Geohazards and Challenges in Karst Terrains

Yamuna Singh[1]*, Amit K. Singh[2], Neelratan Singh[3], D. C. Jhariya[4], D. P. Dubey[1]

Abstract

Carbonate rocks are most susceptible to karstification. The corrosive action of water is responsible for the formation of various types of landscapes. Intense solutioning results in doline formation, paving the way for genesis of cave passages and underground streams in karst terrains. Generally karstification is intense wherever points are weak,namely, at junctions of joints, fractures, interstices and bedding planes. Interconnected network of secondary pore systems in karstic areas create innumerable geohazards and challenges in various developmental activities including construction of dwelling units. The main issues are collapses, environmental degradations, leakages and discharges in distal places, which need to be properly identified and taken care sufficiently. Accordingly, careful evaluation of geohazards is essential prior to initiating any development projects in karstic areas. In this regard, various investigations that are required have been outlined. Furthermore, systematic researches for various issues in karst terrains have also been suggested to ensure a balance between development in one hand and to address properly issues of geohazards, geotourism and environment in karst terrains on the other hand.

Keywords: *Geohazards, Geotourism, Environment, Challenges, Karst terrain*

1. Introduction

The name karst (krs or kras, a Salvic word meaning 'stony ground') represents geomorphic features developed in carbonate terrains close to surface due by corrosive action of moving water (Bogli, 1980; Ford, 1965; Ford and Williams, 2007; Sweeting, 1972; Singh, 1992). The geologic units prone for corrosive action of moving water include mainly

[1] **Yamuna Singh and D. P. Dubey,** Centre for Earth, Ocean and Atmospheric Sciences, University of Hyderabad, Dr. C.R. Rao Road, P.O. Central University, Gachibowli, Hyderabad-500046, Telangana State.
[2] **Amit K. Singh,** Department of Geology, Government Model Science College, Rewa-486 001, Madhya Pradesh
[3] **Neelratan Singh,** Inter University Accelerator Centre, New Delhi-110067
[4] **D. C. Jhariya,** Department of Geology, National Institute of Technology, G.E. Road, Raipur-492010, Chhattisgarh
* Corresponding Author Email: yamunasingh1957@gmail.com

limestone, dolomite, gypsum and halite. Such rocks occupy nearly 20% of the globe and constitute potential aquifers (Ford and Williams, 2007; Andreo et al. 2010; Dar et al. 2014).Although surface coverage of carbonate rocks in India is less, e.g., ~3% (Dar et al. 2014), they have been proven to be very productive aquifers (Singh and Dubey, 1997). Carbon dioxide-rich and/or acidic water infiltrates along joints, fractures and bedding planes and forms secondary and tertiary pore systems. The corrosive action of water is responsible for formation of surface and sub-surface solution passages and vertical and horizontal drainage system. The common surface karst landforms are represented by karren, solution basins, pavements, natural bridges and sinkholes. On the other hand, subsurface landforms include various types of caves, namely, vadose and water table caves, phreatic caves, vertical caves and cave collapse and breakdown, and cave deposits (terra-rossa, rocks falls and stream deposits of external origin). Accordingly, dissolution and karstification lead to formation of various types of landscapes. Interestingly, a few of such landscapes in karst terrains have been converted to World Geotourism centres (Hall and Day, 2011). All over the world, karst landscapes are developed not only in different latitudes but also in various altitudes in tropical and temperate zones. In this paper,the mode of development of pore systems and associated geohazards in karst terrains have been briefly outlined.

2. Nature and Distribution of Karstifiable Rocks

The most common karstifiable lithounits include biogenic, biochemical and chemical sedimentary rocks comprising limestone, dolomite, chalk, anhydrite and evaporites. However, picturesque landscapes are documented from quartzite and granite karst terrains also (White, 1960; Twidale, 1982; Dasgupta, 1993; Singh, 1995, 2005). Karst may occur at all latitudes and elevations, and covers about 20-33% of the Earth's land surface (Milanovic, 1988; Jamali et al., 2015). Distribution of carbonate rocks in India is shown (Figure 1). Innumerable surface and sub-surface karst landforms are noted in karst terrains. Some of them include karren, sinkholes and caves. Features formed due to accretionary processes are also well known in karst terrains. Such speleothems record imprints of past-monsoonal variations. In fact, recently, stalagmite from Meghalaya, North East India, helped define a geological age by the International Union of the Geological Sciences (IUGS). The karst form Earth's most diverse scenic and resourcerich terrains and repository for underground resources, like minerals, oil, natural gas, groundwater reservoirs (Singh and Dubey, 1997; Jeelani et al., 2018).

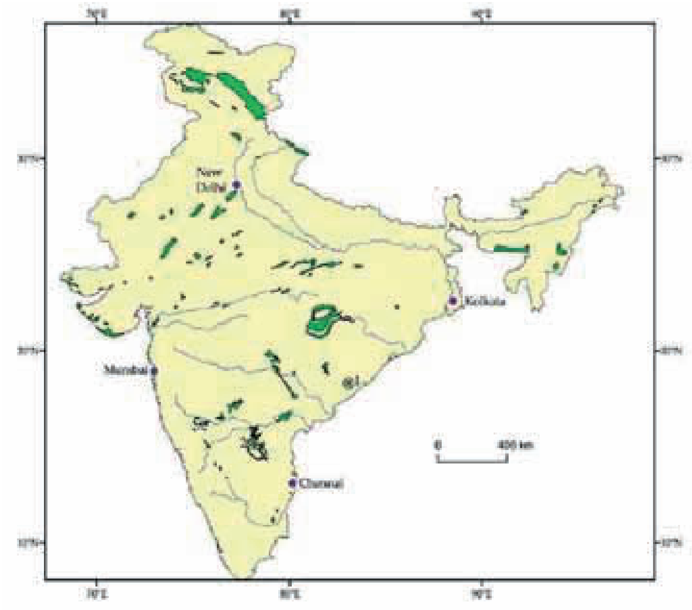

Figure 1: Map Showing Distribution of Carbonate Rocks in India (After Narayana et al.,2014)

The most common factors responsible for the development of karst are the presence of soluble rocks close or near the surface, high density of weak planes, mineralogy, variable response of constituent minerals to solutioning, topography, precipitation, green vegetation, meteorological variables and anthropogenic activity (Singh, 1992; Bonacci, 2004; Narayana et al., 2014; Jeelani et al., 2018). These agents work variously in conjunction with each other in different magnitude. In Meghalaya, North East India, the density of cave system appears to be the highest, and several factors are responsible for their formation, namely, high grade of limestone, high precipitation, elevation and a humid climate (Brooks and Smart, 1995). In each region, some factors play a dominant role relative to others.

3. Genesis of Pore Systems

As such, carbonate rocks possess insignificant primary porosity. However, dissolution of constituent minerals of carbonate rocks initially creates small-scale porosity in them. The continued corrosive action of the water leads to genesis of various types of karst landforms on variable scales both on the surface and subsurface levels (Figure 2 to 9). Furthermore, pronounced solutioning by water along joints, cracks, bedding planes is responsible for genesis of depressions. Such features play key role in development of caverns and sub-terranean drainage in karstic areas. Solutioning is pronounced around weak planes and sets and systems of diaclases (Figure 4 to 7). Apart from network of fracture systems and other factors, differential dissolution of constituent minerals play significant role in variable karstification in rocks like granite and quartzite (Figure 8 and 9). Degree of karstification, depth and interconnectivity of secondary and tertiary pore systems are responsible for geohazards in karst terrains.

Figure 2: Development of (secondary) tubular porosity along the runnels in sloping limeston outcrop. (Note: Initiation of tiny pores throughout the surface of outcrop).

Figure 3: Network of grikes and solution cavities in limestone.

Figure 4: Development of grikes along joint planes in stromalolitic limestone.

Figure 5: Development of vertical caves along the solution widened joints in flaggy limestone.

Figure 6: Well-developed sinkholes, pot holes and grikes in the river bed. Note solution enlarged joints leading to development of vertical caves in horizontal bedded limestones.

Figure 7: Grand statuary of karst in horizontally satisfied limestone showing compartmented karst (After Singh, 1992)

Figure 8: Highly karstified sandstone with pronounced solutioning on surfaces

Figure 9: Preferential solutioning leading to development of cave.

4. Karst Aquifers

Karstified limestones form potential aquifers. Nature of flow in karst aquifers has been documented by various researchers (Ford, 1965; Sweeting, 1972; Legrand and Stringfield, 1973; Bogli, 1980; Adyalkar, 1984; Singh, 1985; Singh and Dubey, 1997; Ford and Williams, 2007; Andreo et al. 2010; Ghasemizadeh et al. 2012; Scheidler et al. 2021). Common flow systems are diffused and conduit types. In the diffuse type, generally joints, fractures, fissures, bedding planes and other interconnected pores simulate flow system, with fairly well-defined water table due to interconnectivity. In the other case, flow is turbulent type, which is simulated by integrated conduit system formed due to preferential corrosive actions along joints, bedding planes and at the intersections of two to three sets of joints. Solutional pathways change from a few cm to >1 m. Karst aquifers occur under semi-confined to confined and unconfined conditions. In shale terrain, semi-confined to confined conditions are reported due to interstratified limestone beds and uneven karstification (Figure 10; Singh and Dubey, 1997).

Interbedded limestone bodies are highly karstified due to pronounced solutioning leading to profound development of secondary pore systems, which act as reservoirs of groundwater. In such interstratified limestone beds groundwater occurs under confined conditions (Singh and Dubey, 1997). In certain cases, tauto-flowing wells have also been reported (Singh and Dubey, 1997). Significantly, in India, amount of water pumped out from karst aquifers equals not only to total amount of water required for ~35 million people dwelling in 106 districts of country, but also for livestock, irrigation and various industries (Dar et al. 2014).

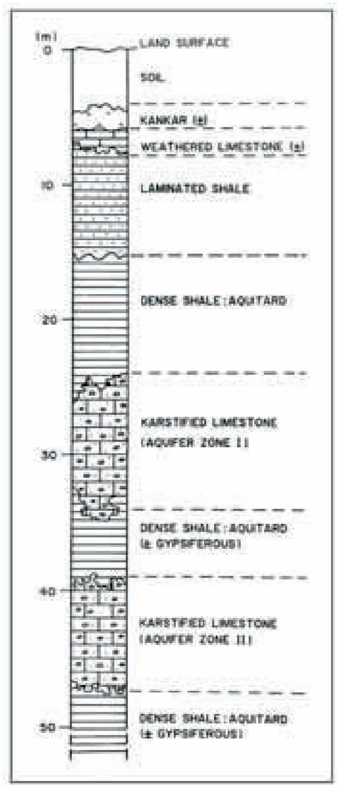

Figure 10. Lithology of a borehole showing interbedded, highly karstified limestone unit with pronounced solutioning leading to development of secondary pore systems and aquifer zones (After Singh and Dubey, 1997)

5. Discussion

5.1 Geotechnical Aspects

Due to interconnected network of secondary and tertiary pore systems, karst terrains pose diversified geohazards and challenges in development of any project. Among others, the notable issues are leakages and discharges in distal places, warranting proper redressal (Singh, 2007). Systematic and meticulous geotechnical assessments of karst terrains are thus essential prior to initiating any project. These studies should include probing of depth continuity, behaviour and occurrences of all types of porosities and their networks through sub-surface drilling in closed intervals, morphometric analysis, geophysical changes and geohydrological assessment. Closing all types of pores involving pervasive pressure grouting by drilling closely-spaced bore holes is a keyword to prevent distal leakages and discharges and structural degradations. Choice of depth and spacing of drilling and grouting is generally guided by the depth, bahaviour and intensity of karstification. Indeed the reason for failure of Hales Gar Dam in Tennessee (USA) is attributed to inadequate treatment of cavities in the carbonate rocks in the basement. Accordingly, for safety of envisaged projects, geotechnical evaluation during prefeasibility, feasibility and detailed feasibility time should be seriously carried out and properly taken care.

5.2 Geohazards in Karst Terrains

The uniqueness of karst terrains is well known in several ways with mysterious surprises throughout their lengths and breadths. Regional, local and lateral changes are unpredictably profound. Similarly, depth variabilities are also equally uncertain. On surface, manifestations of karstification may be minimal, whereas in depth it may be intense (Singh, 1989). These variabilities and uncertainties compound problems. In certain sedimentary sequences, interbedded limestone units have also been found to be intensely karstified at depths (Figure 10; Singh and Dubey, 1997). Identification of such water-bearing zones is equally important for proper assessment of geohazards. Also, cultural heritage monuments are adversely affected by geohazards (Ilies et al. 2020). Accordingly, there are several challenges to overcome geohazards in karst terrains. These challenges include (i) Creating geological and structural maps of karstified areas; (ii) Ascertaining agents, depth and intensity of development of karst; (iii) Mechanism and intensity of formation of pores and their interconnectivity; (iv) Identification of zones of recharge and discharge and delineation of catchments and real source areas; (v) Creation of aquifer map, including geohydrological and geophysical studies; and (vi) Addressing environmental concerns in karst area.

5.3 Researches in Karst Terrains

Based on the studies likes field traverses, karst landscapes, mode of genesis of pore systems, agents of karstification and geohydrological parameters, the following aspects should be kept in mind with respect to geohazards, challenges and remedial measures in karst terrains. (i) Comprehensive geotechnical evaluation of karst terrains are essential prior to initiation of any projects in them. (ii) Natural hazards in karst areas include floods, landslides, sinkholes and subsidence phenomena. (iii) Subsidence of underground caves may manifest in the form of experiencing earthquakes. Strong motion accelerographs and triaxial broad band seismometers can help in locating such collapse of subsurface voids/caves. (iv) Hydrologic hazards in karst terrains need more attention. (v) Paleo-karst and active karst history of the Karst terrain should be properly assessed. (vi) Land degradation, and partial or total destruction of the karst landscape, up to desertification, are among the most serious hazards that karst terrains have to face. These aspects should be properly monitored regularly. (vii) Systematic monitoring of surface and groundwater quality is essential as the risk of pollution is high in Karst areas. (viii) The extraction of limestones through quarrying activity inevitably has dramatic impact on the karst landforms, which are point of attractions for Geotourism. Efforts should be directed to preserve karst landscapes to promote tourism in such areas. (ix) Karst areas need policy and plan for management of sewage and effluent due to its high vulnerability of polluting subsurface and surface water bodies. (x) Risk and vulnerability studies in karst terrains need special training and capacity building.

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