

► — 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 Haghghi, 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

can be as harmful as the initial bullets, says Bewley, but is not well studied.

During their expedition, Mol's team collected data on the surface hardness, resistivity and permeability of rocks, both at points of impact and in undamaged rock. They will combine these data with 3D images of the surface morphology to calculate the size, depth and shape of impacts, as well as the fractures that run along the surface.

In Mol's lab, researchers will shoot guns at rocks to test the microstresses caused by bullet impacts from different weapons — and compare the results with the data from Wadi Rum to work out which weapons created which impacts, and how damage plays out in the rock.

But even with rich on-the-ground data, it can be difficult to determine exactly who shot at the sites and when. Historical conflict is a likely culprit for some of the damage at Wadi Rum, says Kaelin Groom, a geographer at Arizona State University in Tempe who is on the team. But many of the impacts are known to be from acts of vandalism. The researchers also interviewed local residents to narrow the time frames and identify possible shooters.

Heinz Ruther, a geoinformatician at the University of Cape Town in South Africa, says that he's not aware of other researchers doing such ballistic work. Being able to quantify the extent of conflict damage to heritage sites

would be very relevant, says Ruther. So many buildings are affected or destroyed by war, he says, but partial damage is seldom considered.

MEMORIAL SCARS

But there is more to heritage conservation than scientific understanding. Local stories and knowledge about the bullet impacts affect how the sites should be conserved, says Rachel

“If there is no science, people may say, ‘Let’s just slap concrete over it and it will be fine.’”

King, an archaeologist at University College London who was part of the expedition. Some residents think that certain bullet damage should not be repaired but should instead stand as warning against vandalism or as a reminder of the conflict that caused it.

Mohammad Dmayan Al-Zalabiah's family has lived in Wadi Rum since the early nineteenth century. A tour guide, Al-Zalabiah was part of a US programme aimed at managing cultural heritage resources in Jordan. He worked to create a database of local rock art and inscriptions at the site, and helped Mol and her team to collect data about bullet damage. He thinks that the ballistic research has value for the community, because it highlights the extent of bullet damage and dissuades vandals.

“You can't understand something as complex as the physical damage to heritage,” says Groom, “without social outreach, ethnography and geology.” ■

CLARIFICATION

Some phrasing in the News Feature ‘Does science have a bullying problem?’ (*Nature* **563**, 616–618; 2018) did not make it clear that Nazneen Rahman resigned from the Institute of Cancer Research before the Wellcome Trust revoked her funding.

CORRECTIONS

The News Feature ‘Against all odds: science in the Palestinian territories’ (*Nature* **563**, 308–311; 2018) located Mohammad Herzallah at the wrong campus. He is in Newark, not Piscataway.

The News story ‘Mystery supernova known as ‘Cow’ spills its secrets’ (*Nature* **563**, 168–169; 2018) omitted to cite an important reference for the discovery: S. J. Prentice *et al.* *Astrophys. J.* **865**, L3 (2018).

The News Feature ‘The sun dimmers’ (*Nature* **563**, 613–615; 2018) said that David Keith received money from the Bill & Melinda Gates Foundation. In fact, the money came directly from Bill Gates.

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