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Sinkhole occurrence in consequence of heavy rainstorms

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Sinkholes, the most typical geological hazard in karst, are widespread in Apulia (south-eastern Italy), due to the presence in about the whole region of soluble rocks. Sinkholes can cause damage to private property and civil infrastructures such as buildings and roads. Detailed mapping of sinkholes is critical in understanding the hydrological processes, beside being extremely useful to mitigate the related geological risk. Sinkholes typically function as a major connection between the water flowing at the surface and the groundwaters, by collecting rainfall and rapidly draining it within the bedrock. In Apulia, the main risk to the humans is generally linked to anthropogenic sinkholes, with the possibility of collapses related to man-made caves (quarries, mines, civil settlements, etc.; see Parise, 2012, 2015a). Natural sinkholes are less frequent, or appears at least to be less reported, since they generally occur in rural areas, and often are rapidly canceled by landowners.
During the first week of September 2014, the Gargano Promontory (northern Apulia) was affected by an intense storm, characterized by rainfall cumulates well above the seasonal mean values. The total amount of measured rainfall for the whole event (covering the period from September 1, to September 6, 2014) reached a peak of over 500 mm (Martinotti et al., 2015).
As a response to the storm, and due to peculiarity of the Gargano karst setting, several geo-hazards (different types of slope failures, floods and sinkholes) were recorded over an area of 2300 km2. As regards sinkholes, during the September 2014 storm, at least a dozen of phenomena, mostly of small size, were documented. These are prevailingly concentrated in two areas in the surroundings of the towns of San Marco in Lamis and Monte Sant'Angelo. In particular, at San Marco in Lamis, four sinkholes (the deepest about 6 m-deep and 5 m-wide, showing at the bottom the upper portion of the epikarst, with pinnacles of limestone rocks) affected the lower sector of a karst depression. Their shape is predominantly circular, but the dimensions are assorted. Some of the landforms are just subdued, and appear to be less developed. Morphometry and shape of the observed sinkholes allow to attribute them to the typology of collapse or cover-collapse sinkholes.
Additional sinkholes were triggered in a rural area in the northern part of Monte Sant'Angelo. These are five sinkholes linked to natural cavities, that were activated during the September 2014 storm, and subsequently were enlarged. In the area, terra rossa deposits cover limestone rocks. The largest sinkhole is 25.2 m deep and 12 m wide. From its base, speleological explorations documented a series of pits, going down at least until a depth of -130 m below the ground surface, thus testifying the direct link with the subsurface system of groundwater circulation.
The sinkholes occurred in the Gargano area are natural events quite common in karst areas (Waltham et al., 2005; Ford & Williams, 2007; Parise, 2008, 2015b; Gutierrez et al., 2008, 2014; Parise et al., 2015), as a result of intense and/or prolonged rainfall events that increase the superficial and underground outflow. The speed of outflow of large quantities of water may be able to remove unconsolidated soil, creating new ways of underground water circulation, and as a consequence the material on the surface could collapse in the underlying cavities (Parise et al., 2015b).
Documenting these phenomena, especially in relation to intense rainstorms, is of great importance, since in the great majority of cases they go unreported, especially where (as is the Gargano case) the karst lands are thickly covered by forests, or develop in mostly rural areas. The collection of direct data from the observed sinkholes allowed us, further, to update the chronological catalogue of sinkholes in Italy, managed by CNR-IRPI since several years (Parise & Vennari, 2013) within the framework of research projects on karst hazards.

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