Detecting Surface Displacement in Kathmandu Valley with Persistent Scatterer Interferometry

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KEYWORDS

Interferometry, PSI, Subsidence, Persistent Scatterer Interferometry

ABSTRACT

Kathmandu Valley has been susceptible to surface displacement due to natural as well as anthropogenic causes since a long time. Previous studies till 2017 suggest that displacement (specially subsidence) with rates of several centimeters per year have occurred in the Kathmandu Valley indicating uncontrolled groundwater withdrawal as the major cause. Owing to the history of surface displacement, this study aims at detecting the nature of land subsidencein Kathmandu for years: 2017 (18th January to 26th December) and 2019 (2nd January to 28th December) based on Persistent Scatterer Interferometry (PSI) technique using Synthetic Aperture Radar (SAR) datasets from Sentinel 1. PSI is able to detect persistently backscattering targets and evaluate respective displacements from the backscattered signal. The results of 2017 and 2019 revealed significant displacement of -100.54mm and -129.19mm along Line Of Sight (LOS) of radar during the study period at Baluwatar and Lazimpat area of Kathmandu district respectively. Similarly, New Baneshwor, Bode and Imadol exhibited a substantial displacement of -88.81mm,-103.55mm, -127.35mm respectively for year 2019.

1. INTRODUCTION

Surface Displacement here generally refers to change in position of the surface of earth or any feature like building, bridges etc. thereon due to natural as well as anthropogenic activities. Apart from uplifts that occurred during earthquake of 25th April 2015, Kathmandu Valley (KV) has been exhibiting significant land subsidence. Land Subsidence (LS) can be defined as the gentle settling or rapid sinking of the discrete segments of the ground surface due to the consolidation of sediments, causing the subsurface movement of earth materials as a result of increasing effective stress (Galloway and Burbey, 2011; Ma et al., 2018) Due to removal of the extractable materials from underneath the surface of earth, the pressure exerted by the material in the pores and cracks of the storage system is reduced. In case of water and petroleum extraction, the fluid pressure on aquifer system and petroleum reservoirs respectively reduce. Because of the granular structure, the skeleton of the fluid-bearing and storing rocks is not rigid and the shift in balance of support for the overlying material causes the skeleton to deform slightly (Galloway et al., 2008).

The previous studies by Bhattarai *et al.*, 2017; Palanisamy Vadivel and Kim, 2018; Palanisamy Vadivel, Kim and Jung, 2018 have already verified the occurrence of LS in Kathmandu Valley (KV) till 2017 A.D. This study is also aimed at detecting surface displacement, especially subsidence of year 2017 and comparing with LS of 2019 in KV.

1.1 Cause of Displacement in KV

Previous studies ((Bhattarai *et al.*, 2017; Palanisamy Vadivel and Kim, 2018; Palanisamy Vadivel, Kim and Jung, 2018) have already shown that the driving factor for LS in Kathmandu valley are its geology and the persisting overexploitation of groundwater.

1.1.1 Geology of KV

The valley constitutes alluvial plains of Bagmati, Bishnumati and Manohara rivers flowing towards south of the valley. The valley is mainly composed of quaternary sediments overlying bedrock and consists of thick (more than 650m deep), semi-consolidated fluvio-lacustrine sediments from Pliocene to Pleistocene age (Piya, Westen and Woldai, 2006).

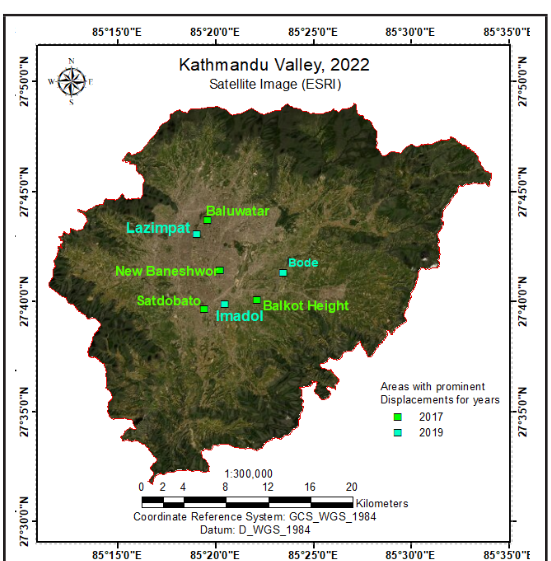

Figure 1: Study Area (Note: Only municipalities of Lalitpur Districts have been selected for study)

1.1.2 Water exploitation in KV

Owing to groundwater exploitation, the valley has been suffering from GW level declination from the very beginning of 1980s when the inception of GW development and extraction occurred with low but noticeable impacts on GW level (Pandey, Shrestha and Kazama, 2012). The water demand in the valley, using Bureau of Indian Standards (BIS) guidelines, was estimated to be 183.9 Million Liters per Day (MLD) in 2001, 224.9 MLD in 2006, 282.5 MLD in 2011, 366 in 2016 and expected to reach about 482 MLD by 2021 (Udmale *et al.*, 2016). Further, ground water extraction rate of 21.56 Million Cubic Meters (MCM)/year in the decade of year 2000, exceeded the aquifer's recharge rate of 9.6 MCM/year and the groundwater level decreased from 13 m to 33 m and 1.38 m to 7.5 m during 1980-2000 and 2000-2008 respectively (Pandey, Shrestha and Kazama, 2012). The data on recent water usage could not be retrieved for this study so inferences on current water exploitation were made from aforementioned studies.

1.2 Methods for Displacement Monitoring and Measurement

The magnitude of subsidence can be measured with several ground-based: spirit leveling, borehole extensometer, GPS, tripod LIDAR and aerial/space-based techniques: satellite SAR interferometry (InSAR and PSI, airborne LIDAR etc. The space-based geodetic technique like: GPS is able to automatically determine three- dimensional coordinates of ground and track a long-term time series with millimeter-level resolution of horizontal position and sub-centimeter level resolution of vertical position and InSAR technique is able to measure sub-centimeter ground displacements at a high spatial detail (10-100m) over regions spanning over hundreds of kilometers (Galloway *et al.*, 2008). Moreover, the remotely sensed approaches have proven to be a highly efficient and accurate means for monitoring deformation processes from millimeters to centimeters level accuracy with large ground coverage (Zhu *et al.*, 2019).

This study also focuses on use of space-based technique viz. PSI, a multi-temporal InSAR technique, for detecting the subsidence occurred in the years 2017 and 2019.

1.3 ABOUT PSI

A Synthetic Aperture Radar (SAR) dataset consists of phase and amplitude information of the reflected signal. The phase differences of same location in two images can provide range with help of interferometry. When a Digital elevation Model is used to subtract the topographic signal components from an interferometric product i.e. interferogram, it generates differential interferogram and the process is termed as Differential Interferometric SAR (DINSAR) (Ferretti *et al.*, 2007). A PSI technique is such a DINSAR technique applied to multi-temporal images that estimates corrections due to temporal and spatial decorrelations along with other noises to calculate remaining deformation signals (Crosetto *et al.*, 2016). These deformation signals can be subsidence, uplifts or any other horizontal movement of an object that strongly reflects the transmitted signals consistently over a required period, termed as Persistent Scatterer (PS) (Höser, 2018) . Thus, this study applies PSI technique to detect subsidence occurring in the valley.

2. DATA AND METHODOLOGY

2.1 Data

SAR datasets of 2017 (25 images) and 2019 (37 images) were used for PSI. The datasets were taken for descending orbits in VV polarization along with SRTM DEM and GACOS correction.

2.2 Methodology

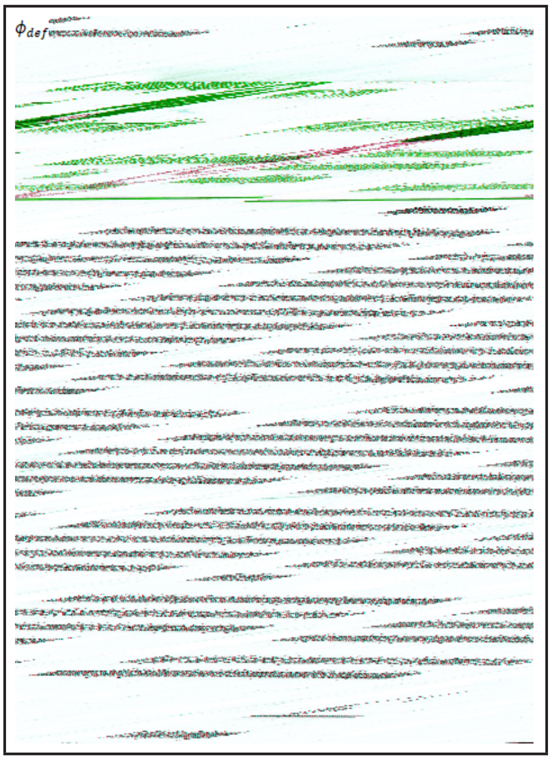

Figure 2:PSI workflow

2.2.1 Jobs in Sentinel Application (SNAP)

First of all precise orbits were applied to the SAR datasets and the required portion of the SAR scenes were extracted from each original swath. Then master image was identified for preparing stacks of the relevant master-slave images and co-registration of slave images with master images was done. The output was then processed to generate interferograms as an input for PSI implemented in StaMPS/MTI package developed by Hooper *et al.*, 2018 .

2.2.2 Jobs in Stanford Methods for PSI/ Muti-temporal InSAR(Stamps/MTI)

PSI technique estimated noise in interferograms and eliminated noisy pixels from each interferogram in the stack. The remaining phase signals in the interferogram contained several components (Equation 1) (Hooper, Segall and Zebker, 2007). These components were estimated and eliminated from the original phase to acquire deformation phase (ϕ_{def}). Then phase unwrapping of each interferogram was performed to calculate actual deformation signals in each pixel. The phase signals (in radians) were then converted to linear units (mm) with equation 2 (Hooper *et al.*, 2004). The velocitiy of each pixel or Persistent Scatterer (PS) were then estimated from these phase signals and atmospheric correction was done. Finally, the output of PSI were collected in csv format with latitude, longitude and history of deformation signals of the PSs. The CSV file was then imported in arcmap and excel for mapping and plotting cumulative displacements, mean velocities and time-series of deformations.

All the deformations were calculated in reference to Kakani CORS station i.e. KKN4 as this station was found to be much stable based on the GNSS datasets at KKN4 (~0.0006m along LOS in 2017).

$\phi_p = \phi_{flat} + \phi_{topo} + \phi_{orb} + \phi_{atm} + \phi_{def} + \phi_{(n}$	(1)
$\phi_{def} = \frac{4\pi}{\lambda} d$	(2)

Where: ϕ_{flat}= phase due to the reference ellipsoid, ϕ_{topo}= phase due to topography of the surface, ϕ_{orb}=phase due to inaccuracy in orbital information. ϕ_{atm}=phase due to atmospheric delay, ϕ_{def}= Phase due to deformation between the acquisitions, ϕ_n = phase due to other noise sources like: temporal changes of scatterers, defocusing, miscoregistration etc. and d=displacement in linear units.

3. RESULTS AND DISCUSSION

Table 1: Cumulative displacements (in mm) and mean velocities (mm/year) for year **2017**

Location	Cumulative displacement	Mean Velocity
Baluwatar	-100.54	-121.80
New Baneshwor	-49.74	-68.51
Satdobato	-67.51	-87.44
Balkot Height	-74.49	-98.57

Table 2:Cumulative displacements (in mm) and mean velocities (mm/year) for year **2019**

Location	Cumulative subsidence	Mean Velocity
Lazimpat	-129.19	-136.34
New Baneshwor	-88.81	-92.59
Imadol	-127.35	-125.62
Bode	-103.55	-101.09

The study area showed variations in the nature of subsidence in KV. Among them, the area with prominent subsidence are depicted in Map 1The Baluwatar and New Baneshwor areas are situated in Kathmandu Metropolitan City (KMC) of Kathmandu district, Imadol and Satdobato areas fall under Mahalaxmisthan municiplality and Lalitpur municipality of Lalitpur district respectively. Similarly, Bode and Balkot Heights are located in Madhyapur Thimi and Suryabinayak municipalities respectively in Bhaktapur district. Table 1 and Table 2 illustrate the prominent displacement values for several locations for years 2017 and 2019. All these displacements were calculated along LOS of radar signal. The maximum subsidence of -100.54mm for 2017 occurred at Baluwatar with mean velocity of -121.8mm/year. Similarly, Lazimpat area seem to exhibit highest displacement of -129.19mm for year 2019 with mean velocity of -136.34mm/year. These areas lie within a same neighborhood and seem to share a similar geology and population. The velocities and subsidence are seemed to have increased significantly from year 2017 to 2019 and almost doubled for some areas. The time series of subsidence have been illustrated in Figure 3. The time series clearly shows the movement away from satellite along LOS direction. The movement can be the consequence of subsidence as well as tectonic movement. The tectonic movement indicates the movement of Indian plate in northeast direction towards Eurasian plate at a rate of 47mm/year(Benedick *et al.*, 2002).The movement away from satellite thus can have

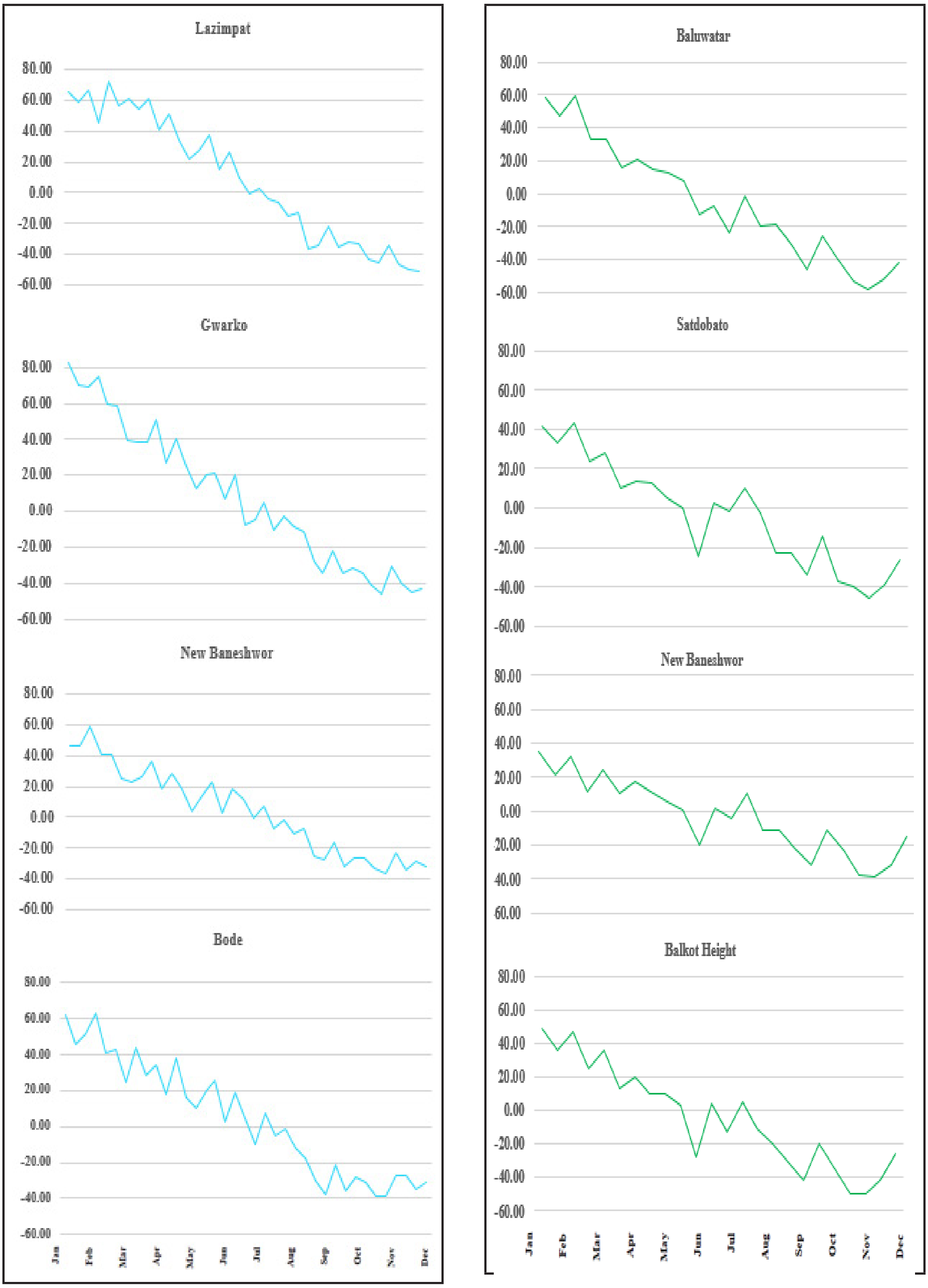

Figure 3: Time-series of subsience along LOS for prominent areas for year 2017 (left green) and 2019 (right cyan)

contribution of both subsidence as well as horizontal movement. The displacement could not be decomposed into its component due to lack of adequate SAR datasets in ascending orbit. However, based on subsiding nature suggested by previous studies and known tectonic movement rate, it can be inferred that the movement away from satellite also suggests a significant amount of subsidence.

Based on fact from the previous studies related to ground water exploitation in KV, it can be suggested that the increased demand of groundwater might be a crucial factor for cause of displacement. Owing to lack of adequate information on ground water usage in the study area, a concrete justification could not be provided for cause of LS, rather only logical inferences could be presented.

4. CONCLUSION AND RECOMMENDATION

The surface displacement occurring in KV was detected using PSI technique for years 2017 and 2019. The results show significant displacement away from the satellite along LOS direction in areas around Lazimpat, Baluwatar, New Baneshwor, Satdobato, Imadol, Bode and Balkot heights. The major cause of displacement can be suggested as the overexploitation of groundwater, supported by tectonic movement occurring towards northeast. Further improvements can be done to this study by incorporating data on both orbits, water exploitation in the valley, peizometric levels of monitoring wells etc.

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