Environmental issues in karst terrain: an example from Central India

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Abstract. In this paper, an attempt has been made to highlight the nature of karst in central India and evaluate possible effects of environmental degradation of groundwater due to indiscriminate disposal of various types of wastes into karst terrains without subjecting them to any treatment before disposal. Karst features associated with carbonate rocks of the Proterozoic Vindhyan basin in central India and environmental issues related to the same area's groundwater resources are briefly given. Based on the process of formation, karst may be categorized as True karst (holo-karst) and (ii) Fluvial karst. On the other hand, based on the types of cover, karsts are classified into three types: (i) Covered karst, (ii) Soddy karst, and (iii) Buried karst. Three types of karst landforms identified in carbonate rocks of the Vindhyans are (i) Superficial landforms (Karren), produced mainly by solution action on the rock surfaces, (ii) Landforms due to fluvial erosion, and (iii) Underground landforms, i.e., Caves. In a particular hydrogeologic setting, the groundwater system consists of minor secondary porosity modified by solution activities. Accordingly, two types of groundwater flow systems (diffuse and conduit) occur in carbonate rocks. Due to karstification, limestones constitute the most productive aquifer in the area. It is noted that untreated municipal and industrial wastes are disposed of directly in surface water bodies and streams and associated sinkhole depressions in limestone terrain. Secondary openings being interconnected with each other gradually carry these pollutants to groundwater reservoirs in karst aquifers. The continued influx of pollutants to groundwater reservoirs through interconnected secondary voids would cause severe groundwater pollution in the long run and degrade the groundwater quality in karst aquifers for various usages.

Keywords Karst, Carbonate rock aquifer, Waste disposal, Environmental issues, Central India.
1. Introduction
The term karst is used for geomorphic features formed mainly due to solution activity [1]. The rocks susceptible to solution activity are mostly carbonate rocks, namely, limestone and dolomite. The distribution of carbonate rocks in various parts of India is shown in Figure 1. Although limited solution activities have been reported in other rocks also [2, 3, 4], we describe briefly karst features associated with carbonate rocks of the Proterozoic Vindhyan basin in central India, and highlight environmental issues related to the groundwater resources of the carbonate aquifer systems.

![Figure 1. Distribution of carbonate rocks in India [5].](image_url)
Figure 2. Geological map of Vindhyan basin showing the distribution of carbonate rocks associated with Semri Group and Bhandar Group in Eastern, Central and Western India [6]

2. Nature of Karst
In various carbonate rocks from Vindhyan of the central India, karst features of different shapes, sizes and types are known [7,8,9]. Based on the process of formation, karst associated with carbonates rocks of the Vindhyan in central India may be grouped into two types: (i) True karst (holo-karst), formed by
karst processes, that is, solution activity and (ii) Fluvial karst, that is, karst developed by the combined action of fluvial and karst processes [10]. On the other hand, based on the types of cover, Vindhyan karst may be categorized into three types: (i) Covered karst (in which limestones are covered under alluvium), (ii) Soddy karst (limestones are covered under soil or terra-rossa formed from limestone itself) and (iii) Buried karst (a karst landscape which has been buried by later rocks). Three types of karst landforms have been identified in carbonates rocks of the Vindhyans: (i) Superficial landforms (Karren), produced mainly by solution action on the rock surfaces, (ii) Landforms due to fluvial erosion, and (iii) Underground landforms, i.e., Caves [7].

The primary porosity in studied carbonate rocks is negligible. Based on the thin section study, types of porosities observed in carbonate rocks include mainly intergranular, vugs, and mouldic, in addition to channels and fractures [10]. In a particular hydrogeologic setting, the groundwater system consists of minor secondary porosity modified by solution activities. Although two types of permeabilities, e.g., matrix and fracture, exist in carbonate rocks, secondary pores' intense effect in augmenting secondary permeability is apparent. Accordingly, two types of groundwater flow systems (diffuse and conduit) occur in carbonate rocks. Extensive solution action at intersections of joints and along bedding planes has resulted in conduits (Figure 3). Accordingly, large variations in water yield and water table gradient have been noted. Due to karstification, limestones constitute the most productive aquifer in the area [11]. Although they do not possess significant primary porosity, large secondary porosity is forming the best groundwater reservoirs due to karstification. Due to the development of solution channels, more springs are also present in carbonate rock terrain.

![Figure 3. Abandoned limestone quarry showing horizontally bedded limestones. Note profuse solution activity along bedding planes with the development of innumerable tubular conduits (TC) and wavy channels (WC).](image)

3. Environmental Issues

3.1 Karst Aquifer System
Sandstone, shale, and limestone of the late Vindhyan Supergroup constitute the major hydrogeologic units and aquifer systems of the area. The sandstones are quartzitic and supply a meagre to moderate amount of groundwater to wells and springs, tapping weathered zones, joints, fractures, and bedding
planes in the zone of saturation. The sandstones gradually grade into thin shales- to thickly-bedded and often jointed. The shales are calcareous and siliceous and contain intercalated/interbedded units of limestone. Although solution activity is noted in all the three bedrock hydrogeologic units, it is the only limestone that displays remarkable solution activity to various degrees. Depending on the nature and type of karstification, two main types of groundwater flow systems have been deciphered. They are diffuse flow system and conduit flow system. Joints generally simulate the first type, fractures, fissures, bedding planes, and other interconnected pores (Figure 3). In this case, generally, the water table is relatively well-defined due to substantial interconnectivity. Accordingly, flow approaches Darcy Law. Hydraulic conductivity does not show perceptible variation. Contrasting this, in the second case, flow is turbulent type, which is stimulated by an integrated conduit system (Figure 3) formed due to accentuated solution along joints, bedding planes, and at the intersections of two to three sets of joints. Solutional pathways vary from a few centimeters to more than 1-2 meters (Figure 3). The anisotropic nature of carbonate rocks is responsible for less hydraulic conductivity.

3.2 Underground Drainage and Depth of Karstification
Data of water level measurements, signatures of permeability in boreholes, locations, and characteristics of spring outlets, karstic resurgence, helped to infer sub-surface drainage. These observations revealed convergence of flow directions along with the courses of the streams. Accentuated karstification appears to have taken place along such flow directions, leading to the formation of sub-surface channels, including even sub-surface drainage patterns. Locally such lateral channels are developed along some joints. The presence of karst cavities up to a depth of 50-60 m reveals that up to such a depth, the karstification of limestone has taken place due to the solution of limestone. This inference is based on the assumption that the dissolution rate of limestone at the surface remained unchanged.

3.3 Groundwater Quality
Groundwater quality shows the variation with respect to the nature of the aquifer. Calcium-magnesium-bicarbonate type groundwater predominates in carbonate (karst) aquifer, as against calcium-magnesium-bicarbonate-sulfate type in the interbedded shale-limestone zone. Commonly, it is strongly alkaline and weakly acidic. Furthermore, it is also low sodium, medium- to high- to very- high salinity water (VHSW), and is free from residual sodium carbonate. Occasionally, in deep aquifer zones wherever gypsum veins are present within the shales, groundwater is VHSW. Excluding VHSW, water is commonly suitable for drinking, livestock, and industrial purposes. However, in some cases, before using, it may require softening. The composition of groundwater from the karst aquifer reveals that it would not lead to the development of salinity in soil profile on being used for irrigation purposes. Nevertheless, VHSW needs to be used judiciously, particularly in areas dominated by fine-textured clayey soil to prevent salinity development in the soil profile over the year.

3.4 Effluent Disposal and Degradation of Groundwater Quality
The prevalent practice in the area is to dispose of untreated wastes directly into the depressions present in the karst terrain. More often than not, the untreated municipal and industrial effluents are being disposed directly either near or in surface water bodies and streams and associated sinkhole depressions in limestone terrain (Figures 4, 5, and 6). Sinkholes (Figure 7), grikes (Figure 8), and other secondary solutional openings (Figure 9), which are present along with the stream courses and in their vicinity, being interconnected with each other through an intricate network of karstified joints and fractures [8], gradually carry these pollutants to sub-surface groundwater reservoirs in karst terrain. Natural drainage systems have been converted into natural effluent discharge sites and carrier systems in several places, which join higher-order streams at various locations (Figures 6 and 10). Such effluents percolate to karst groundwater reservoirs and remain trapped there and keep the deteriorating quality of underground water in the reservoir itself.
Figure 4. Natural stream with karstified limestone in its banks. Note direct discharge of domestic effluent into stream course.

Figure 5. Dump in limestone depressions. Note discharge of untreated effluents into the stream leading to change of water color.

Figure 6. Several effluent discharges in a row along the bank of a stream. Note the presence of karstified limestone beds along the stream course and bank. The change in water color is conspicuous.
Figure 7. Grikes and clints in bedded limestone, with a U-shaped sinkhole. Grike is leading to the formation of a cavern with the perennial river commonly dry at this place. Also, note the development of numerous solution channels along bedding planes and also the collapse of karstified limestone beds.

Figure 8. Solution widened joints' network, leading to the development of gikes and caves, a grand view of karst terrain.

Figure 9. Intensely karstified limestone with solution widened openings leading to the development of interconnected innumerable spongy cavities in karst terrain.

Figure 10. Google image of a part of the Rewa town in central India. Note transformation of the network of natural streams into effluent carrier channels (source: Google Image).
4. Remedial Measures

It is a well-known fact that diverse types of municipal, industrial, and other types of wastes are generated routinely. Commonly they are solid and liquid and biodegradable and non-degradable types. If such wastes are not regularly handled, they will lead to environmental degradation, pollution, and severe health issues. Regular disposal of such wastes is, therefore, unavoidable. However, before disposal, they need to be adequately segregated into solid, liquid, biodegradable, and non-biodegradable types and handled accordingly. After segregation, they need to be appropriately treated before disposal. The selection of proper sites for disposal of these is also equally important, as they cannot be indiscriminately disposed of anywhere. Nevertheless, it is noted that direct disposal of untreated municipal and industrial wastes and effluents in karst depressions is rampant in the area. Therefore it is necessary to discontinue indiscriminate disposal of untreated municipal and industrial wastes and effluents in karst terrains. If due attention is not paid to proper site selection for the disposal of effluents and also for their effective treatments before their disposal, continued influx of pollutants to karst reservoirs through interconnected secondary openings would cause serious groundwater pollution in the long run and degrade the groundwater quality in karst aquifers rendering the same either below required quality or unsuitable for various usages, e.g., drinking, livestock, industrial, irrigation purposes. Anthropogenic induced degradation of water quality is reported from elsewhere also [12,13]. Significantly, the environmental vulnerability of karst water and intricacies involved in its degradation, including precautions to be taken to prevent water degradation, have been highlighted from elsewhere also [14].

5. Conclusions

1. Karst features associated with carbonate rocks of the Proterozoic Vindhyan basin in central India and environmental issues related to the region’s groundwater resources are outlined.
2. Karst features belong to the category of true karst (holo-karst) and fluvial karst.
3. Three types of karst landforms, namely, (i) Superficial landforms (Karren), formed by solution action on the rock surfaces, (ii) Landforms due to fluvial erosion, and (iii) Underground landforms (Caves), have been identified in carbonates rocks of the Vindhyan.
4. Two main types of groundwater flow systems (diffuse and conduit) occur in karst aquifers.
5. Due to karstification, limestones constitute the most productive aquifer in the area.
6. It is noted that untreated municipal and industrial wastes and effluents are disposed directly into surface water bodies and streams and associated sinkhole depressions in karst terrain.
7. Secondary openings being interconnected with each other gradually carry effluents to groundwater reservoirs in karst aquifers. The continued influx of effluents to groundwater reservoirs through interconnected secondary voids would cause severe groundwater pollution in the long run and render groundwater from karst aquifers unsuitable for various usages.
8. It is suggested to discontinue indiscriminate disposal of untreated municipal and industrial effluents in karst terrains to ensure the supply of uncontaminated groundwater supply for various purposes in the long run.

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