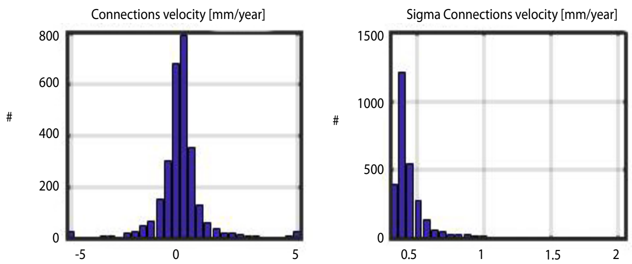


Figure 10 Connection velocity

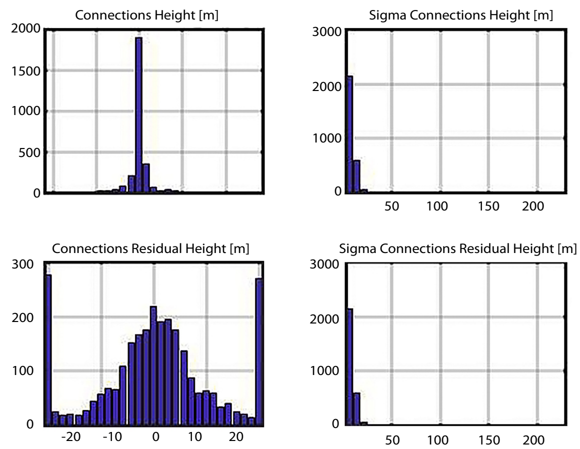


Figure 11. Connection height and residual height

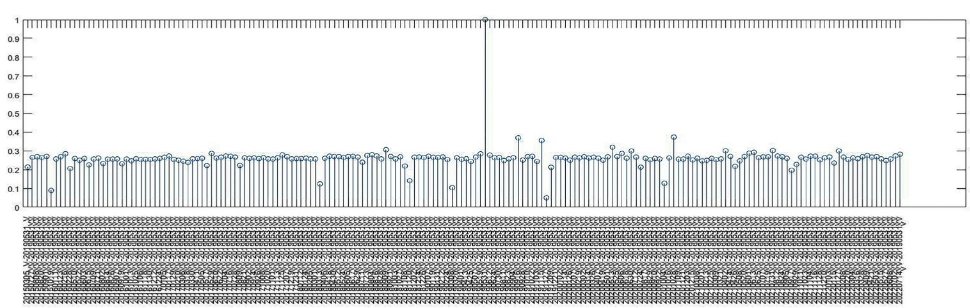


Figure 12 Coherence between each slave date and master date

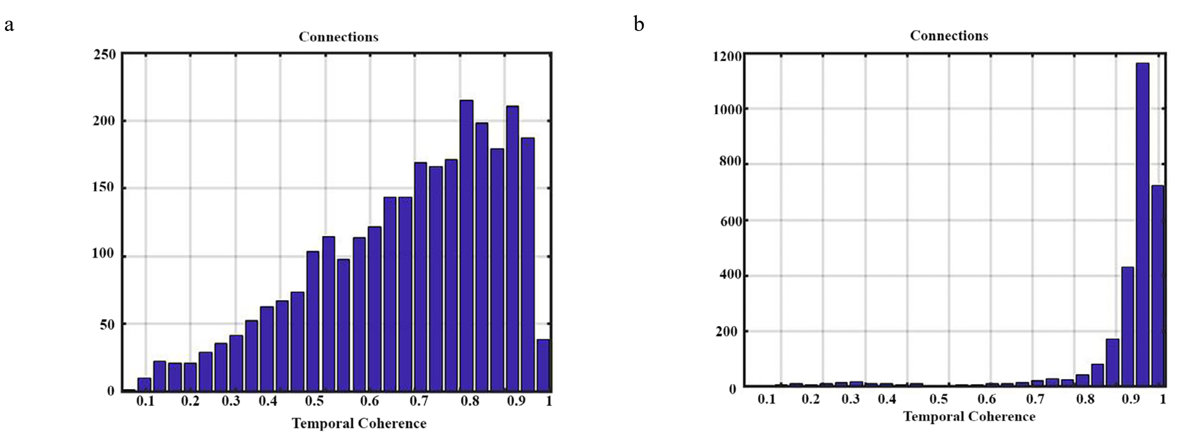


Figure 13 (A) Before APS removal, (B) After APS removal

Multi-temporal analysis

Multi temporal analysis is a strong approach to get valuable information from spatio temporal data. Sparse point processing (Fig. 14A), point processing histogram (fig. 14B), the estimated velocity (Fig. 15A) and cumulative displacement (Fig. 15B) for individual points, the estimated height (Fig. 16A), and residual height (Fig. 16B) This method encompasses everything, from specific points to the other key features. Now, let us look into each of those components closely. Sparse point processing is an important step of multi-temporal analysis. This involves acquiring remote sensing data over different time periods and the extraction and transformation of specific points or features. These dots can represent different types of landforms, vegetation, buildings, and other features present on the Earth's surface. By detecting and analyzing these few points, we are able to follow changes over time and detect salient trends. A more comprehensive understanding of the temporal dynamics is achieved through the sparse point processing histogram. Then, histograms are constructed that display the frequency distribution of specific point properties (e.g., spectral values, geometric features, etc.) on multiple temporal data sets; with this method. On the other side, these histograms give insight into trends like temporal seasonality, outliers, global shifts in variable distributions, etc. Significant differences are readily observable, and their critical findings can be concluded. It is another essential building block in multi-temporal studies, where you are interested in estimating velocity and accumulated displacement at specific times. If we compare the positions of certain locations over several time steps, we can obtain the velocities and cumulative displacements of some areas. This data provides key insights into the magnitude and direction of any activity or shifts occurring in the selected geographies. Examples: This research may lead to recommendations that help in locating subsets of terrain that are prone to landslides, erosive behavior or any other kinetic evolution in geomorphology or ecological dynamics. Moreover, estimating height and residual height helps to gain insight into vertical differences across the study area.

a

b

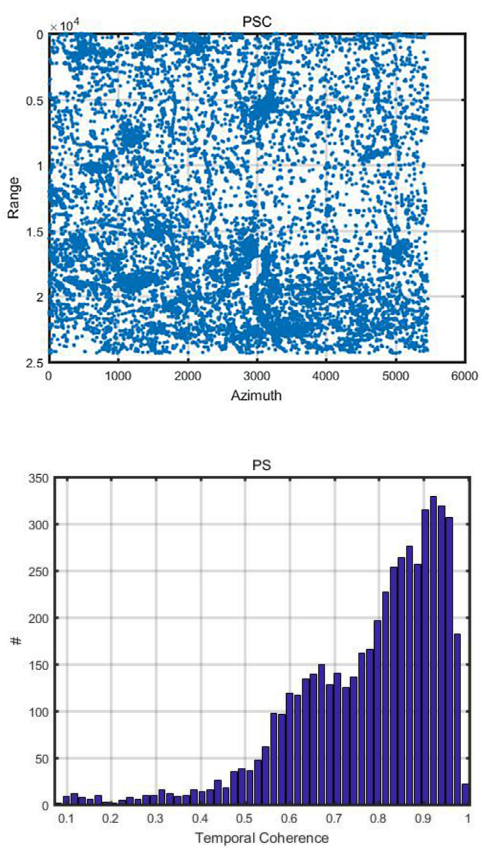


Figure 14 (A)Sparse point processing (B)sparse point processing histogram

a

b

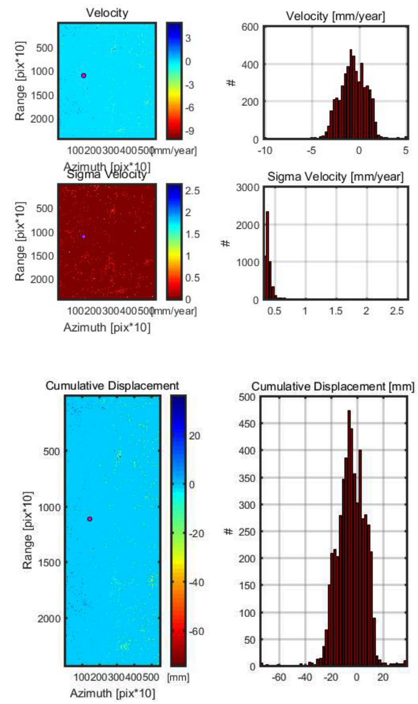


Figure 15 (A) Estimated velocity, (B) Cumulative displacement

a

b

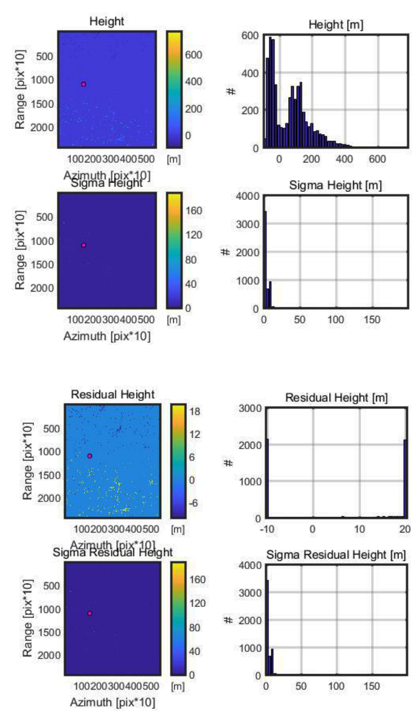


Figure 16 (A) Estimated height, (B) Residual height

5. Result and Discussion

186 SAR images captured from 2016 to 2022 were analyzed to construct a detailed land subsidence map using the complex SARPROZ software. The map served as a visual guide indicating that land subsidence took place within the defined study area. We constructed a robust tool called the Connection Coherence Graph to rapidly visualize the temporal coherence for pairs of SAR

acquisitions. This graph provided an overall picture of the relationships between different SAR acquisitions over time. All SAR acquisitions were represented as distinct nodes in the graph, illustrating their own unique characteristics and features. To highlight the strength of associated SAR the connecting lines were used to visualize the coherency between two nodes.

For the interpretation of Connection Coherence Graph the thickness and color of the connecting lines were used to provide salient information about the coherence values. In this way, researchers to locate and investigate the most relevant relationships with respect to the dataset by assigning thicker and darker lines to denote a higher degree of coherence in the corresponding SAR acquisitions. As shown in Fig. 17 by means of a Scatter Plot module which was figured out to help in examining the coherence correlations. This allowed us to create the scatter plot graphically, with each point being a unique SAR acquisition. The distribution and patterns of these locations could help researchers understand much about the coherence characteristics and changes over time. This information played a vital role in identifying any inconsistencies or major deviations in the dataset.

A final coherence histogram was obtained to provide a comprehensive description of the coherence distributions over the area of study (Fig. 18). The histogram made it easier for the researchers to identify the relative significance of different coherence values, and to detect any significant trends or outliers that might have arisen during the investigation by displaying the frequency distribution of coherence values.

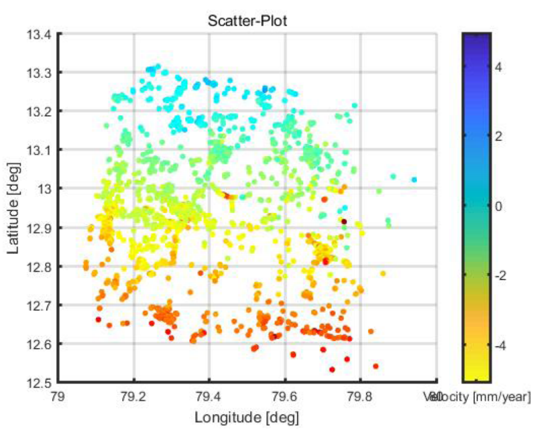


Figure 17 Scatter plot

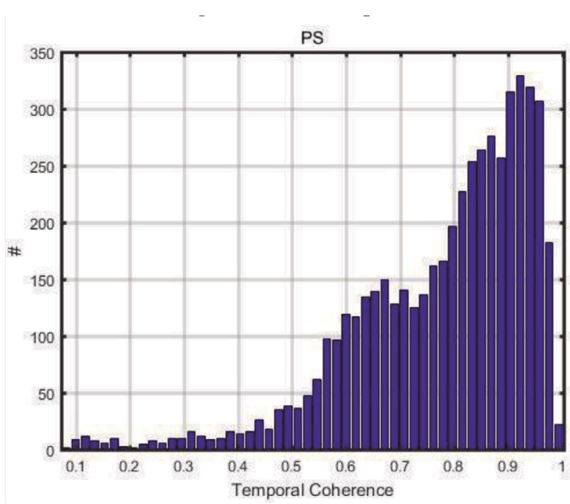


Figure 18 Final coherence histogram

Based on the beast evidence, the subsidence phenomena was most active in the Kanchipuram urban area. The affected area was visualized on Google Earth (Fig. 19). A deeper dive into the data indicated that, the max cumulative displacement observed from 2016-2022 was -60mm (Fig. 15B). Cumulative displacement: Total distance travelled by an object from its original position in a given time. The cumulative displacement for the region was found to be a rate of −60mm/yr. The cumulative displacement vs time plot also known as the integrated displacement graph, one of the widely used plots in SARPROZ, was created by plotting accumulated displacement on the y-axis and time on the x-axis. This graph allowed to visualize the evolution in time of the accumulated displacement for a point of interest through all the time period covered by SAR data. Fig. 20, demonstrating the time series subsidence trend of various points from the beginning of study period.

Two important parameters affecting the processing and interpretation of SAR data within the SARPROZ software package are connection velocity and sigma collection velocity. What these values are will depend on coherence level, time between acquisitions and how quickly you want the processing done. The connection velocity dictates the number of connected interferograms, while the sigma collection velocity impacts the point spread function of the sigma values. As shown in Fig. 15A, for the current study, the best prognosis velocity was additionally assumed to be -10 mm/year. If the expected velocity is negative (-10 mm), it means the ground surface is lowering or compacting at a rate of 10 mm per year. While this rate may not seem especially high at first, over time even gradual rates of subsidence can lead to serious impacts that include more flooding, damage to infrastructure and buildings, and a loss of agricultural land. The region's urbanization and excessively exploited groundwater were the two identified causes of the subsided area and deteriorating groundwater resources, according to the investigation. The case highlights the role human activity plays in incidence of subsidence and the vital importance of managing urban expansion and water resource consumption to mitigate associated risks.

The analysis not only focuses on the time series of the specified point to obtain this quantity, but also considers other relevant additional parameters. Such metrics are temporal coherence (which measures data similarity over time) and other parameters, such as residual height (height difference to a reference point) and velocity (how fast an object changes position in space over time). These parameters are important for understanding the characteristics, patterns, and behavior of the object of study. Median subsidence rates provide valuable insights that can inform researchers in making educated decisions regarding construction methods of infrastructure (e.g., drainage systems), revise land use strategies (possibly based on subsidence trends), and manage water supplies more effectively. Finally, coupled with other geophysical techniques, the combination of subsidence monitoring from multimodal and multiscale perspectives using SAR contributes to a more comprehensive understanding of subsidence processes and the development of appropriate monitoring and management strategies.

Understanding subsidence events and their causes has been critical to enable sustainable development and protect infrastructure and human life. It is only possible to enhance our understanding of subsidence processes and to support decision-makers in implementing appropriate policies for minimising adverse effects by conducting in-depth investigations utilising state-of-the-art technologies and by considering a variety of aspects.

6. Conclusion

The most common method used to extract land subsidence is SARPROZ (SAR Data Processing and Interferometry) software, which is used in detail to construct a land subsidence map showing the various subsidence patterns in Kanchipuram district. Material and Methods The present study utilized the Connection Coherence Graph to display temporal coherence between SAR acquisitions, allowing the detection of correlations and anomalies. The scatter plot module and histogram of coherences provided additional views to assess coherence features and temporality, while thickness and color of connecting lines were associated with the level of coherence. The results revealed notable amounts of sinking over urban area, with a peak rate of subsidence of -60mm/year. This displacement is represented visually in Google Earth and corroborated using a cumulative displacement graph at Datum points to follow temporal development. Analysed parameters were connection velocity and sigma velocity, estimating a velocity of -10 mm per year, with main drivers being urban growth and excessive groundwater extraction. Residual height, as well as velocity and temporal coherence, were also analyzed to reveal how the subsidence occurred.

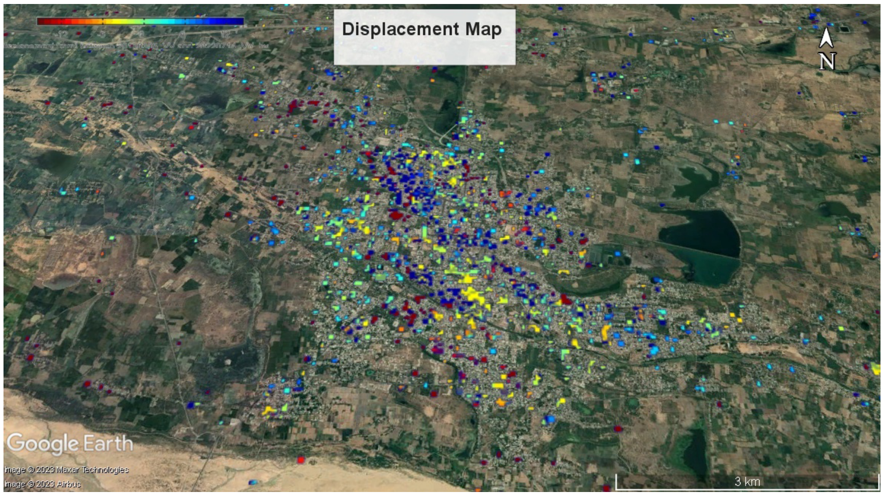
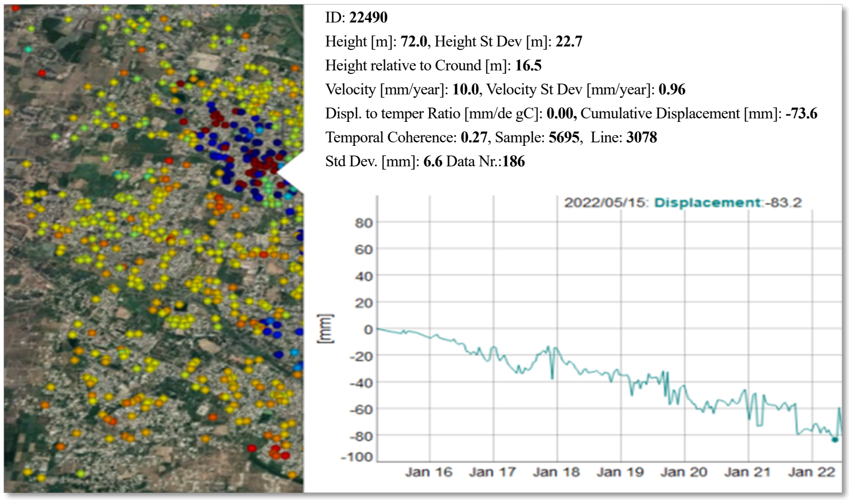
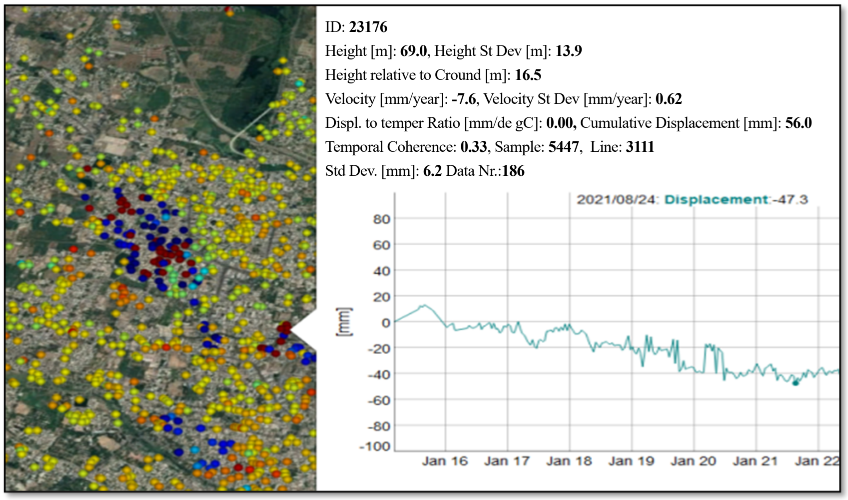


Fig.19 Displacement map of the study area

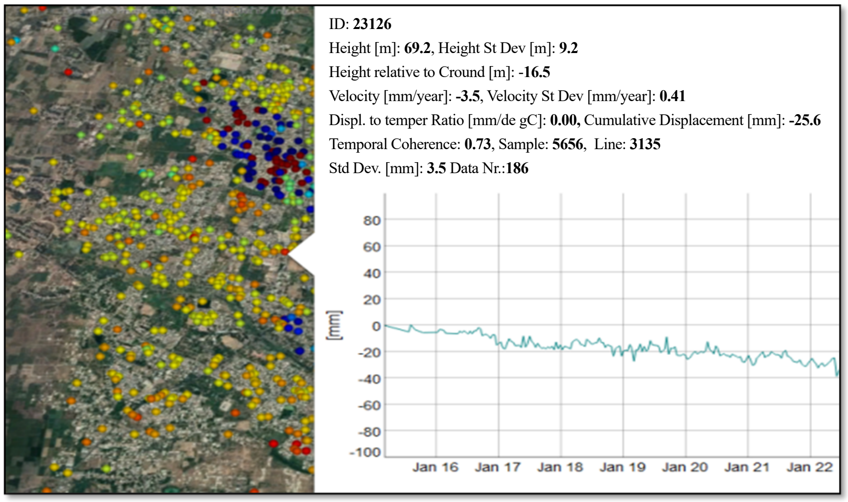
a



b



c



d

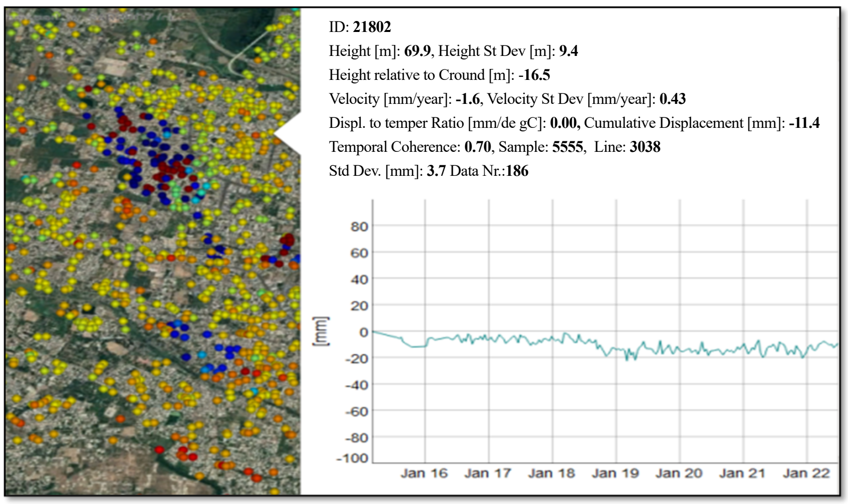


Figure 20. A, B, C & D are showing time series subsidence trend at three different points under the study period

The findings underscore an urgent need for sustainable land use and water management. The Tamil Nadu government aims to mitigate subsidence through measures like limiting groundwater extraction, rainwater harvesting and selling treated sewage water to farmers for irrigation. But the residual subsidence shows we must continue to monitor and respond. The study's authors pointed to the adverse effects over-extraction of groundwater can have on the stability of the land, and also noted the need for urban expansion control strategies that don't threaten infrastructure. The research demands implementing innovative geospatial technologies and integrated studies, in order to diminish the risk of subsidence, protecting communities and enabling sustainable development too. The study functions as a reminder of the consequences of uncontrolled groundwater extraction, and the need to reverse land subsidence through urban ecology and sustainability knowledge.

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References

Abdikan, S., Arikan, M., Sanli, F. B., &Cakir, Z. (2014). Monitoring of coal mining subsidence in peri-urban area of Zonguldak city (NW Turkey) with persistent scatterer interferometry using ALOS-PALSAR; Environ. Earth Sci. 71 4081–4089.

Abdikan, S., Hooper, .A, Arikan, M., Balik, S. F., Cakir, Z.,&Kemaldere, H.(2011). InSAR time series analysis of coal mining in Zonguldak city, Northwestern Turkey; In: Fringe Workshop.

Akshar, T., &Reet, K. T.(2022). Synergetic utilization of sentinel-1 SAR and sentinel-2 optical remote sensing data for surface soil moisture estimation for Rupnagar, Punjab, India, Geocarto International, 37:8, 2215-2236, https://doi.org/10.1080/10106049.2020.1815865.

Amelung, F., et al.(1999). Sensing the ups and downs of las vegas: insar reveals structural control of land subsidence and aquifer-system deformation. Geology, 27(6), pp.483-486.

Ashwani, R., Ritika, N., Anjali, S. &Kapil, M.(2022). Multi-temporal analysis of groundwater depletion-induced land subsidence in Central Ganga Alluvial plain, Northern India, Geocarto International, 37:26, 11732-11755, https://doi.org/10.1080/10106049.2022.2060322.

Bakon, M., et al.(2016). Multi-sensor InSAR deformation monitoring over urban area of Bratislava (Slovakia). Procedia Comput Sci. 2016;100:1127–1134.

Bock, Y., Wdowinski, S., & Ferretti, A.(2012). Recent subsidence of the Venice Lagoon from continuous GPS and interferometric synthetic aperture radar. Geochem GeophysGeosyst. 2012;13:Q03023.

Chatterjee, R. S.(2006). Coal Bre mapping from satellite thermal IR data – a case example in Jharia Coalfield, Jharkhand, India; ISPRS J. Photogramm. Remote Sens. 60 113–128.

Crosetto, M., Devanthery, N., Cuevas-Gonzalez, M., Monserrat, O., &Crippa, B.(2015). Exploitation of the full potential of PSI data for subsidence monitoring. Proc. IAHS 2015, 372, 311–314.

Davila-Hernandez, N., Madrigal, D., Exposito, J. L., & Antonio, X. (2014). Multi-temporal analysis of land subsidence in Toluca Valley (Mexico) through a combination of Persistent Scatterer Interferometry (PSI) and historical piezometric data; Adv. Remote Sens. 3 49.

Dumka, R. K., Prajapati, S., SuriBabu, D., Swamy, K. V., Kothyari, G. C., & Malik, K.(2023). GPS and InSAR derived evidences of intra-basin stress and strike-slip tectonics in the vicinity of 2001 (M7.7) earthquake, Kachchh, western India. Geological Journal, 58(2), 683– 699.

Ferretti, A., Prati, C., & Rocca, F. (2001). Permanent scatterers in SAR interferometry; IEEE Trans. Geosci. Remote Sens. 39 8–20.

Ferretti, A., Prati, C., & Rocca, F.(2000). Nonlinear subsidence rate estimation using permanent scatterers in differential SAR interferometry; IEEE Trans. Geosci. Remote Sens. 38(5) 2202–2212.

Guang, L., Huadong, G., Xiaofang, G., Perski, Z. and Huanyin, Y.(2009). Mining area subsidence monitoring using multi-band SAR data; In: Urban Remote Sensing Event, pp. 1–6.

Gueguen, Y., Deffontaines, B., Fruneau, B., Al Heib, M., De Michele, M., Raucoules, D., Guise, Y., &Planchenault, J. (2009). Monitoring residual mining subsidence of Nord/Pas-deCalais coal basin from differential and Persistent Scatterer Interferometry (Northern France); J. Appl. Geophys. 69 24–34.

Gupta, M., Mohanty, K. K., Kumar, D. and Banerjee, R.(2014). Monitoring surface elevation changes in JhariacoalBeld, J. Earth Syst. Sci. (2020) 129:146 Page 9 of 10 146 India using synthetic aperture radar interferometry; Environ. Earth Sci. 71 2875–2883.

Ishwar, S. G., & Kumar, D.(2017). Application of DInSAR in mine surface subsidence monitoring and prediction; Curr. Sci. 112 46–51.

Jalayer, S., Sharifi, A., Abbasi-Moghadam, D., Tariq, A., & Qin, S.(2023). Assessment of spatiotemporal characteristic of droughts using in situ and remote sensing-based drought indices, IEEE J. Sel. Top. Appl. Earth Obs. Rem. Sens. 16 (2023) 1483–1502, https://doi.org/10.1109/JSTARS.2023.3237380.

Jian, W.(2011). Coal mining GPS subsidence monitoring technology and its application. Mining Science and Technology (China). 21(004), pp. 463-467.

Jiang, L., Lin, H., Ma, J., Kong, B., & Wang, Y.(2011). Potential of small-baseline SAR interferometry for monitoring land subsidence related to underground coal Bres: Wuda (Northern China) case study; Remote Sens. Environ. 115 257.

Jianjun, S., Chunjian, H., Ping, L., Junwei, Z., Deyuan, L., Minde, J., Lin, Z., Jingkai, Z. &Jianying, S.(2012). Quantitative prediction of mining subsidence and its impact on the environment; Int. J. Min. Sci. Technol. 22 69–73.

Kapil, M., Dheeraj, K., & Daniele, P.(2019). Assessment of subsidence in Delhi NCR due to groundwater depletion using TerraSAR-X and persistent scatterers interferometry, The Imaging Science Journal, 67:1, 1-7.

Khorrami, M. (2020). Extreme subsidence in a populated city (Mashhad) detected by PSInSAR considering groundwater withdrawal and geotechnical properties. Sci. Rep. 10, 11357. https://doi.org/10.1038/s41598-020-67989-1.

Kumar, S., Kumar, D.,& Chaudhary, S.K. (2020). Land subsidence mapping and monitoring using modified persistent scatterer interferometric synthetic aperture radar in Jharia Coalfield, India. J Earth SystSci 129, 146. https://doi.org/10.1007/s12040-020-01413-0.

Mahmoodinasab, F. &Mohseni, N., 2021. A spatiotemporal analysis of the relationship between groundwater level and ground surface displacement using Sentinel-1 SAR data. Arab. J. Geosci. 14, 1106. https://doi.org/10.1007/s12517-021-07497-2.

Majeed, M., Lu, L., Anwar, M. M., Tariq, A., Qin, S., El-Hefnawy, M. E., El-Sharnouby, M.., Li, Q., Alasmari, A., 2023. Prediction of flash flood susceptibility using integrating analytic hierarchy process (AHP) and frequency ratio (FR) algorithms, Front. Environ. Sci. 10 (2023) 1–14, https://doi.org/10.3389/fenvs.2022.1037547.

Miao, F., Yan, M., Qi, X., Ye, C., Wang, B., Liu, R. & Chen, J.(2008). Application of DInSAR and GIS for underground mine subsidence monitoring; Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. 37 251–256.

Pacheco-Martínez, J., Hernandez-Marín, M., & Burbey, T. J. (2013). Land subsidence and ground failure associated to groundwater exploitation in the Aguascalientes Valley, México. Engineering Geology, 164: 172–186.

Perissin, D. & Wang, T.(2012). Repeat-pass SAR interferometry with partially coherent targets; IEEE Trans. Geosci. Remote Sens. 50 271–280.

Sahu, S.R., Rawat, K.S., Singh, S.K. et al. Estimation of Subsidence Over a Part of Kanchipuram District Using Sentinel-1 SAR Data. J Indian Soc Remote Sens (2025). https://doi.org/10.1007/s12524-024-02102-x.

SAHU, Smruti Ranjan; RAWAT, Kishan Singh. Analysis of Land subsidencein coastal and urban areas by using various techniques– Literature Review. Indonesian Journal of Geography, [S.l.], v. 55, n. 3, dec. 2023. ISSN 2354-9114. doi:https://doi.org/10.22146/ijg.83675.

Tariq, A., Mumtaz,F., Majeed, M. & Zeng, X.(2023). Spatio-temporal assessment of land use land cover based on trajectories and cellular automata Markov modelling and its impact on land surface temperature of Lahore district Pakistan, Environ. Monit. Assess. 195 (2023) 114, https://doi.org/10.1007/s10661-022-10738-w.

Thapa, S., Chatterjee, R. S., Singh, K. B., & Kumar, D.(2016). Land subsidence monitoring using PS-InSAR technique for l-band SAR data; ISPRS – Int. Arch. Photogramm. Remote Sens. Spat. Info. Sci., https://doi.org/10.5194/isprsarchives-xli-b7-995-2016.

Tripathi, A., Attri, L. & Tiwari, R.K.(2021). Spaceborne C-band SAR remote sensing–based flood mapping and runoff estimation for 2019 flood scenario in Rupnagar, Punjab, India. Environ Monit Assess 193, 110. https://doi.org/10.1007/s10661-021-08902-9.

Tripathi, A., Moniruzzaman, Md., Reshi, A.R., Malik, K., Tiwari, R.K., Bhatt, C.M., &Rahaman, K.R.(2023). 'Chamoli Flash Floods of 7th February 2021 and Recent Deformation a PSInSAR and Deep Learning Neural Network (DLNN) based perspective'. Natural Hazards Research. https://doi.org/10.1016/j.nhres.2023.03.003.

Tripathi, A., Reshi, A., Moniruzzaman, Md., Rahaman, K. & Tiwari, R., & Malik, K.(2022). Interoperability of C-band Sentinel-1 SAR and GRACE satellite sensors on PSInSAR based urban surface subsidence mapping of Varanasi, India. IEEE Sensors Journal. 1-1. 10.1109/JSEN.2022.3208117.

Xiong, S.(2021). Time-Series Analysis on Persistent Scatter-Interferometric Synthetic Aperture Radar (PS-InSAR) Derived Displacements of the Hong Kong-Zhuhai-Macao Bridge (HZMB) from Sentinel-1A Observations. Remote Sensing, 13(4), pp. 546.