

# From aquifers to salt to coal: some lessons on land subsidence and its socio-environmental impacts

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SubRisk Final Workshop; 27 February 2026



**GFZ** Helmholtz Centre  
for Geosciences

**HELMHOLTZ**

- Large parts of the world's population are going to face conditions of increasing water scarcity and food insecurity because of population increase and climate change
- Iran prominent example – significant increase of agriculture during last +30 years
- High increase in water demand for irrigation – 90% of total water usage in Iran
- Because of (semi)arid climate 50% of water supply originates from groundwater
- Result: wide-spread land degradation mainly in form of subsidence



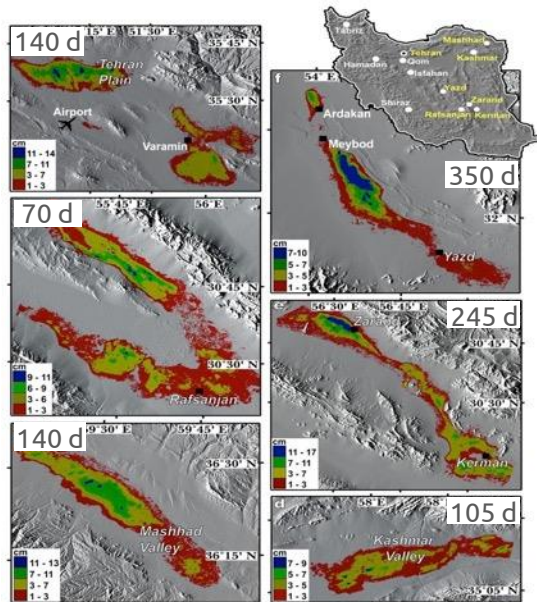
Land degradation near Shiraz, Photo M. Motagh, GFZ



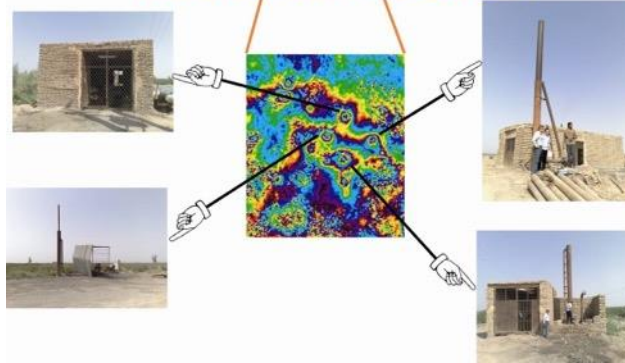
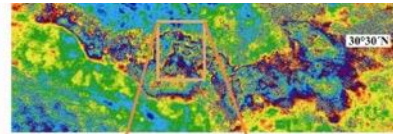
Zayandeh Rud River in Esfahan. Drying-out due to using discharge for agricultural purposes (CC-BY-SA-4.0) Photo Romain Bréget

# Land Subsidence in Iran

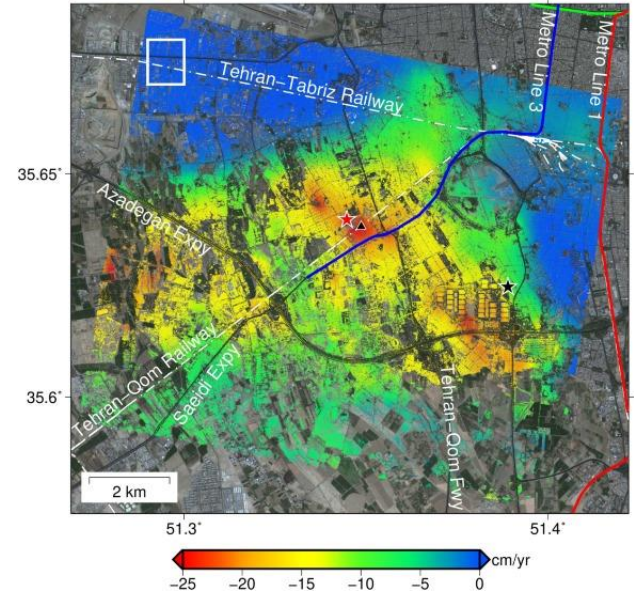
- A widely recognized problem
- The true extent is not fully understood yet



Envisat Survey  
(Motagh et al., GRL 2008)



Pumping wells identified in  
(Motagh et al., ENGEO 2017)



High-resolution TerraSAR-X map of subsidence rates in Tehran  
(Haghighi and Motagh, 2019)

# Sentinel-1 Survey of Land Subsidence in Iran

SCIENCE ADVANCES | RESEARCH ARTICLE

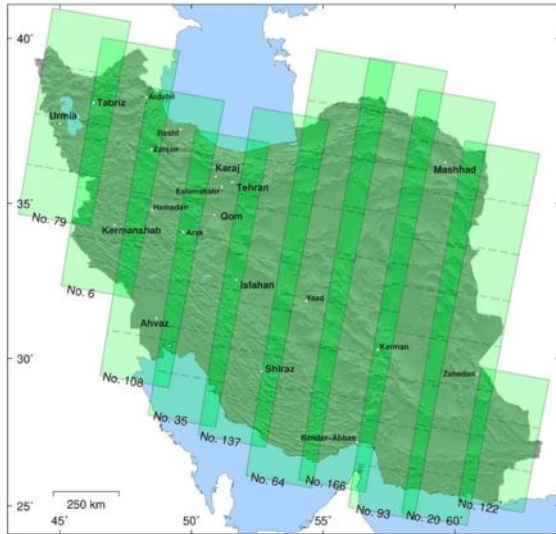
ENVIRONMENTAL STUDIES

## Uncovering the impacts of depleting aquifers: A remote sensing analysis of land subsidence in Iran

Mahmud Haghsheenas Haghighi<sup>1\*</sup> and Mahdi Motagh<sup>2,1</sup>

Intensive groundwater pumping, previously unrecognized in its full extent, is blamed for aquifer degradation and widespread land subsidence in Iran. We use a 100-meter resolution satellite survey from 2014 to 2020 to assess the recent implications of groundwater usage across the country. Results indicate that approximately 56,000 km<sup>2</sup> (3.5%) of the country's area is subject to land subsidence, primarily linked to irrigation; 3000 km<sup>2</sup> of this area experiences subsidence rates greater than 10 cm/year. The central plateau catchment hosts two-thirds of the country's depleting aquifers, with locations sinking at rates higher than 35 cm/year. The results suggest an annual groundwater depletion of 1.7 billion cubic meters (BCM) from confined and semiconfined aquifers, with the long-term inelastic compaction for most aquifers being approximately one order of magnitude larger than their seasonal elastic response. This underscores the permanent loss of aquifers that jeopardizes the sustainability of water resources across Iran.

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### Data analysis

- 2014-2021
- +6000 scenes
- Covering 1.6 million km<sup>2</sup>
- Method



PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science (2024) 92:593–607  
<https://doi.org/10.1007/s41064-024-00304-z>

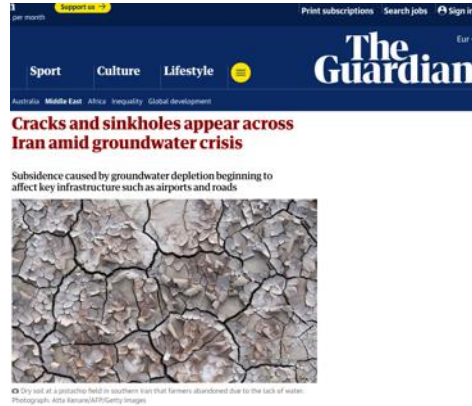
ORIGINAL ARTICLE



### Treating Tropospheric Phase Delay in Large-scale Sentinel-1 Stacks to Analyze Land Subsidence

Mahmud Haghsheenas Haghighi<sup>1</sup> · Mahdi Motagh<sup>1,2</sup>

Received: 14 April 2024 / Accepted: 27 June 2024 / Published online: 2 August 2024  
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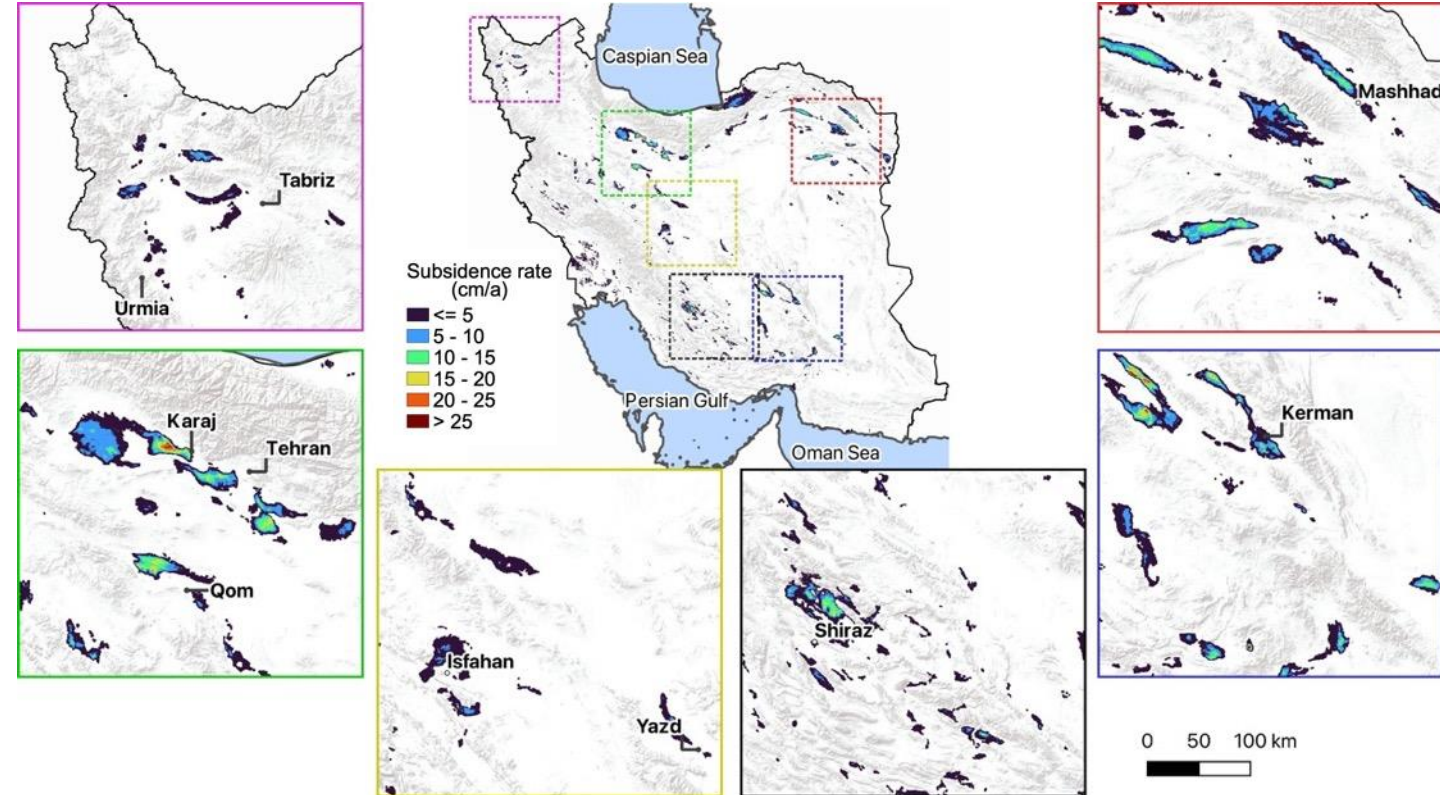


Official daily newspaper of the government of Iran



### L'Iran s'enfonçe à force de pomper ses nappes d'eau

**ENVIRONNEMENT** Une étude par satellite constate l'affaissement du sol dans une partie significative du pays, à un rythme qui dépasse localement 35 cm par an. En cause, le prélèvement des aquifères pour l'irrigation. À long terme, la situation serait intenable



**3.5% of total area in Iran ~ 56000 km<sup>2</sup> is subsiding**

**3000 km<sup>2</sup> > 10 cm/yr**

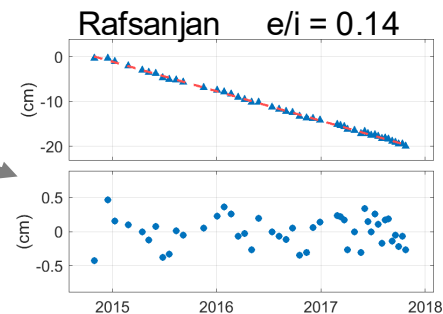
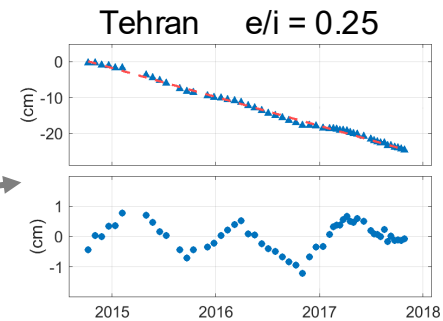
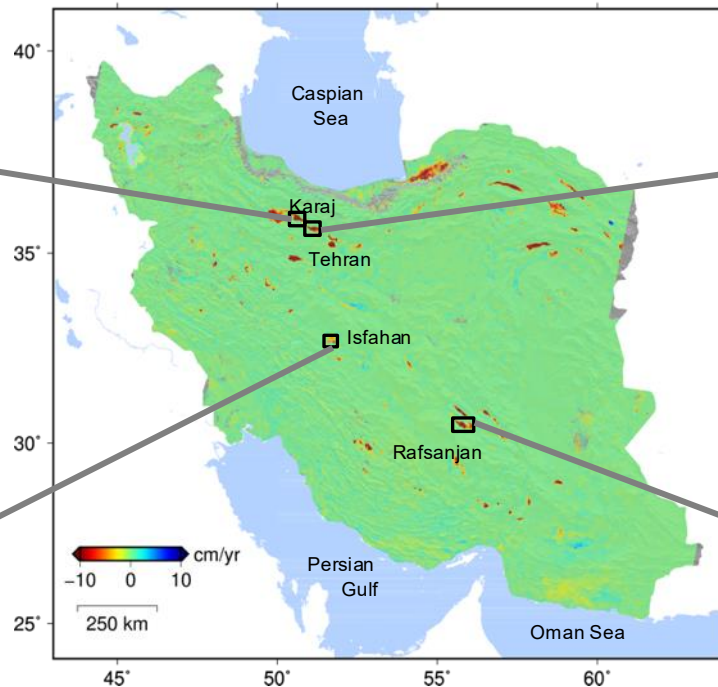
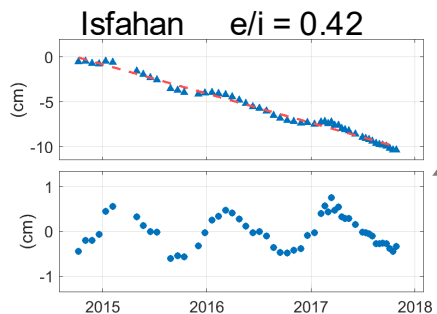
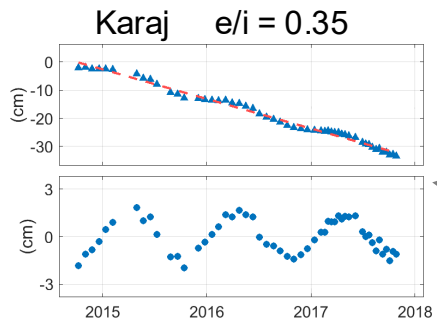
**40000 km<sup>2</sup> > 1 cm/yr**

**8 cities > 1000 km<sup>2</sup>**

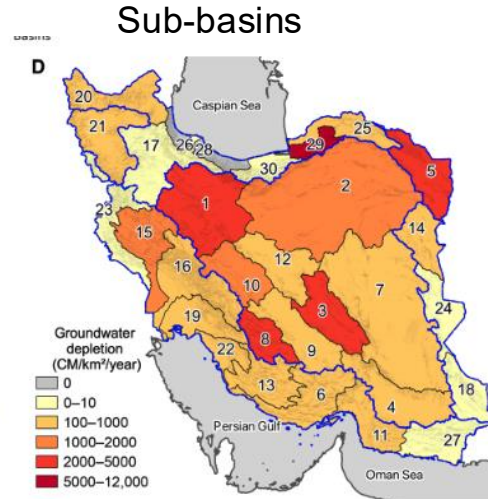
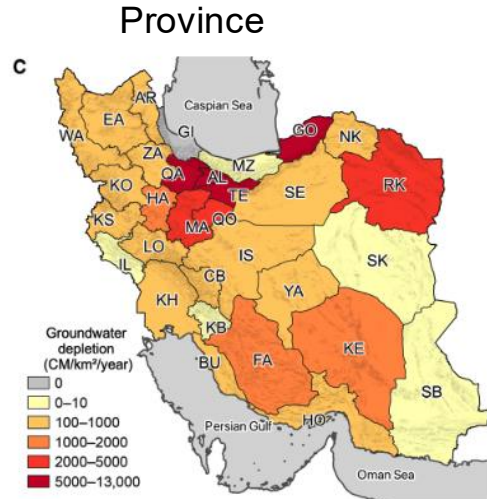
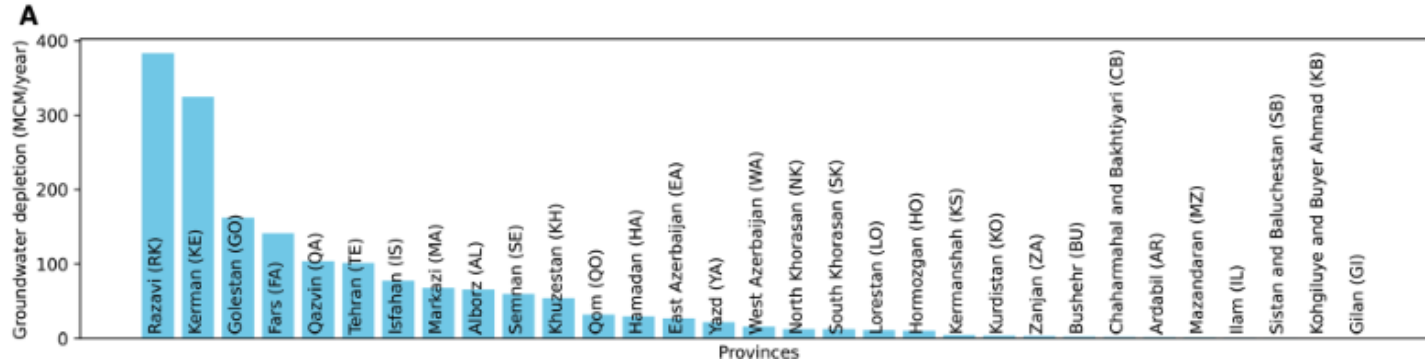
**> 260 cities affected**



# Assessment of Aquifer Health and Sustainability



# Groundwater budget crisis in Khorasan, NE Iran



Storage coefficient

$$S = \frac{\Delta w}{\Delta h}$$

Assumptions:  
Specific yield ( $S_y$ )  $\approx 0$   
Water compressibility ( $S_{sw}$ )  $\approx 0$

~~$$S = S_y + bS_s$$~~

~~$$S_s = S_{SK} + S_{SW}$$~~

$$S_{SK} = \frac{\Delta b}{b\Delta h}$$

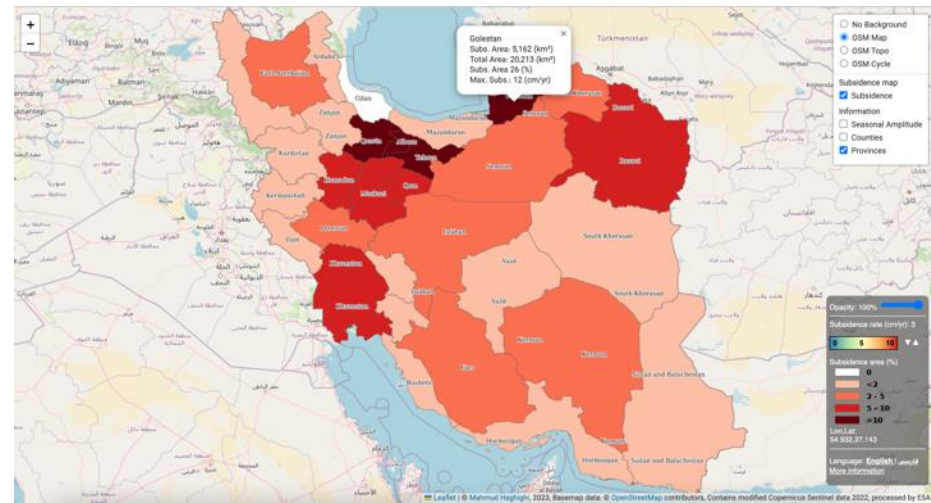
Loss volume

$$\Delta w = A\Delta b$$

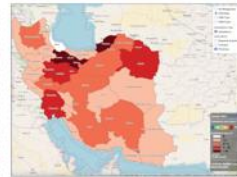
Subsidence area

Compaction

Smith 2020, Water Resources Research



**Payame Ma:** A daily newspaper dedicated to sustainable development in Iran



فرونشست تمام ایران را فرا گرفته

Societal impact in written press in Iran

## JGR Solid Earth

RESEARCH ARTICLE  
10.1029/2024JB030367

**Special Collection:**  
Solid Earth Geophysics as a  
means to address issues of global  
change

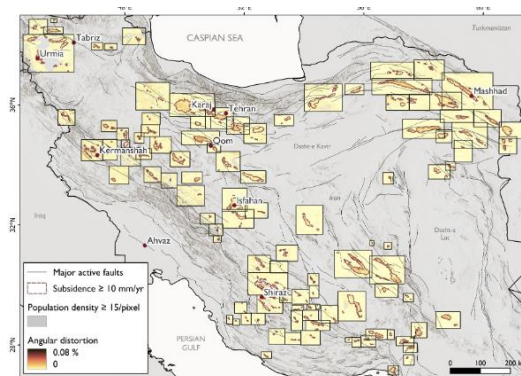
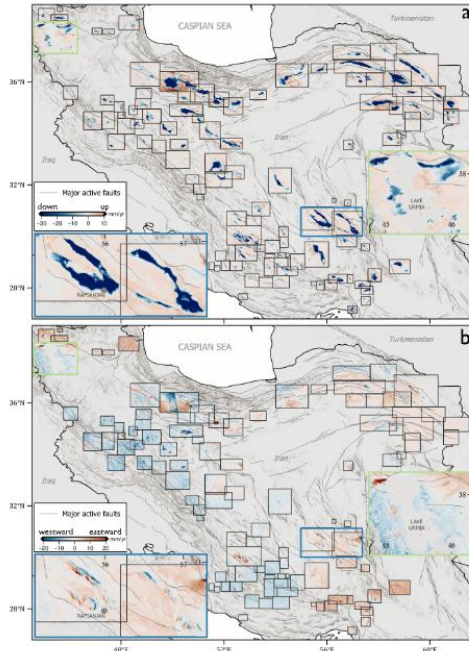
**Key Points:**

- We measure the rates and spatial patterns of subsidence in vertical and

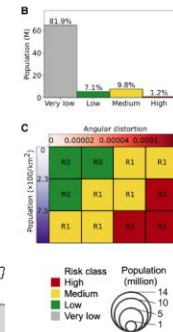
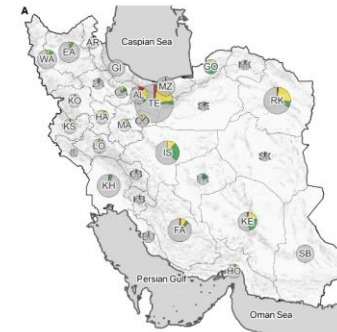
### Widespread Extent of Irrecoverable Aquifer Depletion Revealed by Country-Wide Analysis of Land Surface Subsidence Hazard in Iran

Jessica A. Payne<sup>1</sup>, A. R. Watson<sup>2</sup>, Y. Maghsoodi<sup>3</sup>, S. K. Ebmeier<sup>1</sup>, R. Rigby<sup>2</sup>, M. Lazecký<sup>4</sup>, M. Thomas<sup>5</sup>, and J. R. Elliott<sup>1</sup>

<sup>1</sup>COMET, University of Leeds, Woodhouse, Leeds, UK, <sup>2</sup>SatSense, Nexus, Discovery Way, Woodhouse, Leeds, UK, <sup>3</sup>School of Earth and Environmental Sciences, University of Exeter, Penryn, UK, <sup>4</sup>University of Leeds, Woodhouse, Leeds, UK



Payne et al., 2025



H. Haghighi and Motagh 2024

## Geophysical Research Letters

RESEARCH LETTER  
10.1029/2023GL110497

**Key Points:**

- Largest database of land subsidence rates was compiled
- First global map of land subsidence rates was produced
- Comprehensive zonal statistics were calculated

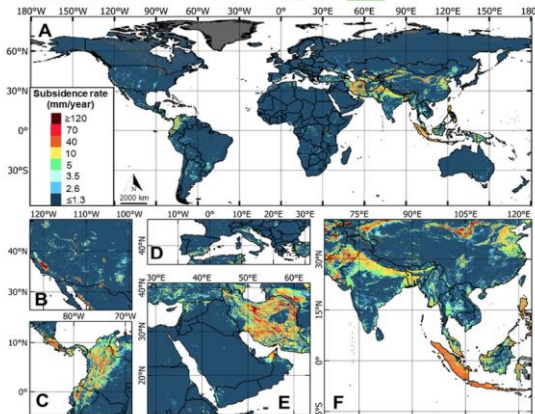
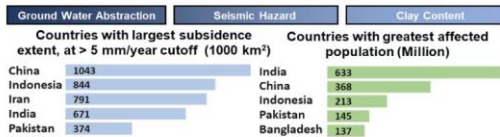
### Unveiling the Global Extent of Land Subsidence: The Sinking Crisis

Tsimur Davydzenka<sup>1</sup>, Pejman Tahmasebi<sup>1</sup>, and Nima Shokri<sup>2</sup>

<sup>1</sup>Colorado School of Mines, Golden, CO, USA, <sup>2</sup>Institute of Geo-Hydroinformatics, Hamburg University of Technology, Hamburg, Germany

**Abstract** Land subsidence, referring to the vertical sinking of land surface, is a significant geohazard

#### Top 3 predictors that positively affect land subsidence rate



## Iran. Subsidence

### Sinking ground risks making Tehran 'unlivable'

Cracks caused by drought and decades of neglect also pose threat to ancient heritage sites

BY SA GAFFARI — TEHRAN  
JANA TAUSCHINSKI — LONDON

A long-running challenge in Iran has recently taken on added urgency: the ground is sinking beneath people's feet, damaging vital infrastructure and endangering public safety.

Iran suffers from some of the worst land subsidence in the world, brought on by drought, climate change and poor water management. Cracks threaten its main airport and UNESCO sites such as the ancient city of Persepolis, while dozens of schools were evacuated in one city because of fears of collapse last year.

The situation is particularly dire in and around urban areas including Tehran, where cracks have damaged railway tracks and homes have become unstable.

This prompted President Masoud Pezeshkian in its recent months even made the idea of moving the capital, saying that the "menacing" phenomenon of sinking ground, coupled with acute water scarcity, was making Tehran "unlivable".

Experts have said that the idea of relocating the capital would be impractical. But the intervention from the country's highest elected official has rekindled debate about the risks posed by a problem that directly affects about half of all Iranians.

"Subsidence has become a huge challenge," said Mehdi Fakhali, a member of Tehran city council. He warned the "massive land sinking will destroy infrastructure and threaten lives" unless it was addressed urgently.

Prolonged drought conditions and decades of inefficient environmental governance have intensified subsidence, according to specialists working in the area. One recent global study said Iran was among the world's top five countries in terms of the extent and rate of subsidence.

Iran's National Cartographic Centre has calculated that southwestern Tehran was sinking by up to 33cm a year. Even an annual subsidence rate of 5mm is deemed concerning by international standards.

In Tehran's Shah-e Ray neighborhood, people fix their doors and windows every year as subsidence pulls at

**Iran's land subsidence**  
Subsidence rate (mm per year)

North-eastern Iran has some of the highest subsidence rates globally, as land sinks at more than 200mm per year in many areas

Subsidence rates are modelled based on observational data and environmental parameters  
Source: Earthsystems, Tahmasebi & Shokri (2023)

**Damage to the foundations, said Mohammad Davarikh, an environmental activist.**

Main rail lines including those linking Tehran and Mashhad needed to be repaired "many times" because of subsidence, which also caused power transmission towers to tilt and the highway between Isfahan and Shiraz to sink, he added.

The government plans to reduce water consumption in agriculture and industry by 45bn cubic metres a year by 2032 as part of efforts to address the water crisis that exacerbates subsidence.

But the cash needed to tackle the problem is hard to come by, as US sanctions throttle the economy.

The scale of the challenge is vast. Subsidence directly threatens 11 per cent of the country's land mass — an area that is home to almost half of its 90m people, Iran's vice-president for environmental affairs Shima Ansari said recently.

Ground fissures have also formed around Persepolis, the ancient Persian capital that dates back 2,500 years, as well as nearby archaeological site of Naqsh-e Rostam, resting place of four Achaemenid kings where massive rock reliefs are carved into a mountain.

Baharan Nadi, a professor of geotechnical engineering at the Islamic Azad University in Isfahan, blamed "unchecked urban sprawl, industrial development and excessive farming" in places where dams were already running dry and aquifers depleted. "It was both 'accelerating ground-level sinking' and contributing to desertification."

The subsidence has led cracks to appear in Isfahan's UNESCO-listed Jameh Mosque and some of the buildings and monuments that line Naqsh-e Rostam Square, he said. The eastern and western columns of the square's Abast

**Continuing agriculture policies of the past will 'accelerate the problem across Iran in the years to come'**

mosque tilted by 5cm and 6cm and cracks were visible at the stone bases, Nadi added.

Hassan Farooqi, secretary-general of the Iranian National Commission for UNESCO, said the UN entity would provide "assistance" to protect heritage sites from subsidence. But he also warned of a worst-case scenario in which UNESCO revoked world heritage site titles "if its guidelines are not adhered to and the monuments are damaged".

The lighter side of Iran's subsidence problem was highlighted by a recent viral video in which a group of bikers rode inside the dried up reservoir of the Larian dam near Tehran. It is one of four main suppliers of water in the capital and its satellite towns. All are close to running dry.

Mehdi Zari, a professor of engineering seismology at the International Institute of Earthquake Engineering and Seismology in Iran, warned the country appeared to be locked into an "unsustainable" pathway that would only get worse. "Continuation of past policies in agriculture and urban planning will accelerate subsidence across Iran in the years to come," he said.



Tot. population ~ 1 million inh.  
15<sup>th</sup> of February 2018 **intense rainfall**  
3<sup>rd</sup> of March 2018 **seismic shock of magnitude 2,4mR**



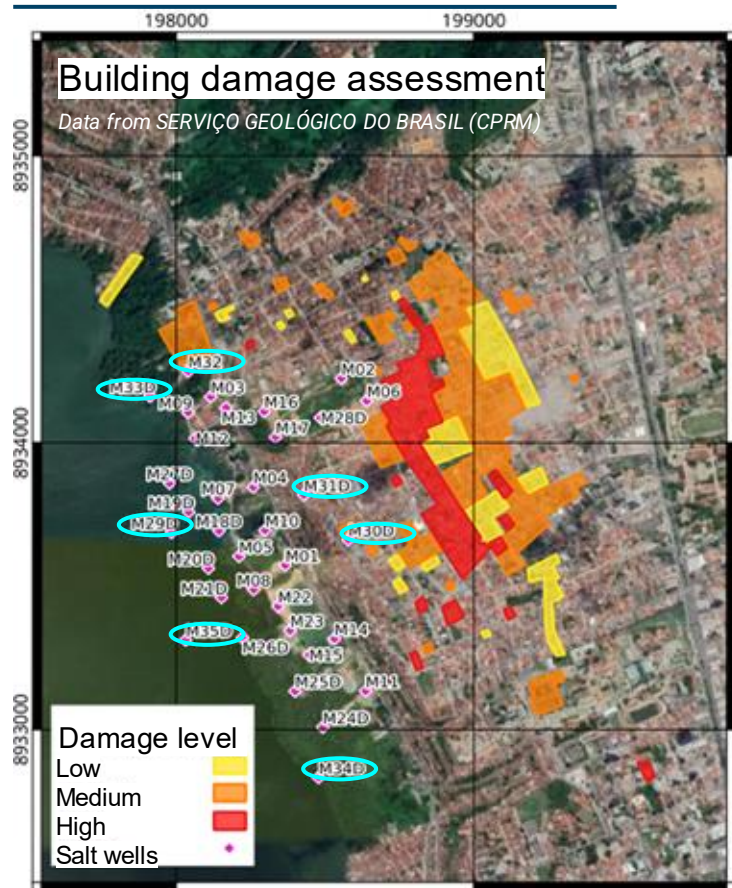
## Social impact (as in 2023):

- Population relocation of more than 60,000 residents;
- 14000 houses under demolition order.



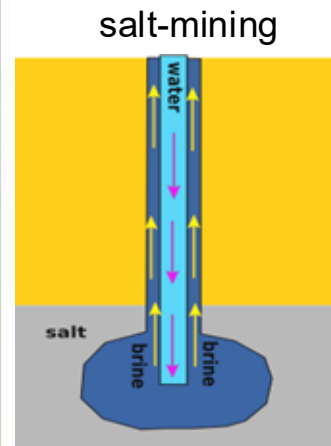
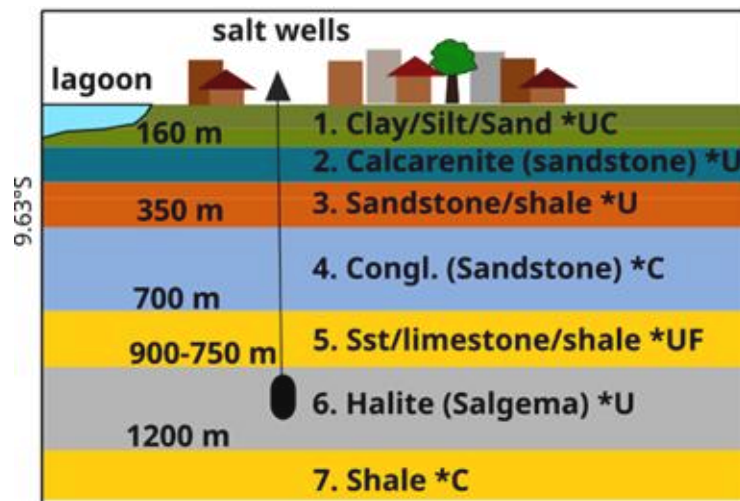
Photo: ERALDO PERES/AP

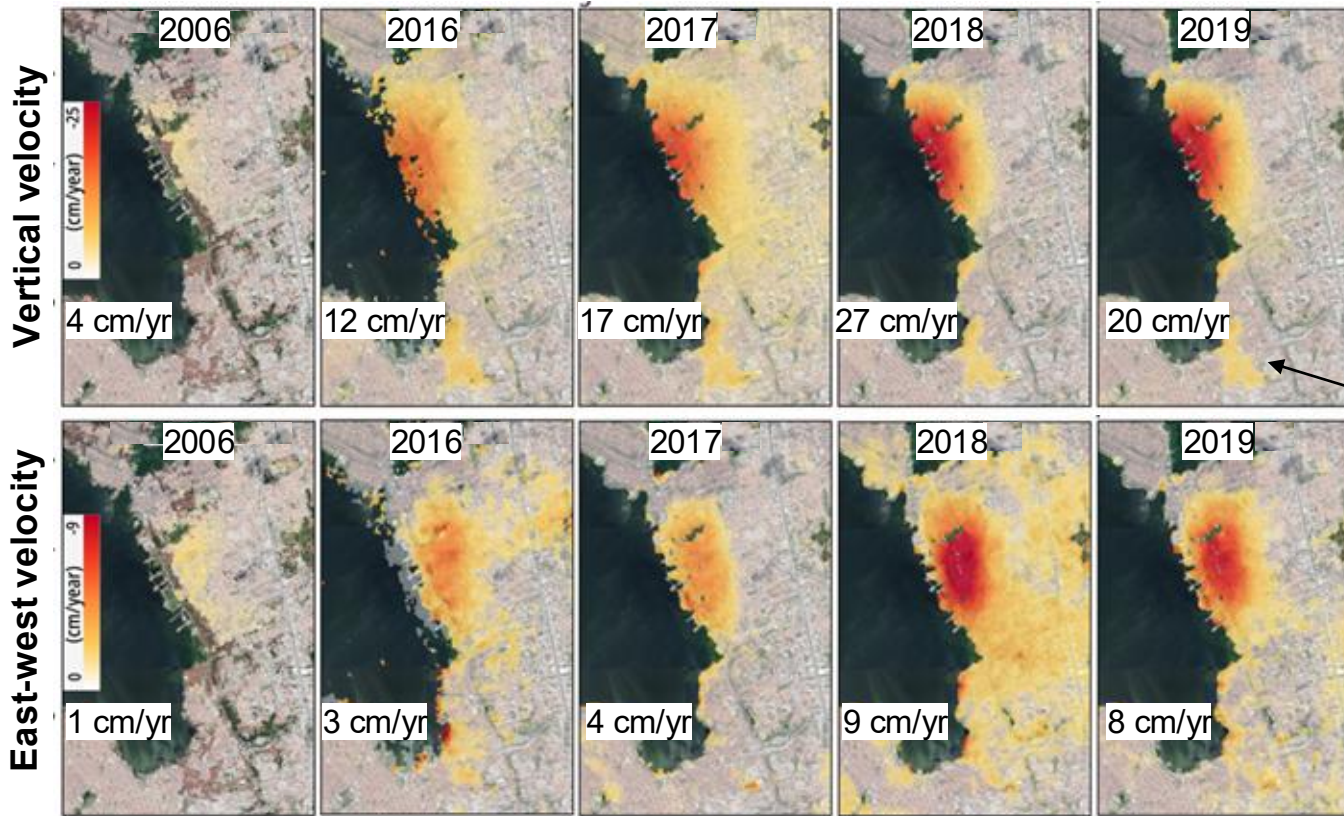




## Salt solution mining:

- **35 wells** installed since **1970**;
- Cavities depth between **550-1100 m**;
- Pressure of extraction **~2.758 MPa**;
- In 2018, **7 wells still active**;
- 2°half of 2019 all wells have been stopped;
- Mining company denied any responsibilities.



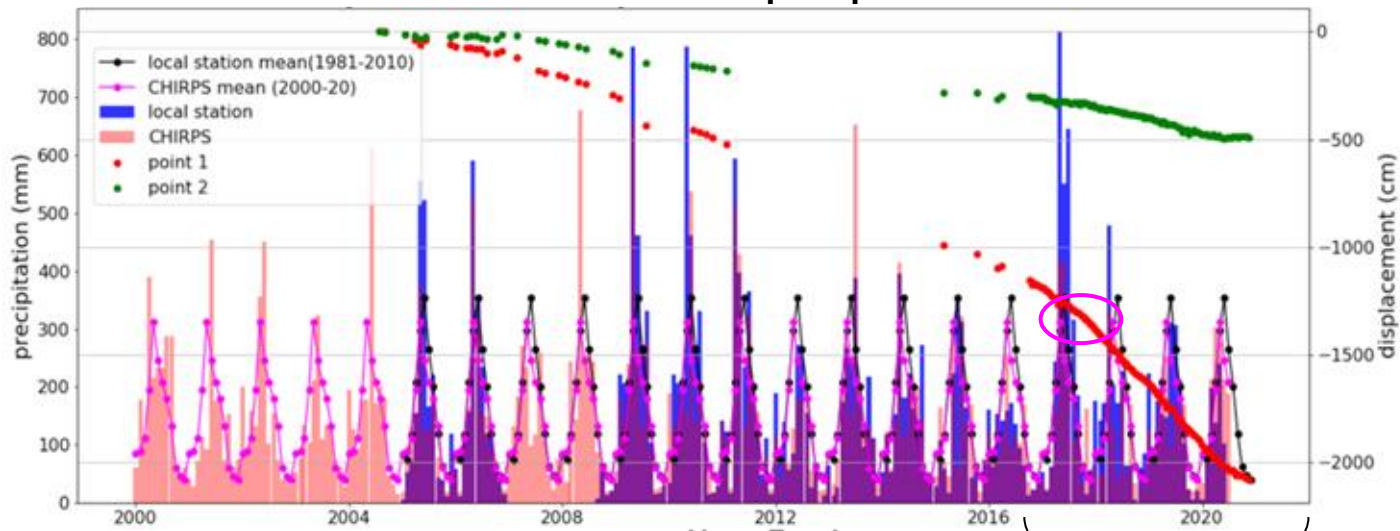
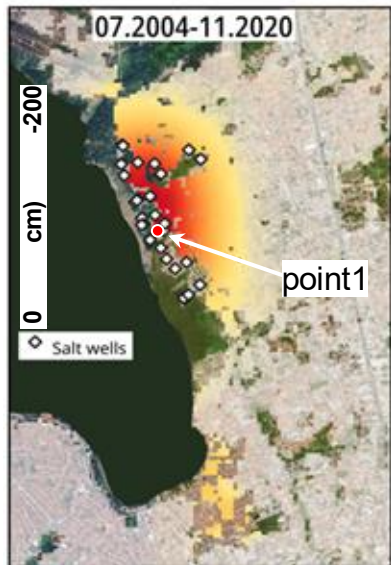


- Max. subsidence close to the lagoon shore;
- Deformations already visible in 2006;
- Increase in velocity during the years.

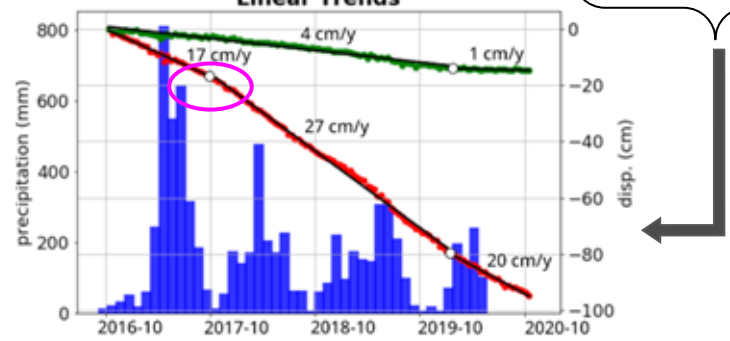
second subsiding area

- Westward motion;
- Max. horizontal disp. inside the urban area;
- Increasing in time as vertical deformations increases.

## Time-series: subsidence vs precipitation

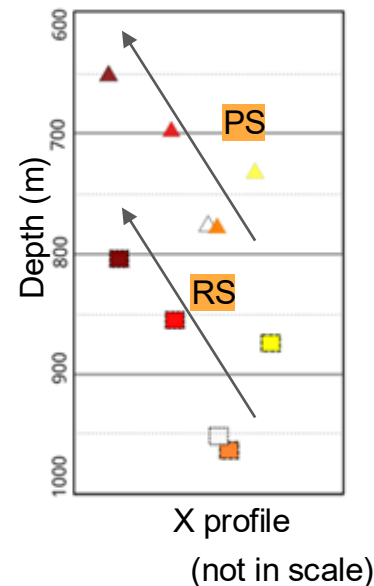
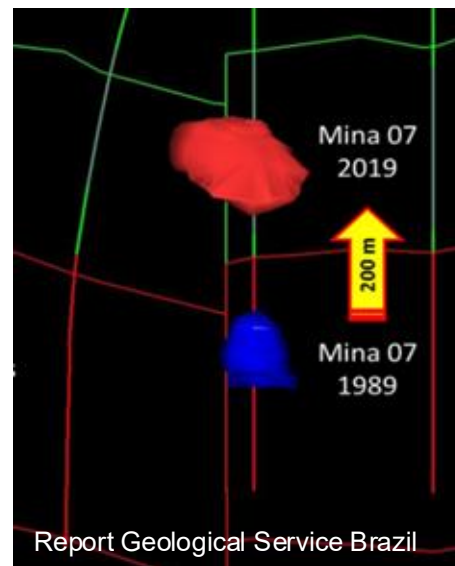
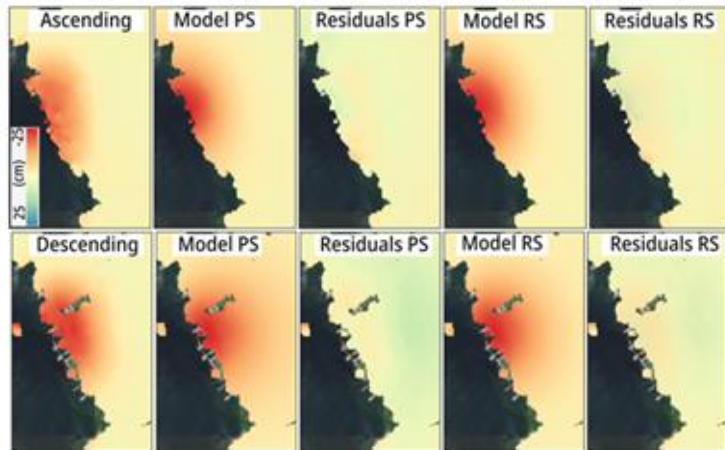


### Linear Trends



- Max. cumulative disp. of **2 m** at the lakeshore;
- Subsidence of **4 cm/yr** already in **2004/2005**;
- **Gradual intensification** to **17 cm/yr** in **2016**;
- **Sudden acceleration** to **27 cm/yr** in the second half of **2017**.

Time interval	Point pressure source (PS)		Rectangular crack 600x150m (RS)	
	Vol. loss (m <sup>3</sup> )	Depth (m)	Vol. loss (m <sup>3</sup> )	Depth (m)
03.2015-03.2016	3.9E+05	774	3.0E+05	953
03.2016-03.2017	3.6E+05	730	2.7E+05	873
10.2016-10.2017	5.3E+05	777	4.2E+05	962
10.2017-09.2018	5.8E+05	697	4.6E+05	857
09.2018-09.2019	5.4E+05	653	4.4E+05	807



- Sources located in the **center of the salt wells** and oriented as the salt wells distribution;
- **Horizontal location** orientation **stable** in the years;
- Same **depth** of the **salt cavities**: 550-1100 m
- The source is **moving upward**.



## scientific reports

Article | [Open Access](#) | [Published: 08 April 2021](#)

# A decade-long silent ground subsidence hazard culminating in a metropolitan disaster in Maceió, Brazil

[Magdalena Vassileva](#) ✉, [Djamil Al-Halbouni](#), [Mahdi Motagh](#), [Thomas R. Walter](#), [Torsten Dahm](#) & [Hans-Ulrich Wetzel](#)



### Terrawatch: a saltmine and a sinking city in Brazil

More than 6,000 buildings in Maceió condemned and research suggests more subsidence to come



© Jose Ronaldo Zanarro photographs damage to his home in Maceió. Photograph: Amanda Perrelli/Reuters

### Die versinkende Stadt

Im Strandparadies Maceió sieht es apokalyptisch aus. Ganze Viertel sind entrükkert. Was ist hier passiert? Ein Industrie- und Umweltkrimi aus Brasilien. Mithrénie: eine Forscherin aus Deutschland

von TORSTEN DAHM



December 2022, Maceió

Maceió

Técnicos da Defesa Civil  
acessam área interdita para  
monitoramento do solo  
próximo à mina 18



TNH1 | 06/12/23 - 07h12



Foto: Reprodução/TV Pajuçara

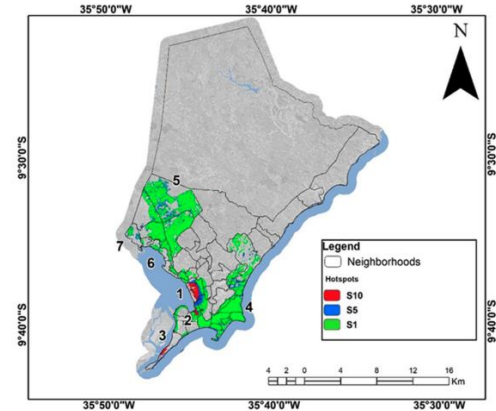
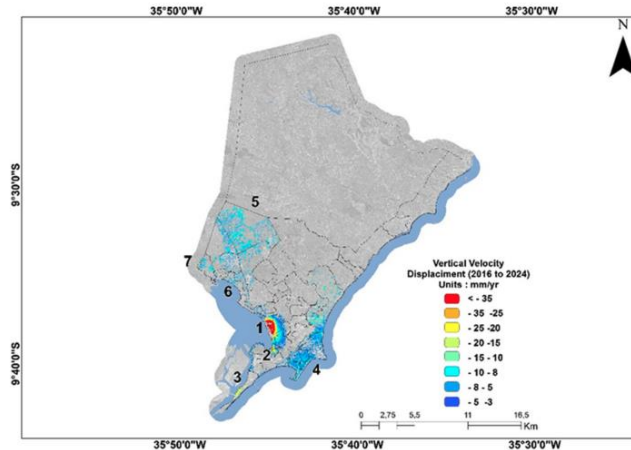


Article

## Beyond Salt Mining: Urban Subsidence Hotspots Characterization in Maceió (Brazil), 2016–2024

Thyago Anthony Soares Lima <sup>1,2</sup>, Magdalena Stefanova Vassileva <sup>3</sup>, Zhuge Xia <sup>4,\*</sup> and Silvio Jorge Coelho Simões <sup>1,2</sup>

- <sup>1</sup> Institute of Science and Technology, São Paulo State University (Unesp), São José Dos Campos 12245-000, SP, Brazil; tas.lima@unesp.br (T.A.S.L.); silvio.simoes@unesp.br (S.J.C.S.)
- <sup>2</sup> Graduate Program in Natural Disasters, (Unesp/CEMADEN), São José Dos Campos 12247-016, SP, Brazil
- <sup>3</sup> Formerly at GFZ Helmholtz Centre for Geosciences, 14473 Potsdam, Germany; magda88@gfz-potsdam.de
- <sup>4</sup> School of Earth Sciences and Engineering, Hohai University, Nanjing 210098, China
- \* Correspondence: zhugexia@hhu.edu.cn

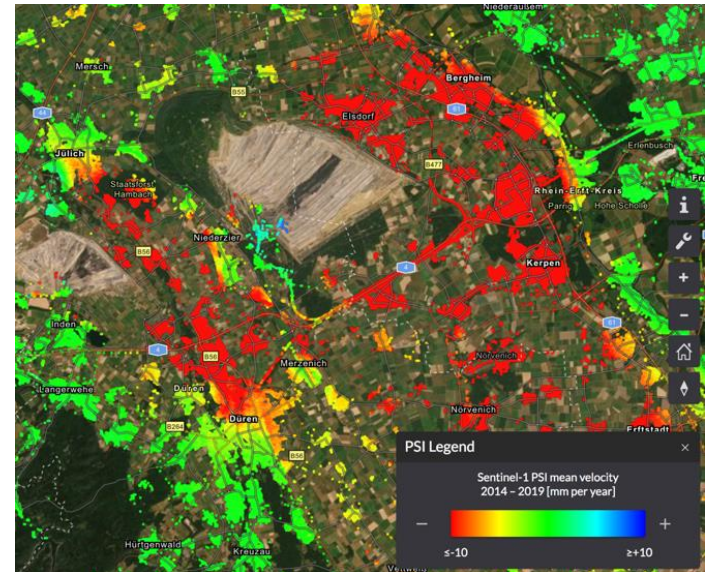
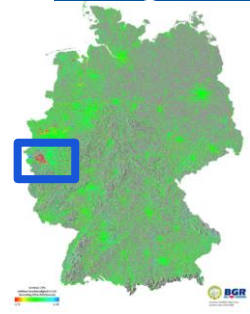


**Figure 11.** Spatial extent of operational subsidence classes across Maceió, as determined by SBAS-InSAR (2016–2024). S1 (green) = low but persistent subsidence ( $-5 < v \leq -3 \text{ mm yr}^{-1}$ ); S5 (blue) = moderate ( $-10 < v \leq -5 \text{ mm yr}^{-1}$ ); S10 (red) = high/priority ( $v \leq -10 \text{ mm yr}^{-1}$ ).





**May 2023, visit by the municipality and civil protection authorities in Maceio, Brazil**



# Caution in InSAR-based Risk Assessment

before demolition

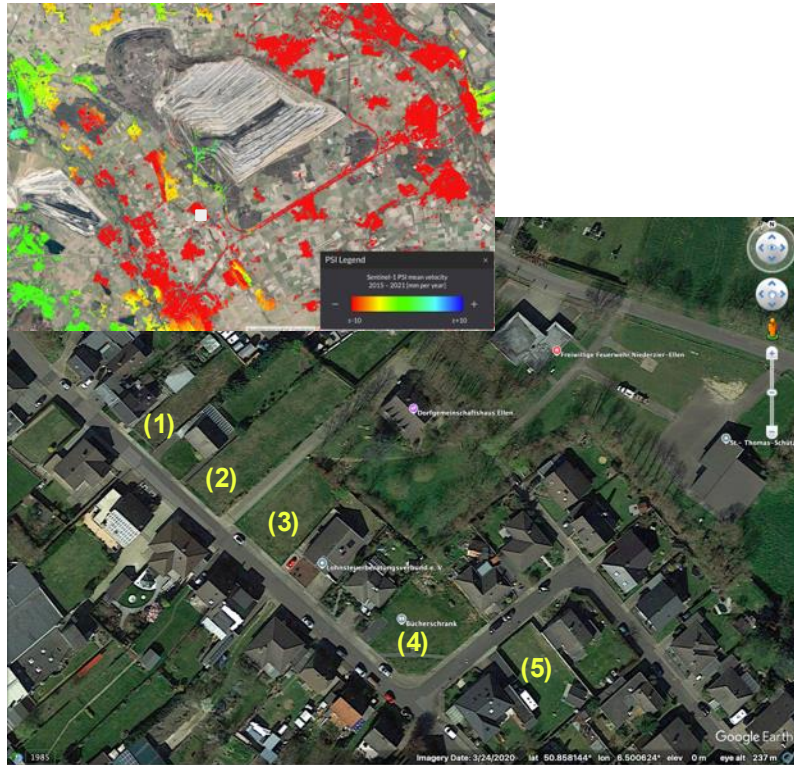
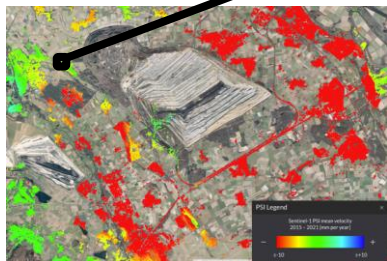


Image Credit: Wolfgang Schaefer





# Thank You for Your Attention!



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