INSIGHTS

PERSPECTIVES

GEOPHYSICS

Earth's sinking surface

China's major cities show considerable subsidence from human activities

By **Robert J. Nicholls**[1] *and* **Manoochehr Shirzaei**[2,3]

Subsidence, the lowering of Earth's land surface, is a widespread and sometimes dramatic process. Potentially 19% of the global population is at high risk of being affected by this process (*1*). Such sinking is caused by a range of natural or anthropogenic factors, including human-induced underground fluid withdrawal, which is generally considered the most important driver. However, present understanding of subsidence is fragmented and qualitative, including measurements, attribution to drivers, prognosis, and appropriate responses. On page 301 of this issue, Ao *et al.* (*2*) report using a radar technique called interferometric synthetic aperture radar (InSAR) to map consistent large-scale measurements of vertical land motion across all the major urban areas of China. Its successful application to quantify subsidence points the way to a systematic approach for assessing its causes as well as potential responses in real time and in the future.

Earth's surface experiences natural uplift and subsidence due to various geological processes such as glacial isostatic adjustment, which is the continuing upward or downward motion of land caused by the removal of the weight of ice sheets at the end of the last ice age. Natural vertical land movement is typically slow and steady, although it can be more abrupt during earthquakes and similar sudden events. In addition, human-induced processes, such as groundwater withdrawal, which accelerates consolidation, can augment vertical land motion and almost always promote subsidence (*1*, *3*). Subsidence most often occurs on coastal sedimentary plains and deltas and is most rapid where human activity is concentrated. Subsidence hotspots are found in many susceptible cities, with changes on the order of centimeters per year to tens of centimeters per year (*4*–*7*). Deltas

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Tianjin, a major port city in northeastern China, is a hotspot for subsidence.

also subside both naturally and as a result of human processes (*8*, *9*), and inland sedimentary plains often show similar behavior. In coastal areas, subsidence also contributes to relative sea level rise (*4*). Although subsidence is widely considered a local problem, there are broader implications because large areas and many people are affected.

Space-borne InSAR uses highly precise radar pulses to measure the change in distance between the satellite and ground surface, which allows users to generate accurate and high-resolution vertical land-motion measurements. Ao *et al.* used this tool (the European Space Agency's Sentinel-1) to assess extensive land regions across China from 2015 to 2022. The authors report on subsidence in 82 major cities (accounting for nearly three-quarters of China's urban population), from the coast to the interior. The study determined widespread occurrence of sinking land across these locations, building on earlier studies across Southeast and East Asia, including China (*5*, *10*, *11*). For example, Shanghai has subsided up to 3 m over the past century (*12*). Ao *et al.* conclude that 45% of the studied city land area, which is home to 29% of China's urban population, is subsiding faster than 3 mm/year. As much as 16% of the city land area is subsiding at a rate of 10 mm/year or more. The authors found common factors such as geology, building weight, groundwater withdrawal, and the lowering of water tables across all cities and call for a national response to this problem.

The impacts of subsidence in urban areas include direct damage to buildings and foundations, infrastructure, drains, and sewage systems. It also exacerbates the occurrence and effects of flooding, especially in coastal cities, compounding climate change. Indeed, after Hurricane Katrina struck New Orleans in 2005, it became apparent that the levees had subsided substantially, which contributed to the high damages and death toll (*13*). Ao *et al.* show that the urban area below sea level in China could triple in size by 2120 when subsidence is combined with sea level rise, which indicates a major threat.

Monitoring regional subsidence is challenging, especially when using ground-based geodetic networks, because it is hard to maintain fixed locations of known elevation. However, new satellite platforms, such as Sentinel-1, are revolutionizing the ability to measure changes in Earth's surface. Measurements made by global navigation satellite systems, such as the United States' Global Positioning System (GPS), are limited to precise locations, whereas InSAR provides spatially continuous measurements with global coverage. InSAR and GPS are also synergistic because InSAR measurements must be combined with GPS observations to precisely estimate long-wavelength deformation signals.

Consistently measuring subsidence is a great achievement, but it is only the start of finding solutions. Although Ao *et al.* associated subsidence with various human activities (such as groundwater withdrawal), they were not able to attribute it to specific physical causes because they lacked data and models. Further, in most cities, multiple subsidence processes are active, yet few, if any, studies have assessed a profile of the causes of the observed sinking. Predicting future subsidence requires models that consider all drivers, including human activities and climate change, and how they might change with time. Human causes have the potential to change substantially if processes such as groundwater withdrawal increase or decrease. This in turn opens the possibility of subsidence mitigation by reducing or removing some of the drivers. An example of such mitigation occurred in Japan (Tokyo and Osaka) in the 1970s (*4*, *5*), where groundwater withdrawal was ceased deliberately and subsidence stopped or was greatly reduced.

One major challenge is to move from measuring subsidence to thinking systematically about its implications. Tools such as InSAR open up the possibility of understanding subsidence in fundamentally new ways to inform response plans. This requires the development of practical assessment guidance and tools to define when and where subsidence is or is not a problem (*14*). A framework is ultimately needed that links subsidence measurements to urban development. This requires an integrated scientific approach as well as the sharing of practical information and experiences. Ideally, this will guide immediate and long-term strategic actions, analogous to strategies that have emerged for coastal areas threatened by sea level rise (*15*). ■

REFERENCES AND NOTES

1. G. Herrera-García *et al.*, *Science* **371**, 34 (2021).
2. Z. Ao *et al.*, *Science* **384**, 301 (2024).
3. M. Bagheri-Gavkosh *et al.*, *Sci. Total Environ.* **778**, 146193 (2021).
4. R. J. Nicholls *et al.*, *Nat. Clim. Chang.* **11**, 338 (2021).
5. A. Cao *et al.*, *Curr. Opin. Environ. Sustain.* **50**, 87 (2021).
6. G. Erkens *et al.*, *Proc. IAHS* **372**, 189 (2015).
7. L. O. Ohenhen *et al.*, *Nature* **627**, 108 (2024).
8. J. P. M. Syvitski *et al.*, *Nat. Geosci.* **2**, 681 (2009).
9. P. S. J. Minderhoud *et al.*, *Environ. Res. Lett.* **12**, 064006 (2017).
10. Y. Q. Xue, *et al.*, *Environ. Geol.* **48**, 713 (2005).
11. J. Fang *et al.*, *Nat. Commun.* **13**, 6946 (2022).
12. J. Wang, W. Gao, S. Xu, L. Yu, *Clim. Change* **115**, 537 (2012).
13. T. H. Dixon *et al.*, *Nature* **441**, 587 (2006).
14. A. Dinar *et al.*, *Sci. Total Environ.* **786**, 147415 (2021).
15. G. Le Cozannet *et al.*, *Environ. Res. Lett.* **18**, 091001 (2023).

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PHYSIOLOGY

Sentinels of the airways

Epithelial cells in the larynx and trachea sense harmful cues and trigger protective reflexes

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The respiratory tract is essential for breathing but is also important for detecting and responding to inhaled harmful (noxious) stimuli, such as pollutants, pathogens, water, and acid. Neuroendocrine cells (NECs)—rare epithelial cells that share characteristics with neurons—are an integral component of this sensory surveillance system (*1*). Although NECs have been proposed to act as airway sentinels capable of perceiving chemical and mechanical cues and can secrete signals to relay information to other cells and tissues (*2*), their functional roles remain poorly understood. On page 295 of this issue, Seeholzer *et al.* (*3*) report the morphological and biophysical diversity of NECs along the respiratory tract of mice, highlighting their ability to sense different noxious stimuli. Moreover, NECs in the larynx and trachea interact with sensory neurons to initiate protective swallowing and expiratory reflexes. These findings elucidate how NECs control fundamental physiological responses and may inform interventions for treating respiratory disorders.

Using a genetic tool to specifically label NECs in mice, Seeholzer *et al.* identified differences in morphology between NECs throughout the airways. The distal pulmonary NECs were cuboidal and often clustered together, in contrast with the proximal tracheal and laryngeal NECs, which were solitary and had snout-like projections to the airway lumen. NECs at these different regions also displayed distinct biophysical properties. Electrophysiology measurements showed that pulmonary NECs did not display spontaneous changes in the electrical potential of the cell surface (action potentials) and only exhibited a single action potential upon stimulation.

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