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Assessing the effects of rainfall, groundwater downward leakage, and groundwater head differences on the development of cover-collapse and cover-suffosion sinkholes in central Florida (USA)

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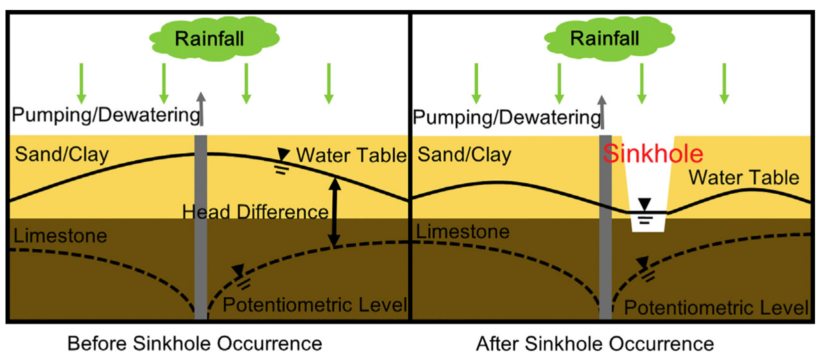
HIGHLIGHTS

- Assess cover-collapse and cover-suffosion sinkhole hazards in central Florida
- Groundwater downward leakage rate affects sinkhole susceptibility.
- Heavy rainfall and rapid head difference change trigger sinkhole occurrences.

GRAPHICAL ABSTRACT



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ABSTRACT

Cover-collapse and cover-suffosion sinkholes are widely distributed in central Florida (USA) karst terrains and have been recognized as the primary geo-hazard threatening human lives and destroying infrastructure. Previous studies indicated that the development of cover-collapse and cover-suffosion sinkholes in central Florida might be related to hydrologic/hydrogeologic conditions such as rainfall, groundwater downward leakage and groundwater hydraulic head differences (groundwater level differences between the water tables in unconfined aquifer and the potentiometric levels in confined aquifer). Here, a case study in central Florida urban areas is conducted to quantify the effects of rainfall, groundwater downward leakage and groundwater head differences on the development of cover-collapse and cover-suffosion sinkholes in central Florida with a focus on the timing of their occurrences. Results indicate that heavy rainfall/storm(s) and rapid increase of head differences within a relatively short period of time are major factors affecting the timing of sinkhole occurrences, and the spatial variation of groundwater downward leakage rate can be used to generate sinkhole susceptibility zonation maps for serving as a useful indicator of the likelihood of sinkhole development at certain areas. Results caution that the groundwater pumping and mining dewatering rate should be setup properly and the starting time of groundwater pumping and/or mining dewatering should be selected carefully in central Florida, i.e., the activities should be put into abeyance after a heavy rainfall/storm(s) to reduce the probability of sinkhole occurrences.

1. Introduction

Sinkholes are common, naturally-forming geologic features occurring at varying frequencies in mantled (buried) karst terrains in central

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Florida due to the dissolution (dissolution rate extremely slow as millimeters per thousand years) and removal of the carbonate bedrock (primarily composed of limestones and dolomites) by the infiltrated weakly acidic rainwater (Beck, 1986; Ford and Williams, 2007). Sinkhole formation is a very complex geologic process being part of a broader karstification process which has been happening in Florida for forty million years, while sinkhole occurrence is only a small event in the broader landscape evolution in Florida (Brinkmann, 2013). Many sinkholes develop naturally because central Florida is underlain by carbonate bedrock that is susceptible to dissolution and removal, while a rapid increase in the numbers of sinkholes developed in the past several decades indicates that environmental-related changes due to climate change (e.g., heavy rainfall/storm(s), prolonged drought) and anthropogenic change (e.g., groundwater over-exploitation, land use change) could trigger sinkhole developments (Gutiérrez et al., 2008c, d; Gutiérrez et al., 2009; Gutiérrez et al., 2016; Kuniansky and Bellino, 2016; Kuniansky et al., 2012; Linares et al., 2017; Tihansky, 1999; Williams and Kuniansky, 2016).

In general, sinkholes are classified into two main groups, including solution sinkholes that are generated by gradually corrosional lowering of the exposed carbonate/evaporite surfaces (no overlying sediments mantled) and subsidence sinkholes that are generated by both subsurface dissolution and downward gravitational movement of the overlying sediments due to internal erosion or deformation (Beck, 2005; Gutiérrez et al., 2008a&b; Gutiérrez et al., 2016; Waltham et al., 2005). Solution sinkholes usually do not pose ground stability problems while subsidence sinkholes often cause land surface subsidence, and subsidence sinkholes are further classified into cover-collapse, cover-sagging, cover-suffosion, bedrock-collapse, bedrock-sagging, caprock-collapse, and caprock-sagging sinkholes, depending on the characteristics of the overlying sediments (if exist) and the underlying carbonate/evaporite bedrock (Gutiérrez et al., 2008a, b; Gutiérrez et al., 2014). In central Florida mantled karst terrains, reported sinkholes are classified as cover-collapse, cover-suffosion, and cover-sagging sinkholes, and cover-collapse and cover-suffosion sinkholes are recognized as the primary geo-hazard in central Florida since the 1950s because their developments have caused vast majority of catastrophic damages to infrastructures such as buildings, roads, bridges, and pipelines (Beck, 2005; Brinkmann et al., 2008; Kuniansky et al., 2015; Waltham et al., 2005). It was reported that insurers had received 24,671 claims for cover-collapse and cover-suffosion sinkhole damages totaling $1.4 billion in the 5 years between 2006 and 2010, with an increasing trend of cost per year (Kuniansky et al., 2015). Cover-collapse and cover-suffosion sinkholes not only threaten human lives and cause structural problems, but also contaminate groundwater in that open sinkholes can create pathways for transmitting polluted surface water directly into groundwater aquifer (Chen, 1993; Lindsey et al., 2010). Thereby, public concern usually focuses on the development of cover-collapse and cover-suffosion sinkholes in that the timing of their occurrences are very important from a hazard and engineering perspective.

In central Florida mantled karst terrains, reported cover-collapse and cover-suffosion sinkholes are not evenly distributed spatially because some areas have considerable numbers of reported sinkholes while some areas have none, and the timing of their occurrences are

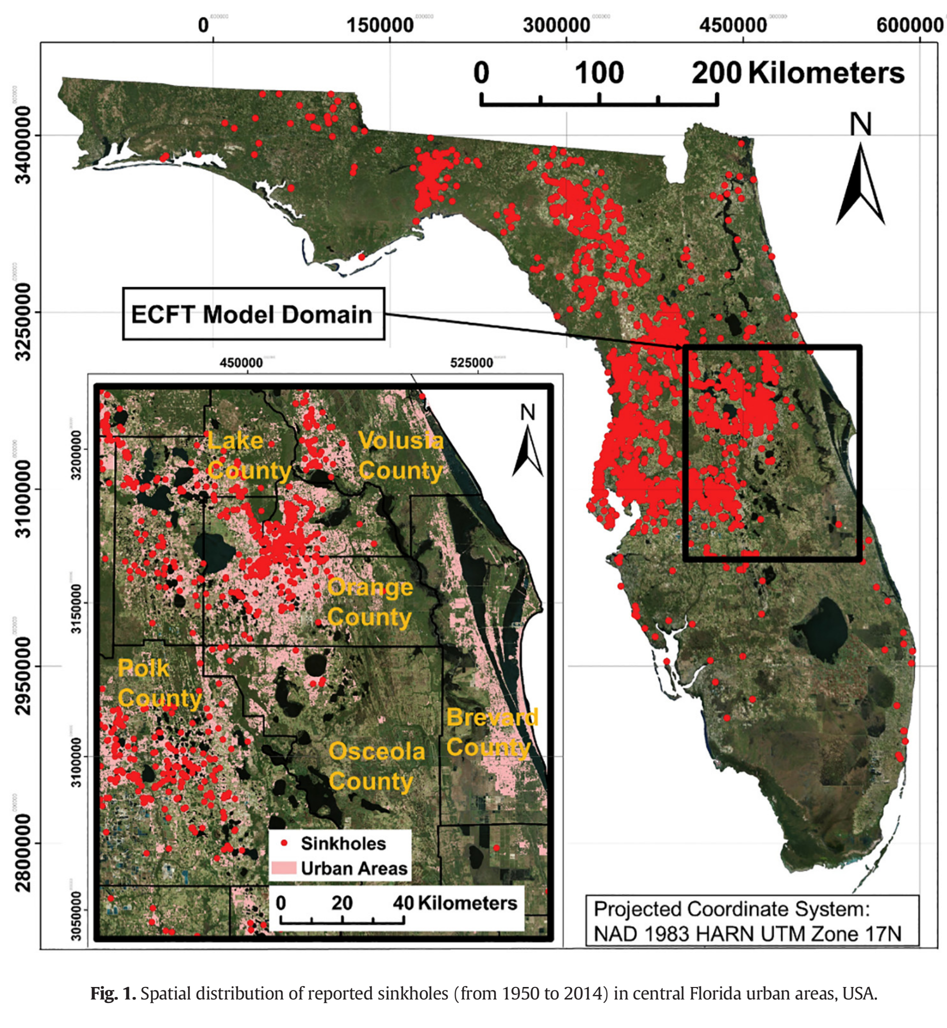

Fig. 1. Spatial distribution of reported sinkholes (from 1950 to 2014) in central Florida urban areas, USA.