



Greater Tehran is home to about 13 million people.

IRAN

Tehran's drastic sinking exposed

Satellites reveal city is subsiding by 25 centimetres a year.

BY KATE RAVILIOUS

Tehran, western Asia's most populous city, is sinking.

Now, detailed satellite images reveal the extent of the problem, showing that some parts of the Iranian capital are falling by as much as 25 centimetres a year, and that the collapse is spreading to encompass the city's international airport (see 'Feeling low').

Geoscientists Mahdi Motagh and Mahmud Haghshenas Haghighi, both at the GFZ German Research Centre for Geosciences in Potsdam, used satellite data to monitor subsidence¹ across the Tehran region between 2003 and 2017.

Previous work² had shown that the capital is sinking, and had linked the subsidence to the depletion of groundwater aquifers, which are being sucked dry to irrigate nearby farmland and serve Greater Tehran's 13 million or so residents³.

The latest data put new figures on the problem. The western Tehran Plain — a mix of Tehran's urban sprawl, satellite cities and agricultural land — is subsiding at a rate of 25 centimetres per year, and the Varamin Plain, an agricultural region to the southeast of the city, is falling at a similar rate. The city's international airport — located southwest of the centre — is sinking by 5 centimetres annually.

"These are amongst some of the highest

current rates of subsidence in the world," says Roberto Tomás, an engineer at the University of Alicante in Spain.

LOSING GROUND

Subsidence, caused by growing populations and increased extraction of underground water, oil and gas, is a problem in cities globally. Previous satellite measurements have shown, for example, that some areas of Jakarta are sinking more than 20 centimetres per

year⁴, and the San Joaquin Valley in California — home to several cities — by up to 60 centimetres per year.

The latest study¹, which has been accepted for publication in *Remote Sensing of Environment*, estimates that around 10% of Tehran's urban area is affected, along with many satellite towns and villages to the city's southwest. "When walking around these areas, we see uneven street surfaces, shifted curbs, cracks in the walls and even tilted buildings, some of which have had to be demolished," says Motagh.

Huge fissures — several kilometres long and up to 4 metres wide and deep — have opened up in the land to the southeast of Tehran, and some are threatening to topple power-transmission lines and buckle railways.

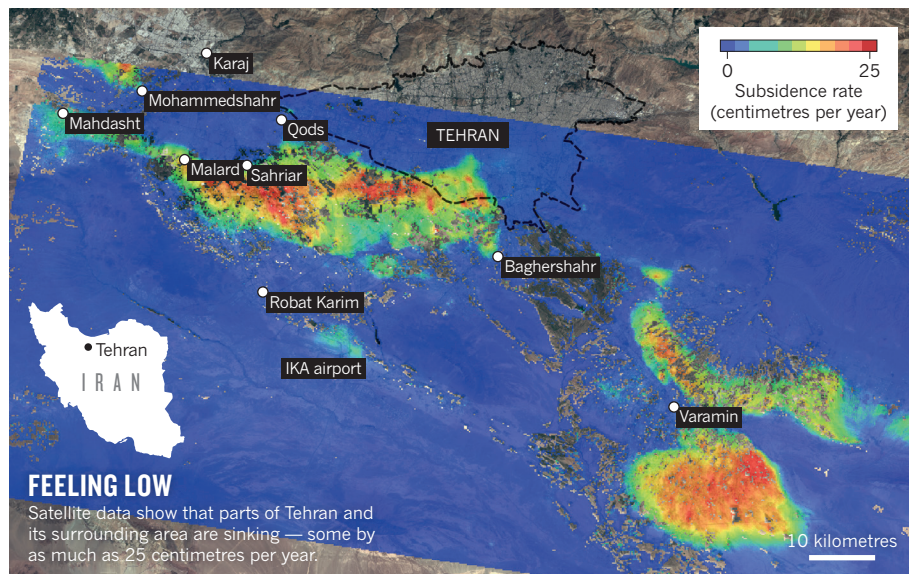
And the growth of underground cracks sometimes produces sudden sinkholes. "One farmer I met was locked up for hours when the ground gave way beneath him and he fell into a 6-metre-deep crack," says Ali Beitollahi, head of engineering seismology at the Building and Housing Research Center in Tehran. Some farmland is becoming unviable, because the cracks drain irrigation water from the surface and leave crops parched.

DRY EARTH IN IRAN

Surveys carried out over the past year by Beitollahi and his colleagues estimate that the areas with significant subsidence in and around Tehran host 120 kilometres of railway, 2,300 kilometres of road, 21 bridges, 30 kilometres of oil pipeline, 200 kilometres of gas pipeline, 70 kilometres of high-voltage electricity lines and more than 250,000 buildings.

Motagh and Haghshenas Haghighi's data show how the subsidence has marched steadily eastwards since 2003, starting with agricultural land and encroaching on the urban fringes of the city. Another subsidence zone is creeping towards Tehran's airport.

A combination of population growth ►



MEHMETO/ALAMY

SOURCE: M. HAGHSHENAS HAGHIGHI & M. MOTAGH (ANALYSIS)/COPERNICUS SENTINEL 2015–17 (DATA)

► — the city's population has doubled in the past 40 years — droughts and large dams, which capture rainwater and prevent aquifers from recharging, has exacerbated the problem.

The authorities are fighting a losing battle as they try to regulate water extraction. Beitollahi thinks that some 100,000 illegal wells have been blocked across Iran, but that an estimated 30,000 are still in operation

across Greater Tehran.

The sinking that has already happened might be irreversible, the study hints. By looking at water-depth measurements from wells in the affected areas, the researchers found that the ground is failing to bounce back, even after rainfall, which suggests that the porosity of the rock has been permanently lost. That loss could lead to more flash flooding, says

Linlin Ge, an engineer at the University of New South Wales in Sydney, Australia, because without pores in the rock, the water no longer has anywhere to go. ■

1. Haghshenas Haghighi, M. & Motagh, M. *Remote Sens. Environ.* (in the press).
2. Pirouzi, A. & Eslami, A. *Int. J. Geo-Eng.* **8**, 30 (2017).
3. Motagh, M. *et al. Geophys. Res.* **35**, L16403 (2008).
4. Abidin, H. Z. *et al. Nat. Hazards* **59**, 1753 (2011).

ARCHAEOLOGY

Geologists track ancient sites' bullet wounds

The ultimate goal is to inform efforts to conserve or repair heritage sites.

BY SARAH WILD

In 2015, Lisa Mol stared at a series of satellite images, distraught. The before-and-after pictures showed how the Islamist terrorist group ISIS had damaged the ancient Syrian city of Palmyra with explosives and bulldozers. An oasis in the desert, Palmyra had been a cultural meeting place in the first and second centuries AD, and contained the fingerprints of many civilizations.

"Seeing that deliberate destruction pushed me into taking action," says Mol, a geomorphologist at the University of the West of England in Bristol. "I am not a lawyer, I cannot do anything medical, but I do know rocks."

Mol, who specializes in rock art and rock deterioration, is now spearheading an initiative — the first of its kind — to quantify and catalogue the impacts of bullets in rock at a heritage site in the Middle East. The eventual goal is to inform efforts that aim to conserve or repair such sites.

Typically, people look at the effects of conflict on a site in its totality, rather than at individual instances of damage, says Robert Bewley, who specializes in endangered archaeology at the University of Oxford, UK. "The science into what's going on is very important," he says. "If there is no science, people may say, 'Let's just slap concrete over it and it will be fine.' It won't."

BALLISTIC EXPEDITION

Satellite imagery has been used to identify damage in conflict areas, such as Syria and Libya. But there is a dearth of information about how stone structures weather after ballistic damage, despite the fact that ancient sites are often casualties of war — and have been for centuries. "I saw something that needed doing, and built up a team," Mol says.

Mol's team, comprising a palaeontologist,



Bullet damage on rock art at Wadi Rum, a site of prehistoric human settlement in Jordan.

two geomorphologists, a heritage specialist and an archaeologist, returned in September from an expedition to Wadi Rum, a heritage site in Jordan. Wadi Rum is home to rock paintings, engravings and archaeological remains that document millennia of human habitation, and it wears the scars of conflicts old and new. The rocks' physical characteristics, or lithology, are also similar to those in areas such as Syria, where safety issues are too great for researchers to make expeditions.

The team hopes ultimately to develop step-by-step guidelines for locals to identify and catalogue ballistic damage to heritage sites — for use in Jordan and beyond. Residents could record and communicate their findings using an information sheet, or send images to researchers

by e-mail or through an app, says Mol.

But the researchers must first determine which stone properties are most crucial for tracking ballistic damage and environmental degradation. "We can't simplify to that level without the high-level scientific understanding," says Mol.

The bullet damage at Wadi Rum spans decades, from guerilla conflict in the early twentieth century to damage from AK-47 guns in the past few months, thought to have been caused by people using rocks for target practice. Over the decades, munitions have changed — as has the extent of the harm they cause. How badly weathering worsens after ballistic hits depends on many factors, including weapon type, rock composition and climate. This degradation

LUCY CLARKE