Ground Subsidence socioeconomic vulnerability in Salamanca, Celaya and Irapuato, Central Mexico

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Abstract

We use a 2014-2020 ground subsidence velocity field obtained with InSAR techniques and data from Sentinel-1 and the Mexican 2020 census to estimate the shallow faulting risk associated with ground subsidence and the estimation of its socioeconomic vulnerability in Salamanca, Celaya and Irapuato, Central Mexico. The fastest recorded subsidence velocities (-7.0 cm/year) and the largest subsidence-affected urban area (84.62% of its area exposed) are localized in Celaya. The highest socioeconomically vulnerable to subsidence municipality is Salamanca, (92.65% of the population has very high and high socioeconomic vulnerability), followed by Celaya (77.09%) and Irapuato with (43% of their population). The municipality with the largest area affected by low socioeconomic risk to ground subsidence is Irapuato (67.7 km2), followed by Celaya (58.4 km2) and Salamanca (38 km2).

Background

Land subsidence and associated shallow faulting is developed along clearly defined swaths in urban zones where shallow faulting damages critical underground urban infrastructure and larger civil structures and housing are affected by differential settlement and angular distortion as a result of ground deformation. Guanajuato is the heart of the industrial corridor in central Mexico, where industrial and agricultural development and population growth has resulted in excessive groundwater extraction, inducing land subsidence. Synthetic Aperture Radar (InSAR) interferometry was used to characterize the land subsidence process in the Celaya, Irapuato, and Salamanca, municipalities and determined the socioeconomic vulnerability and exposure to this process.

Methods

InSAR time series are based on a sequence of interferograms covering the cities of Irapuato, Salamanca, and Celaya. We used Sentinel 1A and B data between April 3, 2014, and December 31, 2020. We selected Orbit 114 covering the cities of Irapuato and Salamanca, and Orbit 41 to cover the city of Celaya. The unwrapped interferograms and time series analysis was processed with the ISCE, SNAPHU and the MintPy packages at UNAM's Miztli (Figure 1).

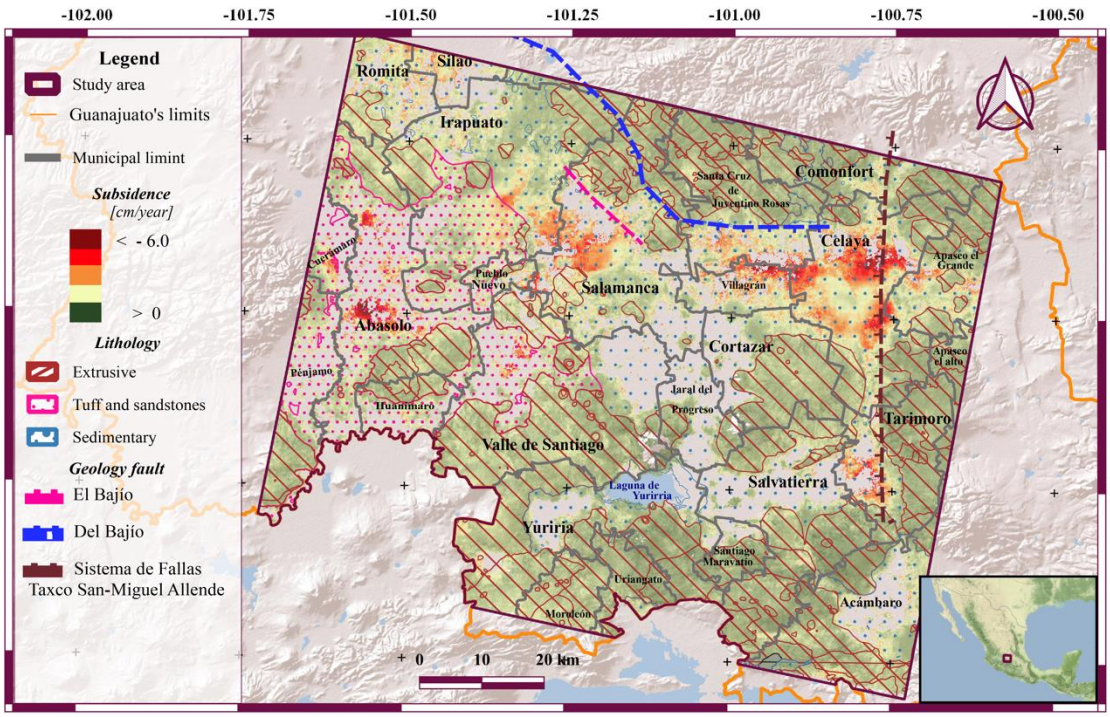

Figure 1 Subsidence velocity map with coherence mask of 0.75. Del Bajío Fault trace and Sistema de Fallas Taxco-San Miguel Allende is taken from Alaniz Álvarez et al. (2005), El Bajío Fault trace is taken from Nieto Samaniego et al. (2012). The base relief map is taken from ESRI (2016).

To determine the socioeconomically vulnerability to subsidence, we used a methodology developed by Novelo-Casanova et al. (2021). This approach is based in the analytical hierarchical process proposed by (Saaty, 1987) and considers 13 parameters that encompass economic factors of the population such as access to basic services, access to health services, population density per dwelling, population with some type of disability and education level, which were considered as social and economic circumstances of the population which may lead a community to have different resiliency to the ground subsidence process and its associated effects. We used the Mexican 2020 population and housing Census (INEGI, 2020,) and the 2020 Guanajuato Geostatistical framework (INEGI, 2020), normalized and then weighted each parameter. This data was then joined with the subsidence velocity map and divided into 5 categories: Very high, High, Moderate, Low and Very Low. The socioeconomic risk is then calculated by multiplying the vulnerability and the subsidence hazard (Figure 2).

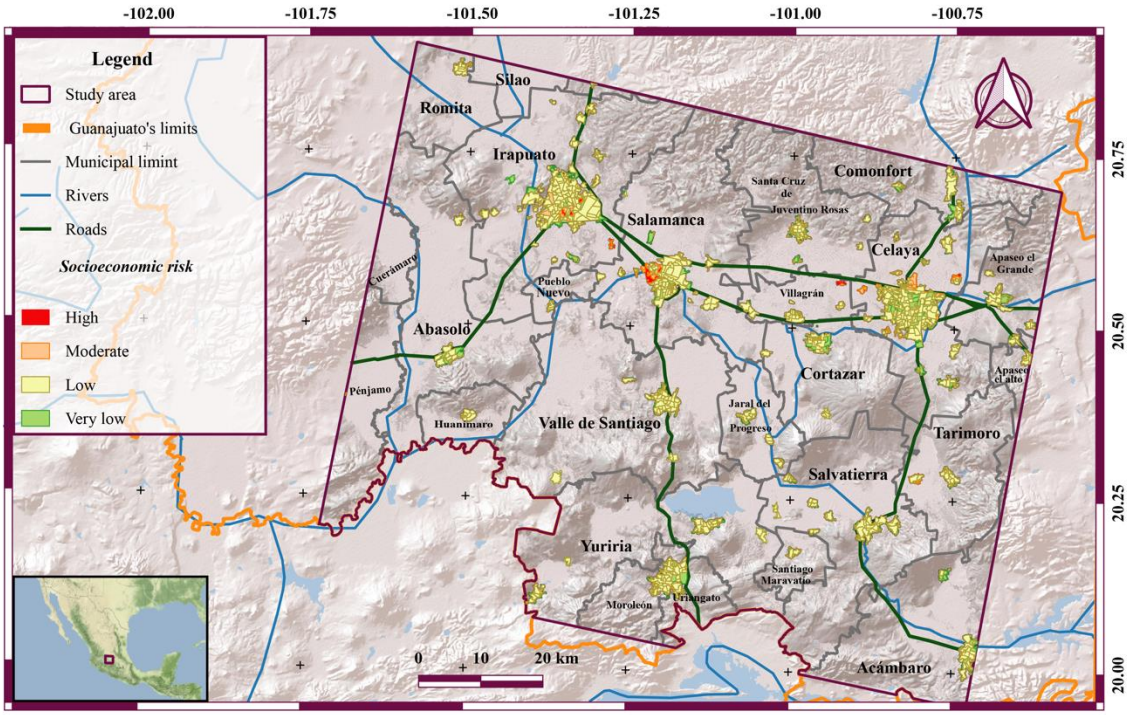

Figure 2 Map of ground subsidence socioeconomic risk.

Results

Our analysis shows that 6.4 km^2 is affected by land subsidence within the municipality of Celaya, 6.6 km^2 within the municipality of Irapuato and 5.7 km^2 within the municipality of Salamanca. The municipality with the highest exposure to subsidence, is Celaya with 84.62% of its urban area exposed, followed by Salamanca with 58.16% and finally Irapuato with 56.5%.

The maximum observed subsidence velocities for Irapuato, Salamanca and Celaya are -4.6 cm/year, -5.8 cm/year and -7.0 cm/year respectively (Figure 1). In Celaya, 71.18% of its population is affected within the low hazard category, which is in the northern sector of the municipality and 15.29% of its population isn't affected by land subsidence, while 13.44% of people is moderately affected; but only 0.09% of people live within the high hazard region. In Irapuato 47.43% of its inhabitants live in the low hazard region, 41.74% live in the non-subsiding region subsidence and 10.74% of its population is located within the moderate subsidence region; while 48% of Salamanca's population live in a non-subsiding region, 29% in the low hazard region, and finally 23% live within the moderate hazard region.

Socioeconomically Vulnerability.

49.26% of the Irapuato's population is moderately vulnerable to land subsidence, 36.5% is under high vulnerability, 6.62% very high vulnerability, 7.2% low vulnerability and 0.40% very high vulnerability. 58.28% of the Celaya population has moderate vulnerable to land subsidence, 18.89% of the population is highly vulnerable, 17.06% has very low vulnerability and 5.74% has low vulnerability. 2.7% of Salamanca's population is very low socioeconomically vulnerable to land subsidence, 4.7%, low socioeconomically vulnerable, 66.8% present moderate socioeconomically vulnerability and 25.9% are highly socioeconomically vulnerable.

Socioeconomically Risk for Subsidence.

Salamanca's population presents 11% of high risk, 16.5% of moderate risk, 48.8% of low risk and 23.3% of very low risk respectively. The distribution of the percentage of affected areas according to the socioeconomic risk associated with subsidence, where 5.4% presents high risk. 6.4% presents moderate risk, 78.7% presents low risk and 9.3% of the area presents very low risk.

The 47% of Celaya's population present very low socioeconomically risk, 38% present low socioeconomically risk, 12% present moderate socioeconomically risk 3% present high socioeconomically risk

The 23.1% of the population has low risk, 48% low risk, 2.54% moderate risk, and 7.2% high risk. 9.9% of the population has very low risk, 82.1% of the area has low risk, 6.1% of the area has moderate risk, and finally 1.8% are under high risk.

Conclusions

56.5% of Salamanca's population (505,779 inhabitants), 47.43% of Irapuato's population (205,588 inhabitants) and 84.71% of Celaya's population (450,118 inhabitants) live within areas exposed to subsidence.

The most socioeconomically vulnerable municipality is Salamanca, where 11.8% of the population is under moderate and high socioeconomic vulnerability to land subsidence, followed by Celaya with 7.2% and Irapuato with 9.7% of its population. Conversely, the municipality with the largest area affected by a low socioeconomic risk is Irapuato (67.7 km^2), followed by Celaya (58.4 km^2) and Salamanca (38.0 km^2).

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