Collapse sinkholes along the Dead Sea shorelines: Earth observations, hazard assessment, and formation models

Gidon Baer, Meir Abelson, Yoav Avni, Nadav Lensky, Vladimir Lyakhovsky, Amit Mushkin, Ran Nof, Eyal Shalev, Yoseph Yechieli,
Geological Survey of Israel, Jerusalem, Israel
Simone Atzori, Stefano Salvi,
INGV, Rome, Italy
Sagi Filin, Reuma Arav,
Technion – Israel Institute of Technology, Haifa, Israel

Contact:
baer@gsi.gov.il

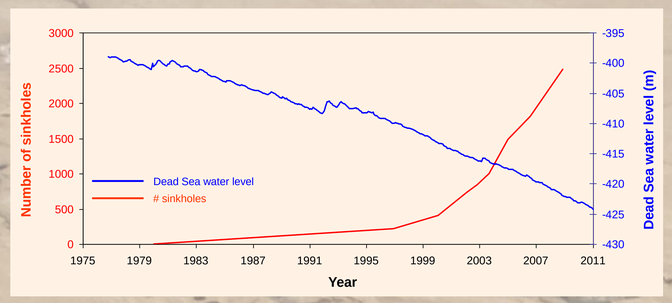
Summary

Collapse sinkholes started to appear along the Dead Sea coast in Israel and Jordan in the early 1960's. Sinkhole development has significantly accelerated with time, from less than 50 new sinkholes each year before the year 1999 to 200-380 sinkholes a year since 2003. Along the western (Israeli) coast, the sinkholes are clustered in ~50 sites, each site comprising between 1 and >500 sinkholes. Most sinkhole sites display linear shapes, which were found to coincide with buried likely active young faults and boundaries of gradual subsidence features.

A ~10 kyr old, 2 m to 26 m thick, salt layer was encountered by several boreholes at depths greater than 20 m and was traced by seismic refraction studies along most of the western side of the Dead Sea. The primary cause for the formation of the sinkholes is dissolution of that salt layer by groundwater due to the Dead Sea level drop, formation of underground cavities, and collapse of the overlying sediments into these cavities. The gradual subsidence features were attributed to consolidation of clay and silt layers within the alluvial fill due to the drop of the groundwater level associated with the receding of the lake.

We present several methodologies developed during the last decade at the Geological Survey of Israel to map sinkhole locations and their temporal and spatial evolution using InSAR (ERS, Envisat, ALOS and Cosmo SkyMed), airborne LiDAR, air photographs and field surveys. Combining these observations with borehole data, we generated a sinkhole hazard map for the entire Israeli Dead Sea coast. Temporal relations between sinkholes, gradual subsidence, and faulting are used to identify precursors to the catastrophic sinkhole collapse. Finally, based on surface and subsurface observations, we show models for sinkhole formation that constrain the location, depth and geometry of the underlying cavities as well as the mechanical properties of the host rocks.

Dead Sea water level and sinkholes

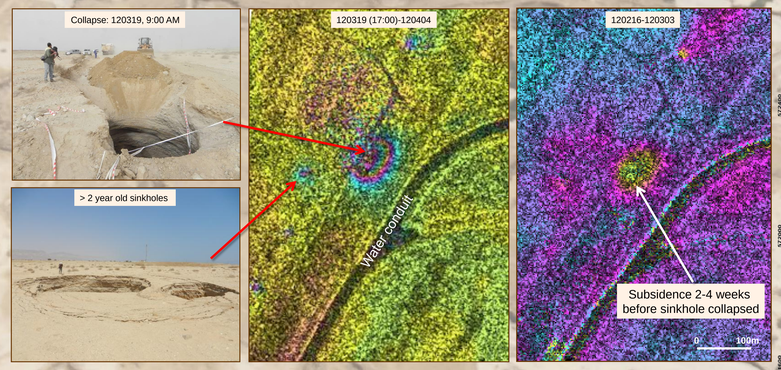


Dead Sea water level drop (Israel Hydrological Service) and increasing number of sinkholes (Geol. Survey of Israel): 1975-2011

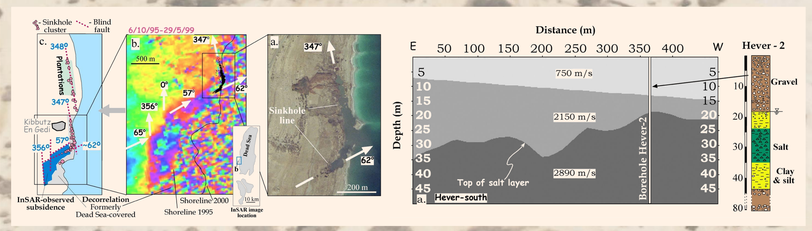
Three methods of detecting active sinkholes

Mineral Beach sinkhole site: Left - 16-days CSK interferogram showing subsidence associated with sinkhole formation; Center - detection of new sinkholes by ratio of 2000 and 2003 rectified images, red arrows mark new sinkholes; Right – subsidence and sinkholes formed between 2005 and 2011, detected by subtraction of LiDAR images made in 2005 and 2011.

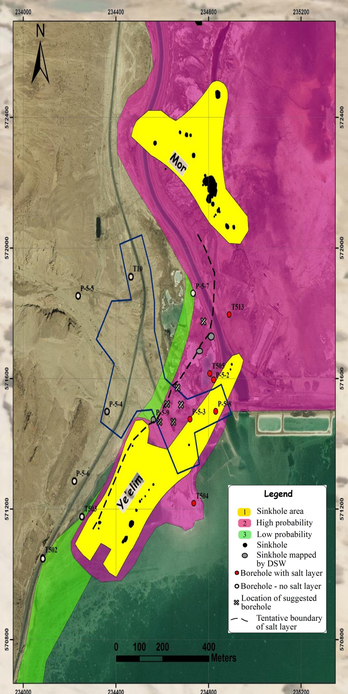
Sinkhole detection, precursors, and hazard map



Detection of sinkholes (center) and pre-collapse subsidence (right) by Cosmo SkyMed (CSK) interferograms of the water conduit from the northern basin to the Dead Sea evaporation pans

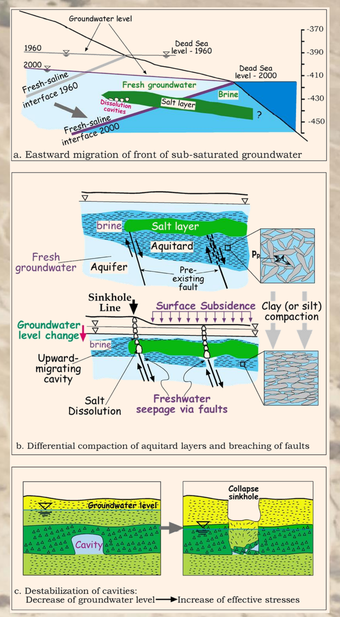


Criteria for sinkhole hazard map. Left: Linear borders of gradual subsidence areas (ERS, 1995-1999); Right – Subsurface salt layer detected by seismic refraction

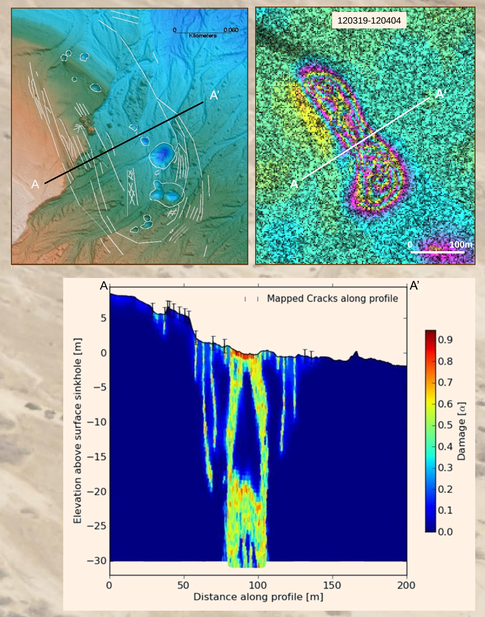


Sinkhole hazard map based on the criteria on left

Models of formation



Sinkholes and subsidence: triple effect of Dead Sea water level drop



Hever sinkhole site: field and InSAR constraints on geometry and depth of underground cavities. Top left – map of surface cracks surrounding a sinkhole cluster; Top right – subsidence detected by 16 day CSK interferogram; Bottom – damage model predicting subsidence and surface fractures

Background photograph: Asaf Tsabar; design assistance: Bat Sheva Cohen, Nitzan Baer