Earth's sinking surface

China’s major cities show considerable subsidence from human activities

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Subsidence, the lowering of Earth’s land surface, is a widespread and sometimes dramatic process. Potentially 19 percent 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, the current understanding of subsidence is fragmented and qualitative, including measurement, attribution to drivers, prognosis, and appropriate responses. On pages xxxx 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 the causes of subsidence as well as potential responses in real time and in the future.

The Earth 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 in 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 promotes 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 at the rate of order cm/yr to tens cm/year (4 -7). Deltas also subside both naturally and due to human processes (8,9) and inland sedimentary plains often showing 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, allowing 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, especially in south-east and east Asia, where subsidence has been previously noted (5,10,11). For example, Shanghai has subsided up to 3-m over the last century (12). Ao et al. concluded that 45% of the studied city land area —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 10 mm/year or more. The authors found common factors such as geology, building weight and groundwater withdrawal and lowering 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, where subsidence increases the threat of coastal flooding, 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 increase about 3 times by 2120 when subsidence is combined with sea-level rise showing a major threat.

Monitoring regional subsidence is challenging, especially using ground-based geodetic networks. This is 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. While InSAR provides spatially continuous measurements with a 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 subsidence to specific physical causes as 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 increases or decreases. 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 (Toyko and Osaka) in the 1970s (4,5), where groundwater withdrawal deliberately ceased and subsidence stopped or was greatly reduced.

One major challenge is to move from measuring subsidence to thinking systematically about the implications of subsistence. 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/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).

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