# Current review of the risk associated with land subsidence in the state of Zacatecas, Mexico.

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## Introduction

Several land subsidence processes have been recorded in different cities in Mexico since the 1970s. Recently in the state of Zacatecas, areas of subsidence associated with water extraction have been detected, accompanied by ground fractures and faults, as well as subsidence over abandoned mines, caused by the sudden collapse of the roof of old mines. Additionally, there has been an increase in shallow and low-intensity seismic activity that could be associated with the subsidence process as reported by Hernández-Marín et al., (2020) for the Aguascalientes valley. This work presents an inventory of subsidence sites reported in the literature and the local press, and a discussion on the progress in the proposal and implementation of risk management in the state of Zacatecas for subsidence and associated ground discontinuities. The work is a contribution to the identification of the hazard associated with subsidence and ground fracturing in the State of Zacatecas.

## Methodology

To prepare the inventory of sites with subsidence and/or fracturing problems, a review of scientific articles, technical publications, and news in local newspapers with information on fracturing and subsidence was made; an analysis of seismicity in the state was also performed. To know the status of risk management implemented by the government of Zacatecas regarding these hazards, public information contributing to the formulation of comprehensive risk management according to CENAPRED (2014) was reviewed.

## Reports of subsidence, cracking, and seismicity in the state

The state of Zacatecas has 58 municipalities of which only four of them have a Natural Hazards Atlas (NHA): Fresnillo, Guadalupe, Valparaiso, and Zacatecas. However, Valparaíso's NHA does not consider any sinkhole-related hazards, while the remaining three NHAs consider sinkhole hazards, but only those associated with the collapse of the roof of old buried canals or abandoned mine tunnels. Regarding faults, in the four NHAs, only those of tectonic origin but not those associated with subsidence.

CENAPRED, (2001) presented a zoning map of subsidence and landslides in which the southern part of the territory of the state of Zacatecas was included (Figure 1-a). However, recent reports show that subsidence and discontinuities also occur in areas further north not included in this zoning. Figure 1-c shows the location of sites and areas affected by subsidence in the state of Zacatecas reported by INEGI (2019 and 2022). Table 1 shows a compilation of the works that have reported subsidence in the state of Zacatecas.

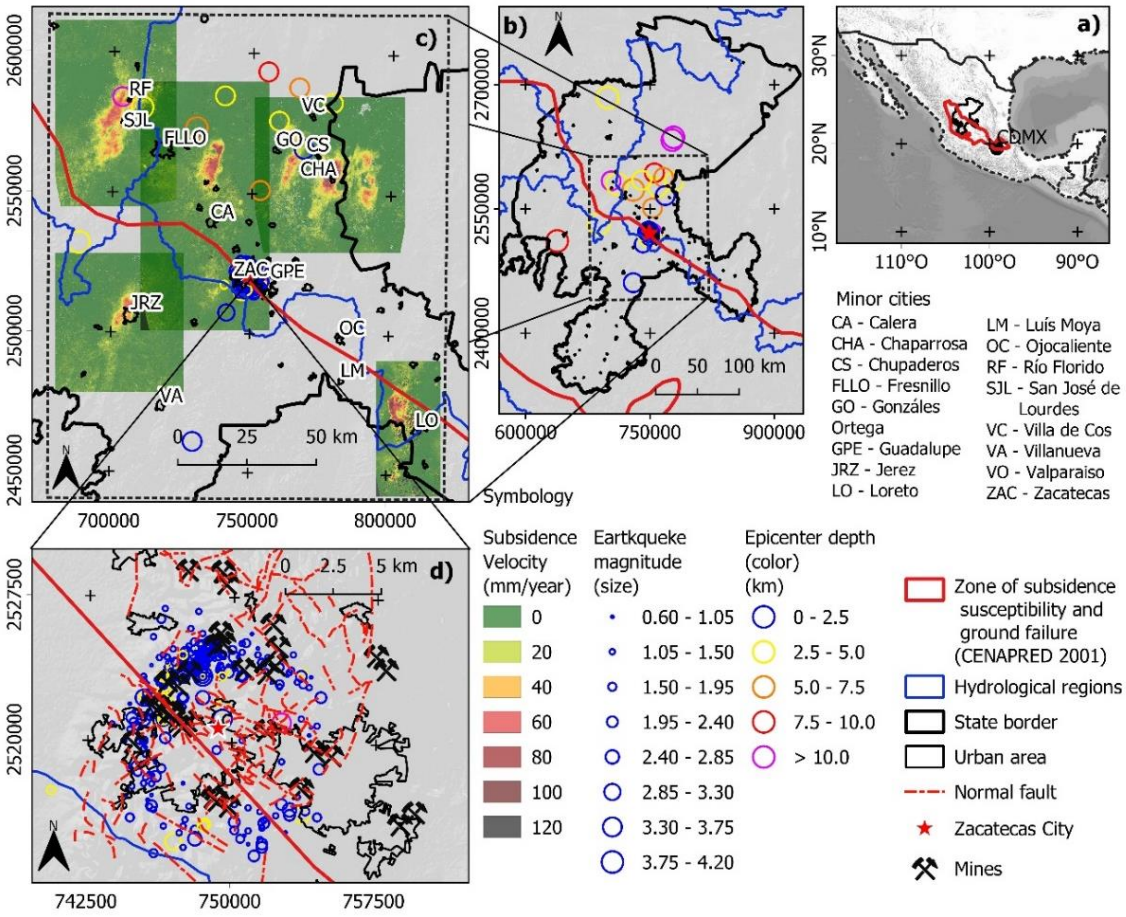


*Figure 1 Subsidence zones and earthquakes in the state of Zacatecas. a) Subsidence zoning, CENAPRED (2001); b) Seismicity in the state of Zacatecas, compiled from SSN between 2017 and 2022; c) Subsidence zones in Zacatecas, compilation from INEGI (2020 and 2022); d) earthquakes, mines and faults in the city of Zacatecas*

| Subsidence Zone | Affected Municipalities | Period | Method | Speed (mm/año) | Source |
|---|---|---|---|---|---|
| San José de Lourdes | Fresnillo | 2019 - 2020 | PSI | 83 | INEGI, (2022) |
| | | 2019 - 2020 | SBAS | ≈ 25 | Cigna y Tapete, (2022) |
| Calera | Calera, Fresnillo, General Enrique Estrada | 2019 – 2020 | PSI | 98 | INEGI, (2019) |
| | | 2019 -2020 | SBAS | ≈ 25 | Cigna y Tapete, (2022) |
| Villa de Cos | Guadalupe, Pánuco, Villa de Cos | 2019 - 2020 | PSI | 156 | INEGI, (2022) |
| | | 2019 – 2020 | SBAS | ≈ 30 | Cigna y Tapete, (2022) |
| Jerez | Jerez | 2019 - 2020 | PSI | 89 | INEGI, (2022) |
| Valle de Loreto | Loreto, Noria de Ángeles | 2016 | PSI | 110 | INEGI, (2019) |
| | | 2019 - 2020 | SBAS | ≈ 12 | Cigna y Tapete, (2022) |

| | | | | | |
|---|---|---|---|---|---|
| | | 2007 - 2011 | SBAS | ≈ 4 | Pacheco-Martínez et al., (2015) |
| | | 2007 - 2011 | SBAS | ≈ 2 | Chaussard et al., 2014 |
| Luis Moya | Luis Moya | 2016 | PSI | ≈ 50 | INEGI, (2019) |
| | | 2019 - 2020 | SBAS | ≈ 12 | Cigna y Tapete, (2022) |
| | | 2007 - 2011 | SBAS | ≈ 4 | Pacheco-Martínez et al., (2015) |
| | | 2007 - 2011 | SBAS | ≈ 2 | Chaussard et al., 2014 |

*Table 1 Compilation of subsidence zones (after different authors).*

According to several reports since 2009, there were records of discontinuities in several municipalities, including Zacatecas. Table 2 shows the record of discontinuities in local media, place, year of the note, description and source.

| Place | Year | Description | Source |
|---|---|---|---|
| Mazapil | 2016 | Inhabitants of the zone are notified to evict the affected community by a geological fault | (Mejía, 2016) – El Universal |
| Fresnillo | 2021 | Length of 160 meters, depth = 40cms and 40cm wide | (Burciaga, 2021) – El sol de Zacatecas |
| Loreto | 2022 | Length 150 m, width 2 m | (Serreano, 2022)- NTR |

*Table 2 Report of discontinuities in the state of Zacatecas performed by local media.*

The National Seismological Service (SSN) has a record of seismic events in the state since 1990, a total of 395 with magnitudes between 0.6 and 4.2. From these earthquakes, 117 occurred in 2019, 96 occurred in 2021 and after October 2022, 154 earthquakes have been recorded. This means that more than 90 % of the earthquakes have occurred from 2019 onwards. The location, magnitude, and depth of earthquakes from 2016 to the present are depicted in Figure 1-b and Figure 1-d. The origin of these earthquakes is still under discussion. On this regard, (Rosaura Rincón, 2020) proposed that the earthquakes have been caused by mining blasting near the city of Zacatecas, while (Ávila, 2020) mentions that the origin is tectonic, associated with faults near the city of Zacatecas.

## Discussion

Although the most important for risk mitigation is the identification of hazards, currently only 4 of 58 municipalities in the state of Zacatecas have a risk atlas, the reason for this is the cost involved in their elaboration, as reported by Román (2022). According to CENAPRED (2004) the first step for risk prevention is to identify the hazards or disturbing agents, and according to the existing NHAs, subsidence and associated terrain discontinuities have been identified as hazards due to mining and tectonic faults, but have not been included in these NHAs.

Currently, there are no studies that elucidate the origin of the discontinuities observed in the state of Zacatecas. However, given the climatic conditions, the excessive pumping, and the location of the discontinuities, we can associate them with subsidence due to groundwater extraction, at least those located in areas where subsidence has already been identified by InSAR image processing.

The reason for the increase of earthquakes in the state has not been studied and the genesis of these events has not been completely clarified, so more research is required to provide elements for the associated risk management; the two hypotheses presented could be considered by the effects of different types of subsidence; subsidence due to water extraction and subsidence due to mining extraction. Hernandez-Marin et al. (2020), have documented cases of subsidence-induced seismicity, this same phenomenon could be occurring in the state of Zacatecas, especially in earthquakes occurring in subsidence zones (Figure 1c).

Regarding the earthquakes whose epicenter is concentrated in the surroundings of the city of Zacatecas (Figure 1d), they are earthquakes that occur mostly at depths less than 2.5 km, and with magnitudes less than 2, while most of the earthquakes with epicenters outside this area are generated at depths greater than 2.5 km and with magnitudes of up to 4.2. Additionally, the location of the epicenters of the earthquakes occurred in the surroundings of the city of Zacatecas (Figure 1d) and corresponds to the mining areas that circumscribe the urban area of the city of Zacatecas and Guadalupe and are not aligned with the trace of the reported geological faults, suggesting a relationship between seismicity and mining activity.

## Conclusion

The state of Zacatecas is still at an early stage concerning integrated risk management due to subsidence and ground fracturing. Although there is information on which are the disturbing phenomena for the different municipalities, this information has not been included in the NPAs of the four previously mentioned.

At the moment in the state of Zacatecas, there are five active subsidence zones, with records up to 11 cm of annual deformation. Discontinuities of up to 160 meters long, 2 meters wide, and 40 centimeters deep have been recorded in 5 municipalities. The lower magnitude of the earthquakes near the urban area, the shallow depth at which they have been recorded, and the spatial coincidence with the location of mines in the area, suggest that they could be related to mining activity nearby.

The seismic activity could not be directly caused by mining activities such as blasting or mine collapse, but by some processes of reactivation of fault zones and tectonic fractures that affect the rock masses and that experience a change in the state of stress due to the excavation of tunnels. On the other hand, earthquakes with epicenters in subsidence zones seem to be similar to the cases of induced seismicity reported in the literature; however, more research is needed to verify this assertion.

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