

Bedrock Structural Controls on the Occurrence of Sinkholes : A Case Study from Chintakommadinne Area, Part of Cuddapah Basin, South India

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ABSTRACT

Heavy precipitation in the Chintakommadinne area in the Y.S.R Kadapa District, Andhra Pradesh during November 2015 has induced ground subsidence resulting in rapid increase in the frequency of 15 sinkhole occurrences. Most susceptible to future sinkhole development, determined by different factors: (1) bedrock type has the most significant impact on predicting sinkhole risk, (2) proximity to faults, lineaments (3) sudden recharge and raise in the groundwater table, and (4) depth of overlying soil to bedrock has an existent yet insignificant effect on sinkhole development. Alignment of sinkholes mainly occurs along strike of bedding. Enhanced rock solution and conduit formation correlates with carbonate units of greater limestone purity and finer grain size, suggesting some lithologic control on karst formation. Density of sinkhole occurrence tends to increase in areas where water-table fluctuations are large. Given the correspondence between geologic structures such as faults, geologic maps showing such structural data are useful tools for predicting future sinkhole occurrence.

Key words: Sinkholes, Structural control, Karst Topography, Buggavanka River, Cuddapah Basin

INTRODUCTION

Sinkholes can be of artificial, natural or combined origin as studied and observed in urban and rural areas in various regions (Beck, 1991; Aisong and Jianhua, 1994; Salvati and Sasowsky, 2002; Williams, 2003; Beck, 2004; Waltham et al., 2005). Sinkhole collapses in urban areas however, may be a man-made result of a forgotten and covered as well as outdated sewer system, of which its real magnitude appears to be a potential risk of unknown proportions. Such sinkholes may be absolutely devastating in the area where they appear and the appearance itself may be with signs or without any warning. Prominent examples of sinkholes appeared in recent years in the United States like the Macungie Sinkhole in 1986 (Dougherty and Perlow, 1988), Daisetta Sinkhole in 2008 (Paine et al., 2009), and in Guatemala City, Guatemala 2007 and 2010 (Hermosilla, 2012) and even in desert areas like in Kuwait (Shaqour, 1994). Man induced sinkholes are associated with the increasing industrialization and urbanization of cities and the intense human economic activity in the investment of the corresponding hydrological systems (Reese et al., 1997; Gutiérrez et al., 2007; Brinkmann et al., 2008; Gutiérrez et al., 2009). Based on significantly high economic damages caused by sinkholes in urban areas, the monitoring and detection with geophysical tools and geographic as well as historic data of sinkholes has recently been a major focus in city planning and hazard prevention (Orndorff and Lagueux, 2000; Lei et al., 2004; Gutiérrez-Santolalla

et al., 2005; Gutierrez et al., 2008; Brinkmann et al., 2008; Bruno et al., 2008; Kaufmann and Romanov, 2009; Krawczyk et al., 2012; Margiotta et al., 2012). It is of fundamental interest to society, and authorities, to identify their potential distribution and to prevent the occurrence of further sinkholes, and assess the potential economic damage and loss of lives.

STUDY AREA

The study area lies in Chintakomma Dinne Revenue Mandal of YSR (Kadapa) District of Andhra Pradesh, India as shown in the Figure 1, bounding with latitudes from 14° 20' 41" N to 14° 29' 51"N and longitudes 78° 39' 1.11"E to 78° 56' 37.57"E. In geological point of view this area falls in south western part of Proterozoic Cuddapah Basin. Physiographically this area form part of the Palakonda hills with average rainfall of 700mm. The area of study experiences tropical weather climate with 28-30^o C during November to January and 40-45^o C during April-May. Based on the Agro-climatic conditions the District falls both in Southern and scarce rainfall zone.

METHODOLOGY

A systematic approach was made to carry out the present study. Detailed field survey was carried out in the areas where the sink holes were distributed and all the location information were collected by using Global Positioning

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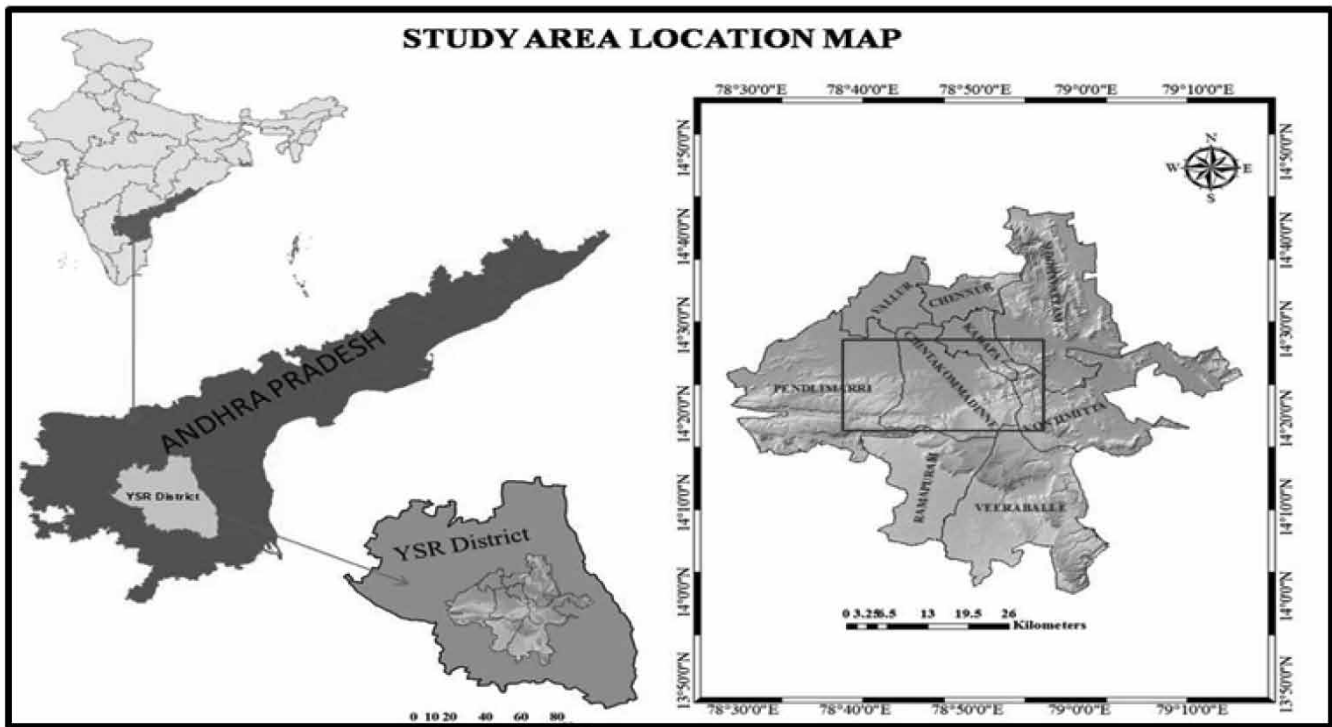


Figure 1. Location map of the study Area.

System (GPS) and SOI Toposheet No: 57J/11 and 57J/15. The GPS points were imported to Google earth software. Identification of closed depressions was aided through the use of Google Earth data, and these locations were compared with the GPS Data. These compared sink holes locations were exported to ArcGIS10 software. Digital Elevation Model was constructed by using SRTM DEM. These sink holes data were added as layer file within a Geographic Information System (GIS), Identified depressions were field-checked. The thematic layers of information viz. DEM, Geology map and sink hole location data permitted the qualitative observations between sinkholes and geologic structure.

RESULTS AND DISCUSSIONS:

Lithological control

Karst topography is the landscape that is formed due to dissolution of soluble rocks like limestone. During the present study the relationship between karst features and geologic structures is well documented. On a large scale, the geologic attributes determine the exposure of a limestones terrain to the karst processes (White et al., 1970). At a medium scale geologic structures determine the flow paths in karst quifers (Parizek, 1976; Nelson, 1988). At a small scale, geologic structures have a significant impact upon the ultimate morphology of conduit systems (Ford and Ewers,

1978; White, 1988; Palmer, 1991). Karst development is characterized by well-developed and integrated underground drainage systems, long segments of losing and disappearing streams, long segments of gaining streams, hundreds of caves, thousands of sinkholes, and dozens of major springs, some of which are world class. The generation of these karstic depressions is related to the dissolution of carbonate and evaporitic rocks. Sinkholes in evaporite karst areas occur worldwide (Klimchouk et al., 1996).

From a geological point of view, the rocky substrata of the study area is mainly constituted by Shales, Lime stones and unconsolidated sediments in the northern part and by Limestone and Quartzites in the southern part (Figure 2). These rock types, belong to different stratigraphic units (Papaghni, Nallamalai and Kurnool groups), are juxtaposed by means of a E-W oriented, Northerly dipping fault boundary. This boundary occurs due to major faulting between the Koilakuntla Limestone and the Quartzite Formations of Kurnool Group and Birankonda (Nagari) formation of Nallamalai group of Cuddapah Supergroup. The major drainage in the study area is Buggavanka River, (Bugga = Spring ; Vanka = Stream) and it is tributary to the Pennar River.

Structural control:

Sinkholes are a common feature used to identify subsurface lineaments or "photo-linears" (Littlefield et al., 1984;

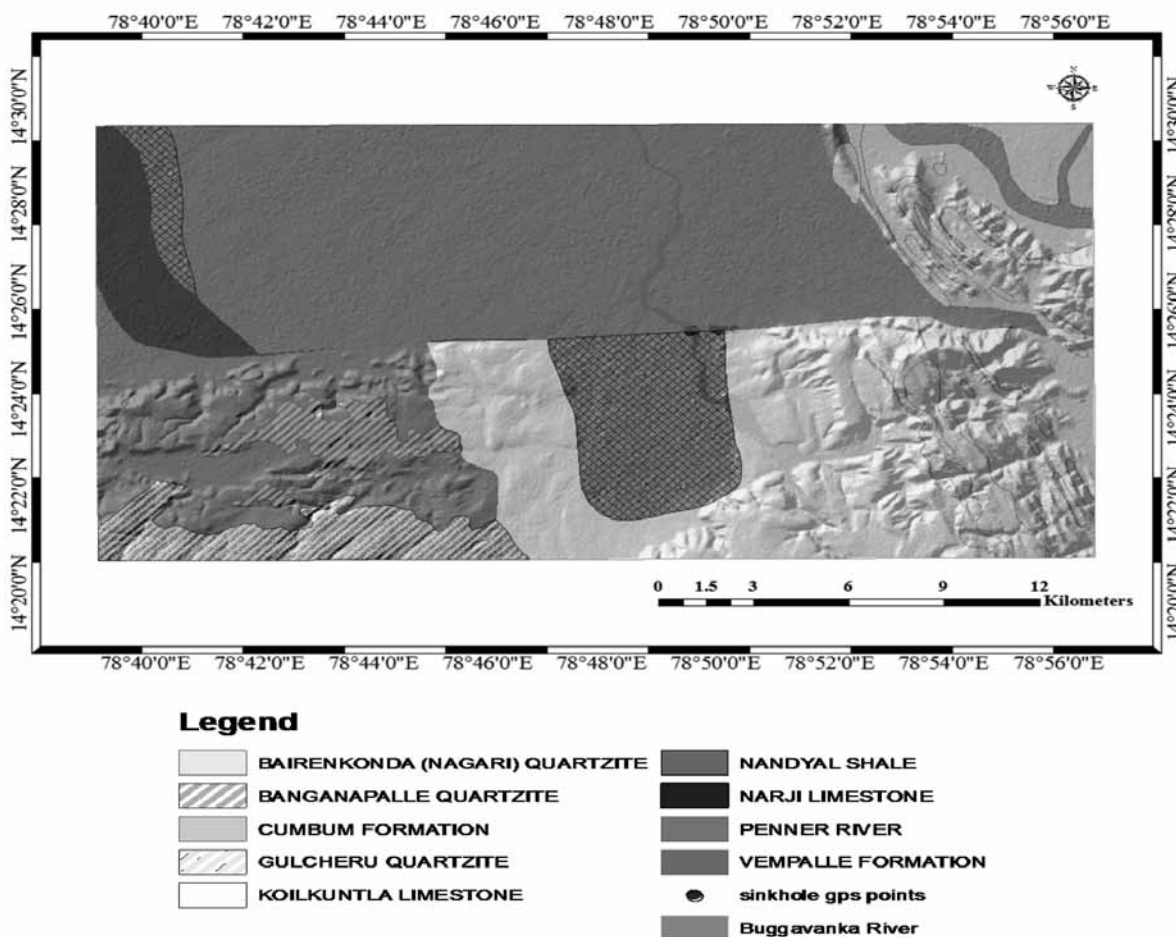


Figure 2. Generalized Geological map showing the various litho units and GPS locations of the sink holes (black circles) in the study area.

Howard, 1968; Kastning, 1983; Orndorff and Lagueux, 2000). Thus, sinkhole alignments are considered an indication of preferential flowpaths for groundwater (Elvrum, 1994; Taylor, 1992). Secondary permeability features, such as fractures, faults, and bedding planes, are frequent in telogenetic limestones, such as those in Kentucky, due to brittle deformation during uplift and exhumation (Vacher and Mylroie, 2002). Fault offsets often produce geologic boundaries for karst development. Irrespective of their origin, these fracture traces play an important role in the direction of groundwater flow (Taylor, 1992). Interestingly, while some sinkholes align with known faults, other faults have no overlying sinkholes, and many sinkhole alignments suggest currently unknown faults or fracture traces (Florea, 2005). Sinkhole GIS data, combined with field reconnaissance, is a proven tool for tracing significant medium-scale structural features in Kentucky (Florea, 2002). Additionally, the ability of the sinkhole GIS data to assist in identifying yet unknown structural features is a valuable resource unanticipated at the beginning of digitization (Florea, 2005).

The complex history of the Cuddapah Basin dates back to the Palaeoproterozoic. It records tectonic events that shaped the SE margin of proto-India from when it became part of Columbia (Saha 2002; Rogers and Santosh 2004; Santosh 2010). N-S trending major fault (around 30 km) in the study area (south western part of the Cuddapah Basin) is the major structure control for the formation of sink holes as shown the figure 3 all the sink holes that are produced along the fault zone, which acts as the boundary between the Nandyal Shale, Koilkuntla Limestone and the Bairankonda Quartzite Formations.

Hydromorphology:

The regional scale analysis indicates that the karst collapse sinkholes are not the mere response to the concurrence of the climatic and lithological conditions which commonly favour the development of karst processes, the occurrence of such landforms appearing strongly influenced by distinctive structural and hydrogeological conditions. These evidences point to the important role played by

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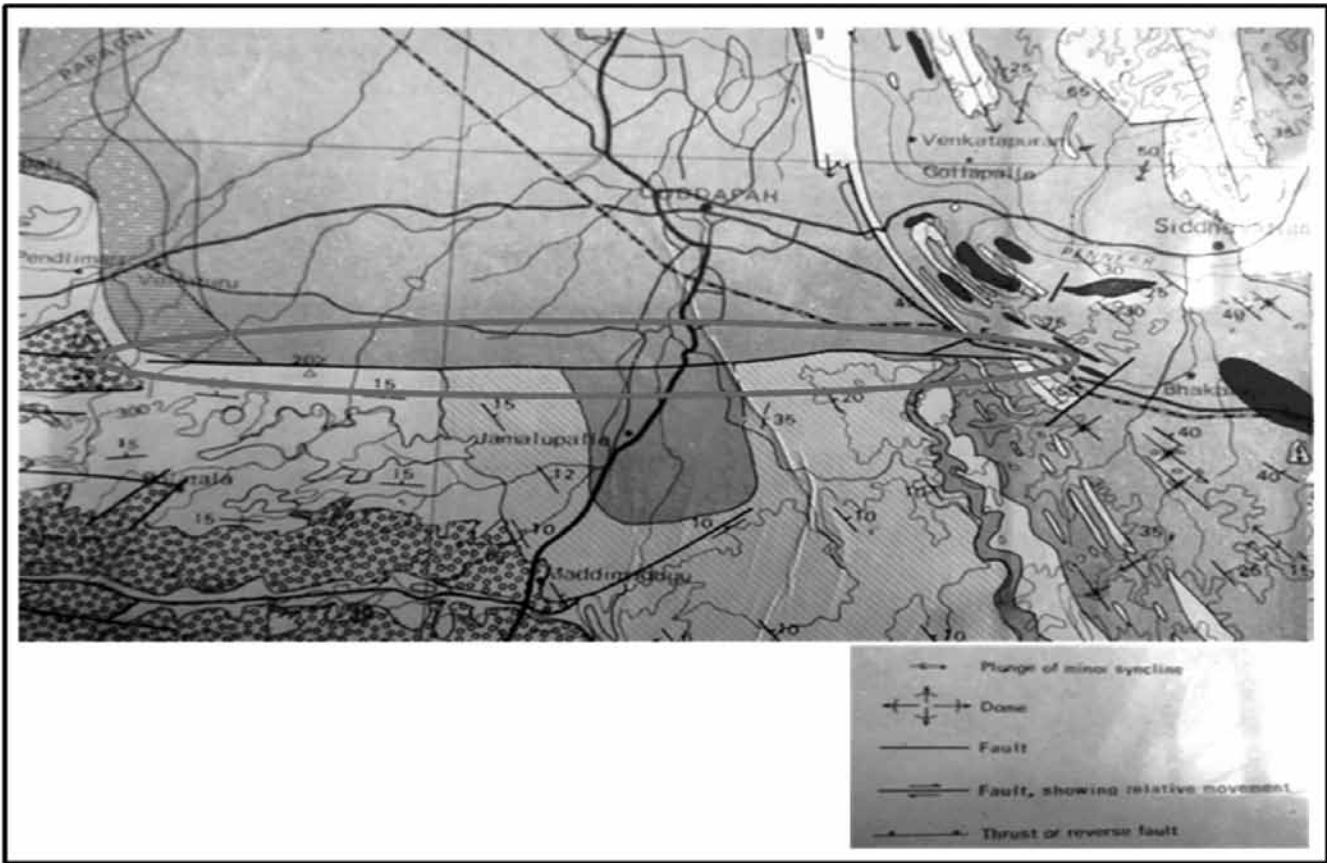


Figure 3. A portion of Geological & Mineral Map of Cuddapah Basin (GSI, 1981) on 1: 2,50,000 Scale. Showing the major fault in the study area (E-W trending dark line in red circle)

Time Series, Area-Averaged of Precipitation Rate monthly 0.25 deg. [TRMM TRMM_3B43 v7] mm/month over 2000-Jan - 2016-Mar, Region 78.2E, 14.2N, 78.8E, 14.8N

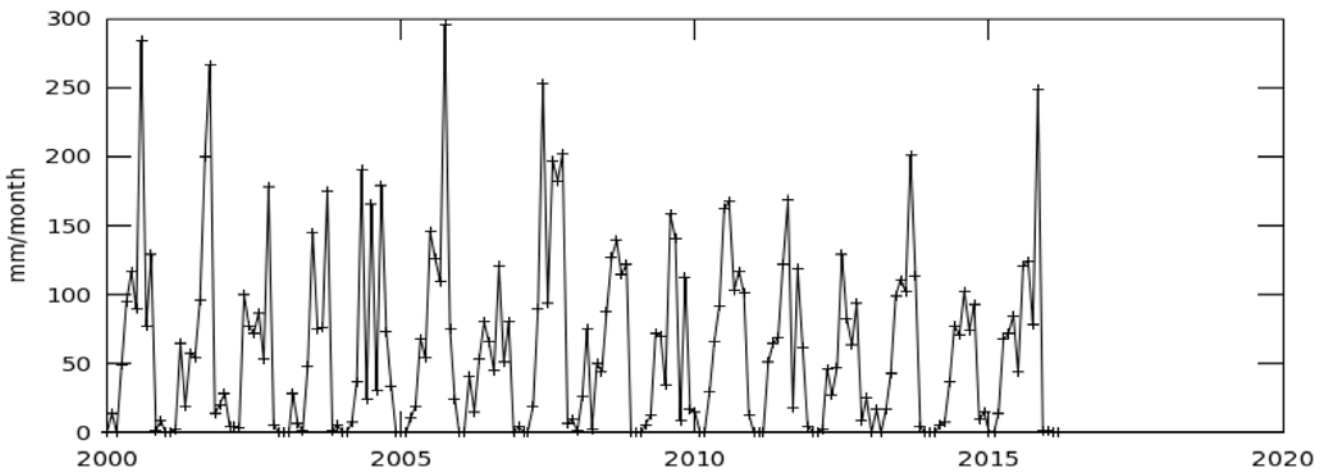


Figure 4. Goddard Earth Sciences Data and Information Services Center 2016. NASA TRMM satellite based time series area averaged map of the study area showing the monthly average rainfall from January, 2000 to March, 2016.



Figure 5. A&B: sinkholes in Buggavanka River near Bugga Ramalingeswara temple; C: sinkholes human by induced activity (about 20 feet height overhead water storage tank submerged) F: subsidence due to vegetative stress; E: turbid water from the adjacent bore well; G&H : Collapse ; I: News paper article on sinkholes (Andhrajyothi Telugu Daily 2015).

extensional fault zones in the migration of deeply derived fluids, thus suggesting that active faults, in particular, represent preferential pathways for fluid rising and mixing with shallow groundwater. In addition, a focus on the relationships between karst collapse sinkholes and extensional fault zone properties has shown how the fault length and depth, and the dimension of the damage zone, influence the sinkhole formation and evolution (Antonio et al., 2013).

Shales, quartzites, limestones / dolomites of the Proterozoic Cuddapah basin are the dominant lithounits in

the area of present study. Ground water occurs under water table conditions in weathered portion of the formation and the thickness of the weathered portion is around 10 m bgl. Ground water is developed in weathered portion through large diameter dug wells (6m). As the pressure on ground water increases, the water levels were lowered and the yields from dug wells decreased and occasionally dried up in the drought years (CGWB, 2013). Decline in water levels cause loss of support to the bedrock roofs over cavities and to surface material overlying openings in the top of bedrock. Alternate swelling-shrinking and support-

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withdrawal caused by seasonal fluctuations in water level tend to disrupt the cohesiveness of unconsolidated surficial material and promote collapse (Williams, 2003; Sinclair, 1982).

Analysis of the causes of the sinkholes

After heavy rain fall during the month of November 2015 (248mm) (Goddard, 2016) as shown in the figure 4 out of 700mm annual average rainfall, around 15 sinkholes were developed in and around Nayanori palle, Balijapalle villages in Chintakomma dinne mandal (The Hindu national daily, 2015). Among these majority of sinkholes were formed with in the Buggavanka River and adjoining areas. Google earth Imagery shows that the locations of sink holes (before and after their formation) along a major fault zone falling in the study area (see Figure 3). These sink holes were filled with groundwater (Figure 5 A & B). By analyzing and integrating geology structures, Remote Sensing data, the rainfall data and CGWB reports, it is concluded that the area was dried up due to prolonged drought caused by scanty rainfall leading to over exploitation of groundwater. Subsequently heavy rain fall in the upstream side of the Buggavanka dam resulted in flooding, there by causing sudden recharge and raise in groundwater table leading to shrinkage of ground along the weak zones controlled by the major fault.

CONCLUSIONS

This study identifies the main triggering factors for the development of land subsidence and sinkhole formation. During the present study it is concluded that around 15 sinkholes were developed in and around Nayanori palle, Balijapalle villages in Chintakommadinne mandal after heavy rain of 248 mm fall during the month of November 2015. The study indicate that Geology, Geomorphology, structural information combined with hydrologic data is crucial for predicting future sinkhole susceptibility. From the analysis conducted in this study, it was found that sinkhole risk was most sensitive in the area underlain by carbonate bedrock in the region where the rock types are mainly limestone and dolomites.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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