Landslide Susceptibility and Ground Displacement Assessment of Austin City and Surroundings

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ABSTRACT

The city of Austin and surrounding area is experiencing growth and expansion as a consequence of fast urban development and population growth. This has led to increased constructions and other anthropogenic alterations of the environment to accommodate the growing population and economy. These activities, coupled with the natural conditions and forcing, have made areas within the metropolis susceptible to the threats of landslides. The present study aims to identify zones in the study area that are susceptible to the threats of slow-moving creep/slow-slide landslide hazards and understand the factors and processes that control the occurrence of these events through an integrated study approach. This includes: (1) generating a landslide susceptibility (LS) map through a combination of the triggering factors including local geology and tectonic features, land use/cover, elevation/slope, and precipitation; (2) detect active deformation processes that could lead to landslide failure using Interferometric Synthetic Aperture Radar (InSAR) analysis techniques applied on Sentinel-1 SAR datasets (2015 – 2020) and validated through datasets from campaign GPS surveys and permanent stations; and (3) identify the factors and processes that directly or indirectly constrain the occurrence of the phenomenon through spatial analysis of relevant datasets. Our findings show: (1) the main concentration of vertical displacement (-1 to -6 mm/yr) is around the northern region of the study area; (2) zones with a moderate subsidence rate coincide with urbanized areas (up to -2 mm/yr) whereas pockets of high displacement rates (up to -6 mm/yr) are noted on NW parts; (3) most of the areas experiencing subsidence are underlain by the Comanche Series characterized by alternating beds of harder and softer limestones interbedded with beds of marly/clayey layers, and formations of marine marl, sandstone, and carbonaceous shale from the Gulf Series; (4) there is a high spatial correspondence between areas with high subsidence rates and high LS index; and (5) efforts are currently underway to analyze relevant datasets to determine factors and processes that control the occurrence of the hazard.

BACKGROUND

- Landslides classification is primarily dependent on the composition of the material and its type of movement down a slope.
- The Landslide Susceptibility Map (LSM) is used to assess potential liability in local to regional scale areas for the threat of a landslide phenomenon. It is based on GIS analysis techniques, which integrates parameters that may trigger a landslide such as the factors that affected the area.
- Multi-temporal Synthetic Aperture Radar (SAR) observations allow detecting surface deformation, based on how the radar signal travels more (subsidence) or less (uplift) distance from the sensor to the target.
- Small Baseline Subset (SBAS) technique is used to identify surface deformation allowing to analyze their space-time attribute between the observed deformation and controlling factors.

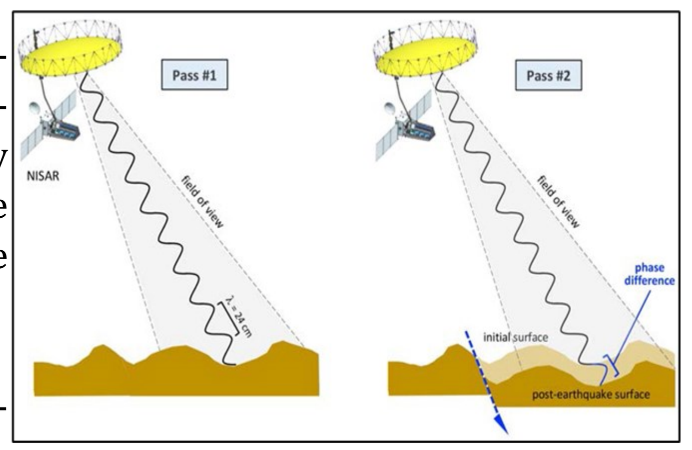

Figure 1: InSAR deformation geometry. In left (Pass/flight 1), a ground surface is imaged. In right (Pass 2), the satellite passes over the same area. If a ground deformation incident occurs between flights, the change in phase, is used to calculate the rate of displacement.

OBJECTIVES

- Identify areas that are susceptible to slow-moving landslides and quantify the rate of displacement in Austin City and its surroundings.
- Identify the factors that control the occurrence of the hazard and model the potential relationship between the controlling factors and the size and geometry of the landslides.

STUDY AREA

- Austin City and its surroundings are getting more susceptible to landslides resulting from new development and population growth encroaching into unstable terrain that is vulnerable to slides. (Fig. 2)
- A recent landslide has occurred (May 2018) on a cliff that overlooks Shoal Creek (Fig. 3) causing significant damages to public and private properties.
- The geologic setting of the area is dominated by fractured limestone lying on top of a clay layer. This layer loses its cohesive strength when it gets moist increasing the risk of slumping and sliding, even on gentle slopes.

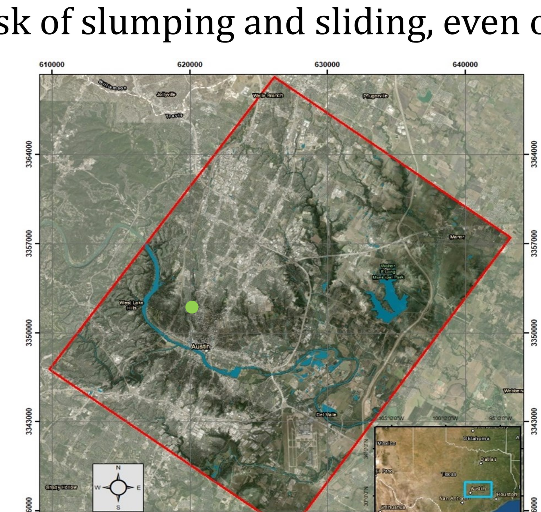

Figure 2: Study area spatial location, and Shoal Creek (Green circle)

Figure 3: Landslide on Shoal Creek

DATASETS

Dataset/Source	Technique used	Purpose
Sentinel 1 (SLC) 53 Scenes from 2017 -2021	SBAS	Generate velocity displacement map
DEM 30 m resolution	SBAS	Support for SBAS analysis
DEM 1 m resolution	GIS integration	Support for slope and drainage network analysis for LSM
Geology and faults (1:250.000)	GIS integration	Support for LSM analysis
Land Cover map	GIS integration	Support for LSM analysis
Real-Time Kinematic (RTK) GPS	Field-based	Validation
Nevada Geodetic GPS Networks map	Office-based	GPS - Permanent Stations for calibration
Soil samples	Field-based	Soil textural analysis for validation

METHODOLOGY

- Integrated approach that combines empirical methods and SBAS techniques was used to generate the landslide susceptibility map of the area, identify the spatial distribution of slow-moving slides and quantify their rates. In-situ datasets and observations were used to support, validate, and calibrate the analysis result derived using the above-stated approach.

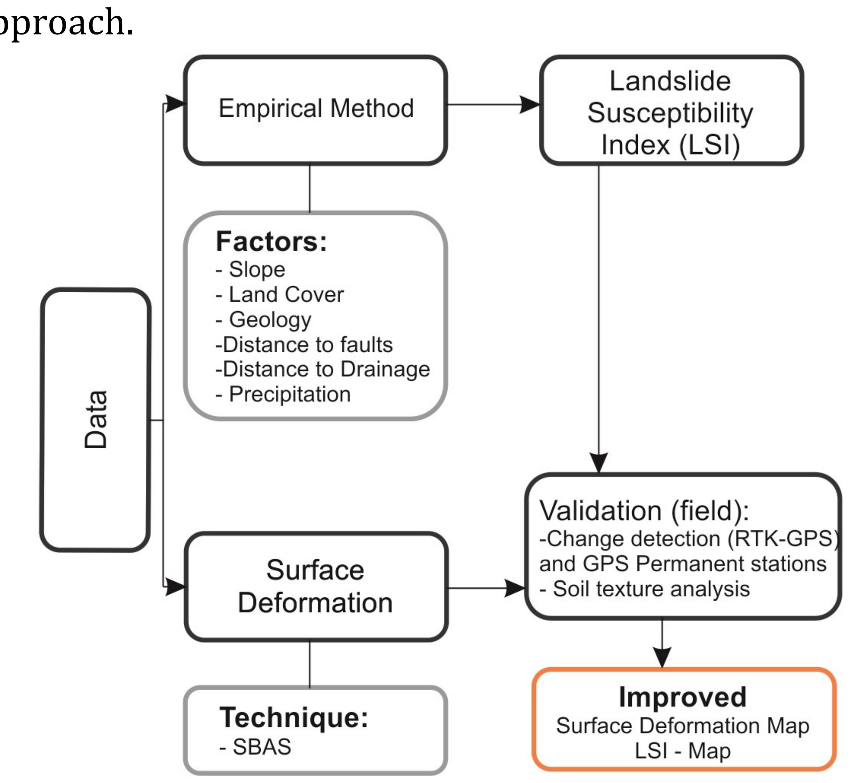

Figure 4: Flowchart of main processes for this study

Factor and Weight (W) considered

Slope (**S**) (degrees) 30%	Land Cover (**LC**) 22%	Geology (**G**) 18%	Distance to Faults (**DF**) (m) 15%	Precipitation (**P**) (Avg: mm) 6%	Distance to Drainage (**DD**) (m) 9%	**Rating (R)***
0 - 5	Forest/Woodland	Limestone	>1500	852 - 863	>1200	1
5-14	Shrubland/Grassland	Shale	1000 - 1500	863 - 868	800 - 1200	2
14-36	Cropland	Marl	500 - 1500	868 - 876	200 - 800	3
36 - 86	Urban/Bare Soil	Unconsolidated	<500	876 - 884	<200	4

$$R_S(W_S)+R_{LC}(W_{LC})+R_G(W_G)+R_{DF}(W_{DF})+R_P(W_P)+R_{DD}(W_{DD})/4$$

*R= Rating based on 1 being least susceptible and 4 being the most susceptible

Figure 5: Computation of landslide susceptibility index

- The soil texture analysis was estimated by using the hydrometer method. It calculates the physical proportion of the soil based on the settling rates in an aqueous solution, identifying three classes of particle size: sand, clay, and silt. The resulting particles sizes are plotted in Figure 8.

RESULTS AND DISCUSSIONS

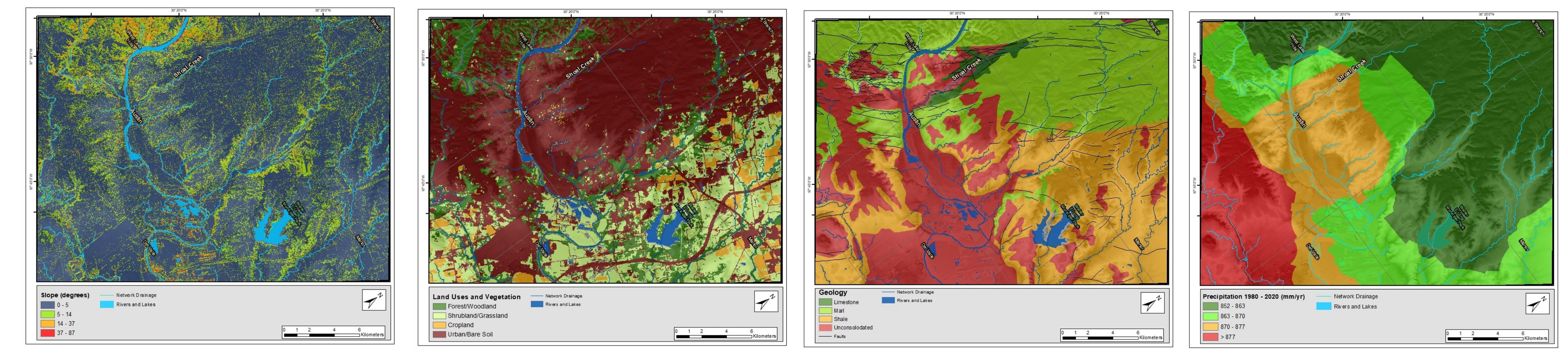

Figure 6: Left to right Slope analysis and drainage network, land cover analysis, geology and faults analysis, precipitation analysis; respectively.

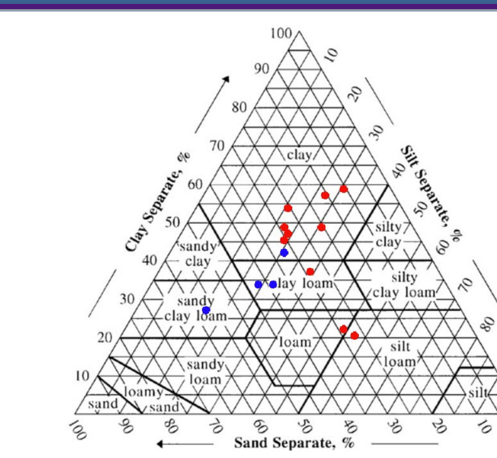

Figure 8: Textural soil analysis. Red dots represent samples from Shoal Creek landslide (Stop 2) had a major percentage of clay, and blue dots represent samples from a different location on Shoal Creek (Stop 3) with more sand content.

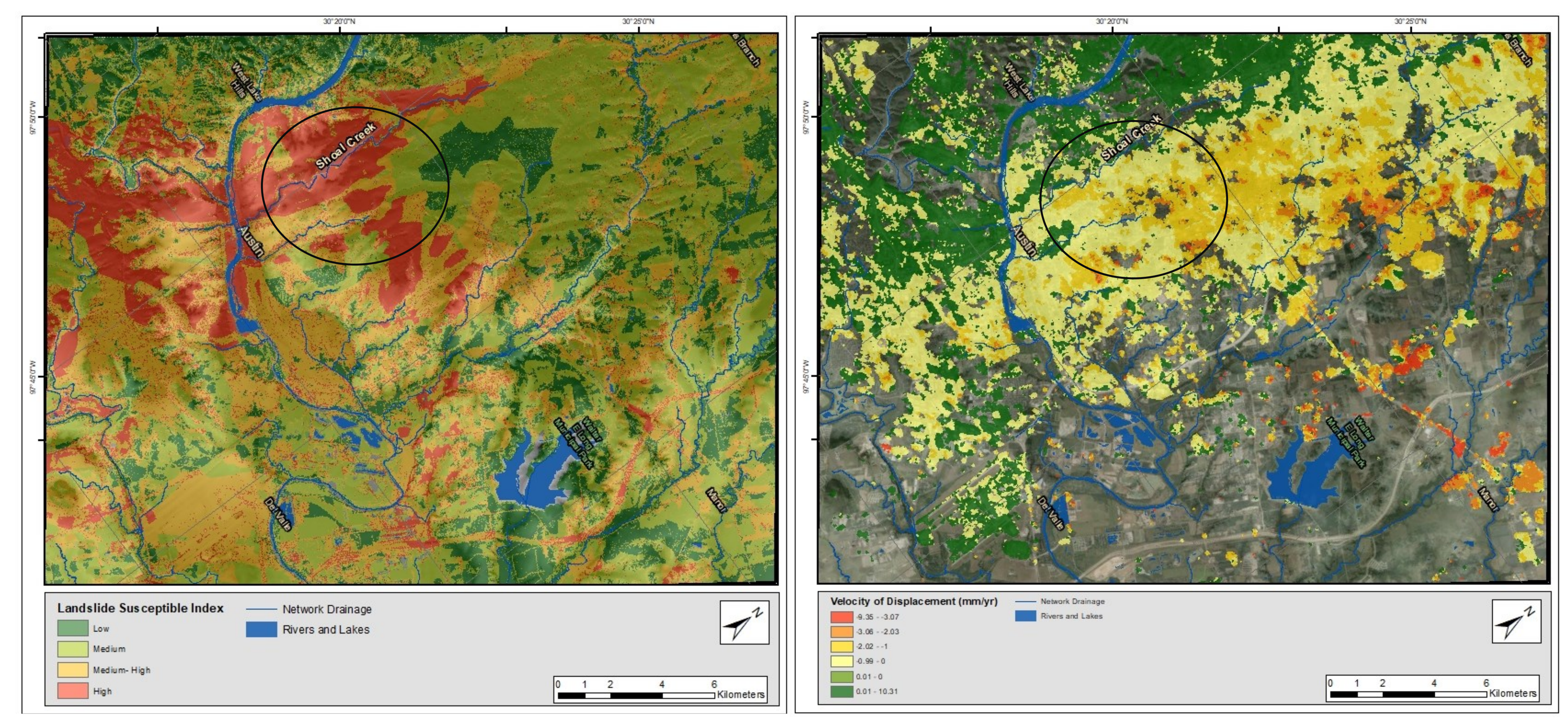

Figure 7: Susceptibility index map and Velocity of Displacement map showing spatial location of fieldwork stops and GPS permanent station uses for analysis. Black circles highlight areas that represent correspondence of susceptibility and surface displacement on the study area based on our models proposed.

Figure 9. A: Fieldwork RTK-GPS measurements (Shoal Creek, Stop 2). B: Observations of landslides material displaced down the slope. Fractured limestone from the Buda Formation on top of clayey and lose material from Del Rio Formation. C: 3D-Model generated from Orto photometric images taken from UAV. The sliding surface shows the eroded and fractured limestone where houses are settled. The landslide was covered by vegetation making it difficult to quantify the magnitude of material displaced.

- The study area was classified into four susceptibility categories based on the LSI values: low, medium, medium high, and high. The LSI analysis is calculated based on key triggering factors known for inducing landslides as slope, rock composition, land cover, distance to faults, precipitation, and distances to drainage.
- We proposed a conceptual model to demonstrate the mode of occurrence of a slow-moving landslide in the study area. The model assigned higher weight values to steep slopes and unconsolidated rock materials, including the expansive clay layer underlain by the fractured limestone from the Buda Formation. We believe that when the clay layer from Del Rio Formation is in contact with water through fractures, it expands, increasing the driving forces amplified by the steep slopes of the slip plane. This force gradually overcomes the shear strength and results in a landslide failure.
- The LS map shows that at central region of Austin (black circles in Fig. 7) has a moderate– high to high potential for landslide occurrence. The displacement analysis derived from the SBAS technique spatially corresponds well with the LSI analysis in this region. The displacement in this region ranges from -0.01 to -3.06 mm/year indicating the potential occurrence of a slow-moving landslide as witnessed in the slow-moving landslide event that precipitated in the Shoal Creek area.
- The soil Samples texture analysis of the Shoal Creek area indicates the presence of expansive clay further corroborating the conceptual model discussed above.
- The SBAS analysis of the Shoal Creel landslide area (see site 2, Shoal Creel landslide event in Fig. 7, right) indicates low to medium rates of displacement (-0.99 to –2.03 mm/year) and medium to a high level of susceptibility.

CONCLUSION

- The GIS approach on this research was able to assess the potential slope instability in Austin City and surroundings that potentially result in a slope failure/landslide. This analysis delineated the study area based on the susceptibility of the areas to landslides occurrence as low, medium, medium high, and high level by taking different controlling factors and their perceived significance into consideration.
- Preliminary SBAS technique results validate that the Shoal Creek area had experienced moderate to low ground displacement. Ongoing displacement is currently being tested with multiple campaign RTK-GPS measurements.
- The identification of areas susceptible to slides would be useful for effective land use management that can support decision-makers for urban and infrastructural plans.