



## **Spatio-temporal development of sinkholes on the eastern shore of the Dead Sea**

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The ongoing, largely anthropogenically-forced decline of the Dead Sea is associated with the most prolific development of sinkholes worldwide. The fall in hydrological base level since the 1960s is thought to enable relatively fresh ground waters to dissolve underground salt deposits that were previously in equilibrium with hypersaline Dead Sea brine. Sinkhole development in response to this dissolution began in the 1980s and is still ongoing; it represents a significant geohazard in the Dead Sea region. We present new research undertaken within the Dead Sea Research Venue (DESERVE) on the spatio-temporal evolution of the main sinkhole-affected site on the Eastern shore of the Dead Sea, at Ghor Al-Haditha in Jordan. Our data set includes optical satellite imagery, aerial survey photographs and drone-based photogrammetric surveys with high spatial (< 1 m<sup>2</sup> – 0.05 m per pixel) and temporal (decadal from 1970-2010, annual from 2004-2016) resolution. These enable new quantitative insights into this, the largest of all the Dead Sea sinkhole sites. Our analysis shows that there are now over 800 sinkholes at Ghor al-Haditha. Sinkholes initiated as spatially distinct clusters in the late 1980's to early 1990s. While some clusters have since become inactive, most have expanded and merged with time. New clusters have also developed, mainly in the more recently exposed north of the area. With the retreat of the Dead Sea, the roughly coastline-parallel zone of sinkhole formation has expanded unevenly but systematically seawards. Such a seaward migration of sinkhole formation is predicted from hydrogeological theory, but as yet not consistently observed elsewhere at the Dead Sea. The rate of sinkhole formation at Ghor Haditha accelerated markedly during the late 2000s to a peak of about 100 per year in 2009. Similar accelerations are observed on the western shore, but differ in timing. The rate of sinkhole formation on the Eastern shore has since declined to about 50 per year. Such differences in the overall spatio-temporal evolution of sinkholes on the eastern and western shores of the Dead Sea likely highlights the important role of local hydrogeological conditions and processes in governing sinkhole development.