Sinkhole precursors and formation mechanisms along the Dead Sea shorelines, Israel

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Summary

The water level of the Dead Sea (Israel and Jordan) has been dropping at an increasing rate since the 1960s, exceeding a meter per year during the last decade. This water-level drop has triggered the formation of sinkholes and land subsidence along the Dead Sea shorelines, resulting in severe economic loss and infrastructural damage. We demonstrate the use of InSAR measurements from COSMO-SkyMed images, combined with airborne Light Detection and Ranging (LiDAR) Digital Elevation Model to detect sinkhole-related subsidence.

In several locations, precursory subsidence tends to more than a hundred meters wide, at rates between 0.5 and 2 mm/day started a few months to more than a year before an actual collapse of a sinkhole (A). The sinkholes, a few meters wide and up to 20 m deep, form generally at the perimeter of the subsiding areas (B). By means of a simplified elastic model representing a stressed closed shave of a sill-like crack we estimate the cavity deflation due to the subsiding sedimentary overburden. Applying a Coulomb failure function, we calculate the stresses above the cavity and explain the spatial relationships between the greatest surface subsidence and the sinkholes.

Combining InSAR measurements with sinkhole mapping and chemical and isotopic analyses of groundwater and surface water, we find a new mode of sinkhole formation (C). The sinkholes initiate by dissolution of a 10-20 m deep and 3-15 m thick halite layer by fresh groundwater. The process continues and accelerates as flash-flooding are driven by existing or by newly formed sinkholes, the subsurface salt layer dissolves rapidly, the overlying ground subsides, and salty-saturated water seeps out downstream of the dissolving sinkholes. The number of sinkholes and the rate of dimension of subsidence increase significantly during and immediately after the flood events, and decay exponentially thereafter.

A. Sinkhole precursors

B. Why do sinkholes form at subsidence perimeters?

C. A new mode of sinkhole formation

Top: time series of interferograms in Hazer riverbed, showing significant increase of subsidence and sinkholes after flash-flood, and gradual decrease thereafter. Bottom: subsidence isochrones and isolines.

Induced Coulomb stresses by deflating cavity. Left: inverted source models. Right: orientations and magnitudes of the induced extensional stress fields at the surface. Note that sinkholes form in regions with high extensional stresses.

Frames of a Time Lapse Camera movies of a flash flood in the Arad riverbed, showing the entry of fresh water into existing (top) and newly formed (bottom) sinkholes.

Three months precursory subsidence before the sinkhole collapsed. Three additional sinkholes formed during the following 2 weeks.

C. A new mode of sinkhole formation

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Conceptual model of a new mode of sinkhole formation, in which filling water is drained by sinkholes, dissolves a subsurface salt layer, induces subsidence and sinkholes at the surface, and seeps out downstream saturated with salt.

Link to YouTube movies (courtesy, Elad Dente).

Typical relationship between surface subsidence features and subsequent sinkholes along their perimeters.

Three months precursory subsidence before sinkhole collapsed. Three additional sinkholes formed during the following 2 weeks.