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An Integrated Study On The Geology And Hydrogeological Conditions Of Bhopal, Madhya Pradesh, India

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Abstract: This research presents a comprehensive study of the geological and hydrogeological framework of the Bhopal region in central Madhya Pradesh. Bhopal's subsurface conditions are shaped by a complex geological history encompassing the Vindhyan Supergroup of sedimentary formations, Deccan Trap basaltic flows, and Quaternary alluvium. This paper delineates the lithostratigraphy, structural controls, and aquifer systems that define the region's groundwater regime. It investigates how topography, sedimentology, and tectonics influence aquifer characteristics and groundwater availability. Given the growing urban pressure and climate variability, the study emphasizes the need for sustainable groundwater management strategies informed by geological understanding. The findings can support integrated water resource planning, urban development, and climate adaptation in the region.

Index Terms: **Vindhyan Supergroup, Deccan Trap, Aquifer System, Hydrogeology, Urbanization, Groundwater Management**

1. Introduction

The capital city of Madhya Pradesh, Bhopal, holds a unique geotectonic position that makes it significant from both geological and hydrogeological perspectives. It lies at the intersection of the Vindhyan sedimentary basin and the Deccan volcanic province, two of the most ancient and geologically diverse terrains in peninsular India. The Vindhyan formations, dating back to the Proterozoic era, provide important insights into early sedimentary processes, while the overlying Deccan Traps, formed during the Late Cretaceous to Early Paleocene, represent one of the largest volcanic outpourings in Earth's history. These formations together create a distinct lithological and structural framework that influences the region's surface and subsurface water dynamics.

Bhopal is located on the Malwa Plateau, characterized by an undulating topography of ridges, valleys, and mesas. This terrain, coupled with seasonal monsoon patterns, dictates surface runoff and recharge characteristics. The city's geological complexity is further intensified by anthropogenic pressures such as rapid urbanization, industrial expansion, and deforestation, which affect the natural recharge systems and pose challenges to groundwater sustainability.

Over the last few decades, Bhopal has experienced significant stress on its water resources. Rising demand for domestic, agricultural, and industrial water has led to a steady decline in groundwater levels. Urban sprawl has resulted in the encroachment of recharge areas and contamination of aquifers. Therefore, understanding the geological setting is not just an academic exercise, but a practical necessity for informed water management and urban development planning.

This study is undertaken with the objective to systematically map and analyze the geological formations of Bhopal, evaluate aquifer systems and recharge zones, interpret the structural features influencing groundwater flow, and assess the current groundwater status and challenges. By integrating geological, hydrological, and environmental data, the research aims to provide a scientific basis for sustainable land and water resource planning. The study is also expected to support regional development strategies, environmental conservation efforts, and disaster risk reduction related to urban flooding and groundwater depletion.

2. Materials and Methods

2.1 Study Area

The study area is situated in the northwestern part of Bhopal district, encompassing a geographical area of approximately 713 square kilometers. It lies between latitudes 23°05′ and 23°30′ North and longitudes 77°15′ and 77°30′ East, and is represented by Survey of India (SOI) toposheet numbers 55 E/7 and 55 E/8. The region is bounded by the districts of Sehore in the southwest, Raisen in the east, and Rajgarh in the northwest. The terrain consists of a mosaic of urban zones, agricultural fields, forest patches, and hilly uplands, contributing to a varied topographic profile that plays a critical role in shaping surface runoff and recharge potential.

The climate is typically subtropical with distinct seasonal variations—hot summers, monsoon rains from June to September, and cool winters. Average annual rainfall ranges from 1000 to 1200 mm, most of which contributes to aquifer recharge during the monsoon season. The study region also includes major surface water bodies such as the Upper Lake (Bhojtal), which interacts dynamically with the groundwater regime.

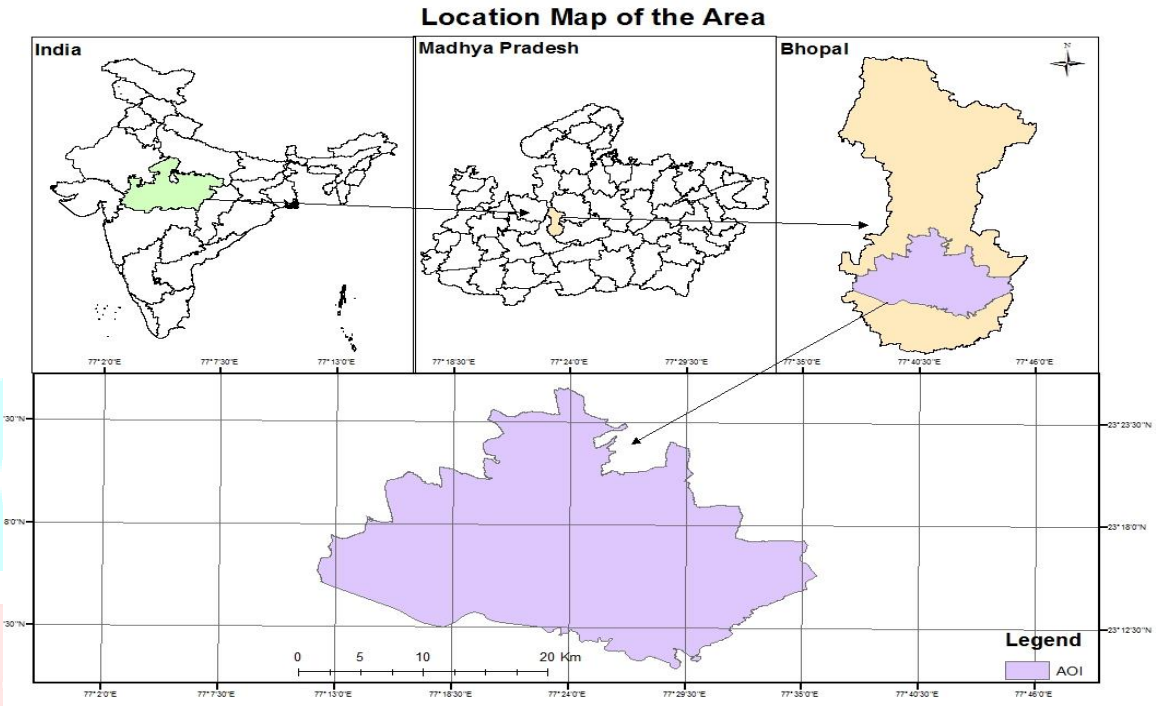

Fig. 2.1 Location map of the study area

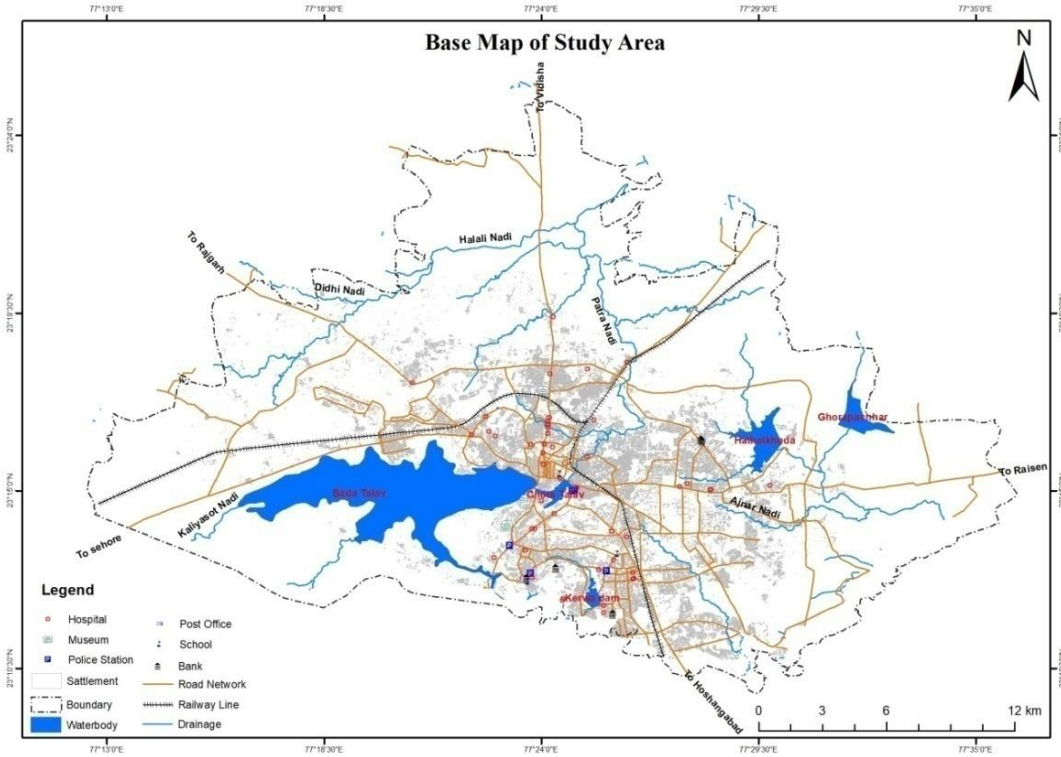

Fig. 2.2 Map showing approach and accessibility map to the study area

2.2 Methodology

The research methodology was designed to integrate multiple sources of data and techniques to achieve a holistic understanding of the region's subsurface conditions. The key components of the methodology included:

- **Field Investigations**: Systematic geological fieldwork was carried out to identify rock types, measure stratigraphic contacts, and document sedimentary structures such as cross-bedding, ripple marks, and nodules. Key outcrops were studied in detail at locations like Manuabhan Tekri, Shyamla Hills, and Bhadbhada Gate.
- **Remote Sensing and GIS**: Satellite imagery (Landsat and IRS) and Digital Elevation Models (DEMs) were used to prepare geomorphological and land use maps. GIS tools helped in delineating drainage patterns, lineaments, lithological boundaries, and potential recharge zones.
- **Secondary Data Compilation**: Groundwater data including water level fluctuations, aquifer characteristics, and yield assessments were obtained from Central Ground Water Board (CGWB) and Madhya Pradesh Ground Water Department. Historical geological maps and reports published by the Geological Survey of India (GSI) were consulted for baseline stratigraphic and lithological information.
- **Structural Mapping**: Structural features such as joints, fractures, and faults were mapped using compass measurements in the field. Orientation data were analyzed using stereographic projections to infer stress regimes and their implications on groundwater flow.
- **Hydrogeological Survey**: Depth to water table, aquifer thickness, transmissivity, and recharge rates were assessed through a combination of secondary data review and selective field validation using hand-dug wells and tube wells. Hydrogeological cross-sections were constructed to visualize subsurface conditions across the study area.

This multidisciplinary approach enabled the integration of lithological, structural, hydrological, and remote sensing datasets to generate a detailed and spatially coherent understanding of Bhopal's geology and groundwater dynamics.

3. Results and Discussion

3.1 Physiography and Lithological Composition

Bhopal lies on the northern edge of the Malwa Plateau, a physiographic zone known for its elevated basaltic terrain and undulating landscape. The topography of the study region features a mix of structural hills, dissected plateaus, residual ridges, and intervening shallow valleys. These features are strongly controlled by underlying lithology and structural disposition. The elevation ranges between 400 and 550 meters above mean sea level.

The geological formations influencing the physiography are:

- **Vindhyan Supergroup**: These formations, especially the Upper Bhander Sandstone, dominate the ridge and hill formations. The sandstones are ferruginous and exhibit sedimentary structures like ripple marks and cross-bedding, forming resistant escarpments.
- **Deccan Trap**: Comprised of horizontal basalt flows with vesicular and massive zones, forming flat-topped mesas and structural benches. Weathered basalt supports fertile black cotton soils.
- **Quaternary Alluvium**: Found in low-lying tracts and river valleys, composed of reworked sediments—sand, silt, clay—these formations are agriculturally productive and hydrogeologically significant.

This diversity in lithology has led to spatial variation in soil types, landforms, and groundwater potential zones.

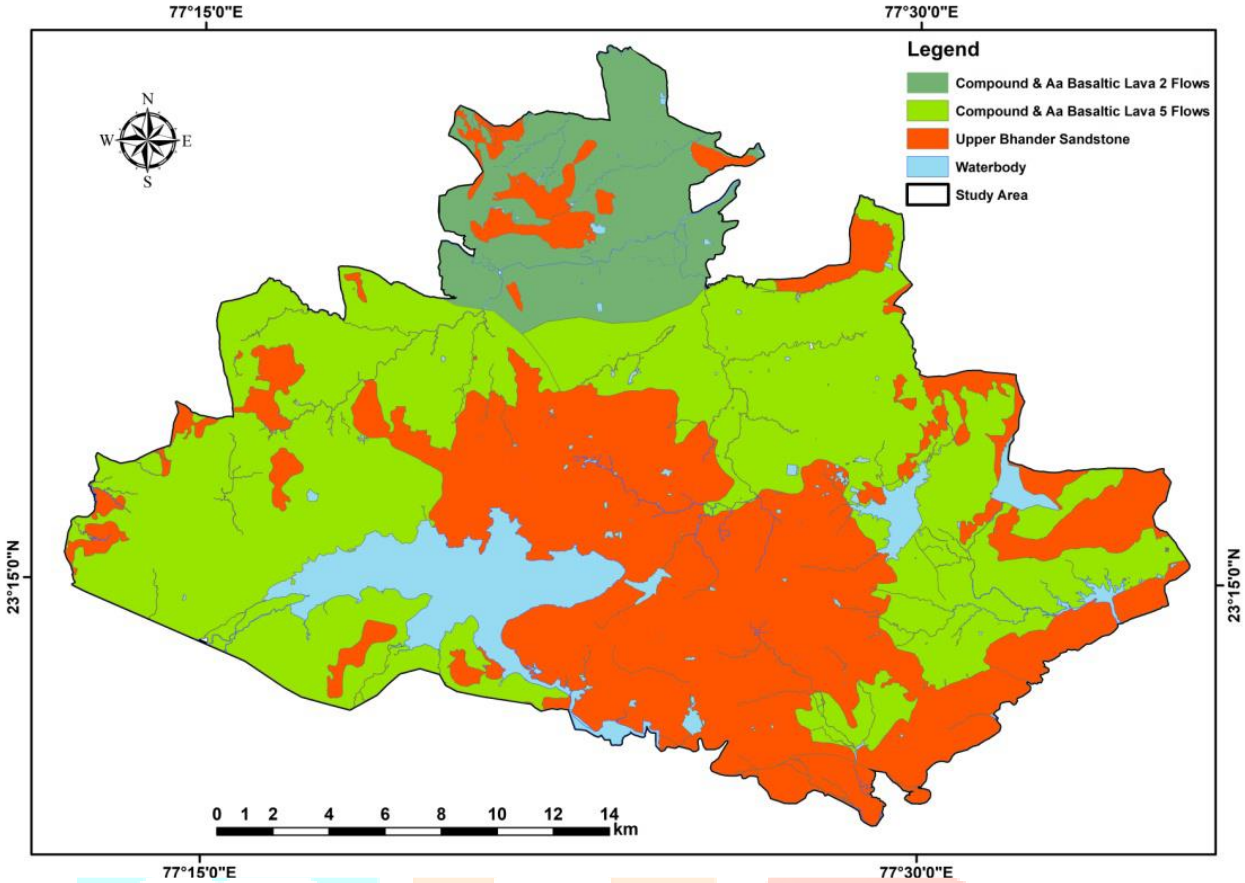

Fig. 3.1 Geological map of the study area

3.2 Stratigraphy and Structural Attributes

The stratigraphic succession in Bhopal presents a complex interplay of Proterozoic sedimentary sequences and Cretaceous-Paleocene volcanic units. The generalized stratigraphic order is:

- **Upper Bhander Group** (Vindhyan Supergroup): Predominantly sandstone with interbedded shale and occasional conglomerate beds. This is the oldest exposed formation in the study area.
- **Lameta Formation**: A narrow, localized horizon of calcareous sandstone, siltstone, and limestone, forming the basal part of the Deccan volcanics.
- **Deccan Trap**: Characterized by layered basaltic flows with vesicular, amygdaloidal, and massive zones, interspersed with red bole layers.
- **Alluvium and Laterite**: Representing the youngest deposits, consisting of valley fills, soil horizons, and lateritic caps.

The structural framework includes:

- **Joint Sets**: Developed due to tectonic and thermal stresses, found in multiple orientations (NW–SE, NE–SW, E–W). These joints enhance vertical and lateral permeability.
- **Fractures**: Common in both sandstone and basalt, they influence secondary porosity and act as conduits for groundwater.
- **Gentle Warping**: Seen in Upper Bhander units, these soft-sediment deformations suggest syn-depositional tectonics and basin subsidence.

(a) (b)

(c)

(d)

(e)

Fig. 3.2 (a) Field photographs showing cross cutting joints in sandstone near Guphamandir area, (b) Field photographs showing the pebbles at the top of a bed, (c) Field photograph showing cross – cutting vertical joints in Sandstones near Bhadbhada dam, (d) Field photograph showing open, sub – parallel, vertical joints at near Bhadbhada area, (e) Field photograph showing warping in the upper layer of sedimentary beds at road cutting near lalghati area.

3.3 Sedimentary Structures and Paleoenvironment

The sandstone exposures across Manuabhan Tekri, Shyamla Hills, and Idgah Hills reveal several primary sedimentary features:

- **Cross-Bedding**: Planar and trough varieties are abundant. These indicate directional current flow—confirmed by paleocurrent measurements (SSW–W–NNW).
- **Ripple Marks**: Symmetrical ripples denote wave action, while asymmetrical ripples reflect unidirectional fluvial currents. Their preservation reflects subaqueous depositional environments.
- **Concretions and Nodules**: Iron-rich nodules are diagenetic features, resulting from mineral precipitation in pore spaces. Their presence suggests early lithification in an oxidizing environment.
- **Convolute Bedding**: Formed due to rapid sedimentation and loading; indicates unstable, high-energy environments, possibly deltaic or floodplain conditions.

These structures support a model of deposition in a shallow, energy-variable environment influenced by marine incursions and fluvial inputs during the Upper Proterozoic.

Fig. 3.3 Field photograph showing cross bedding in an exposure of Sandstone

at Manuabhan tekri

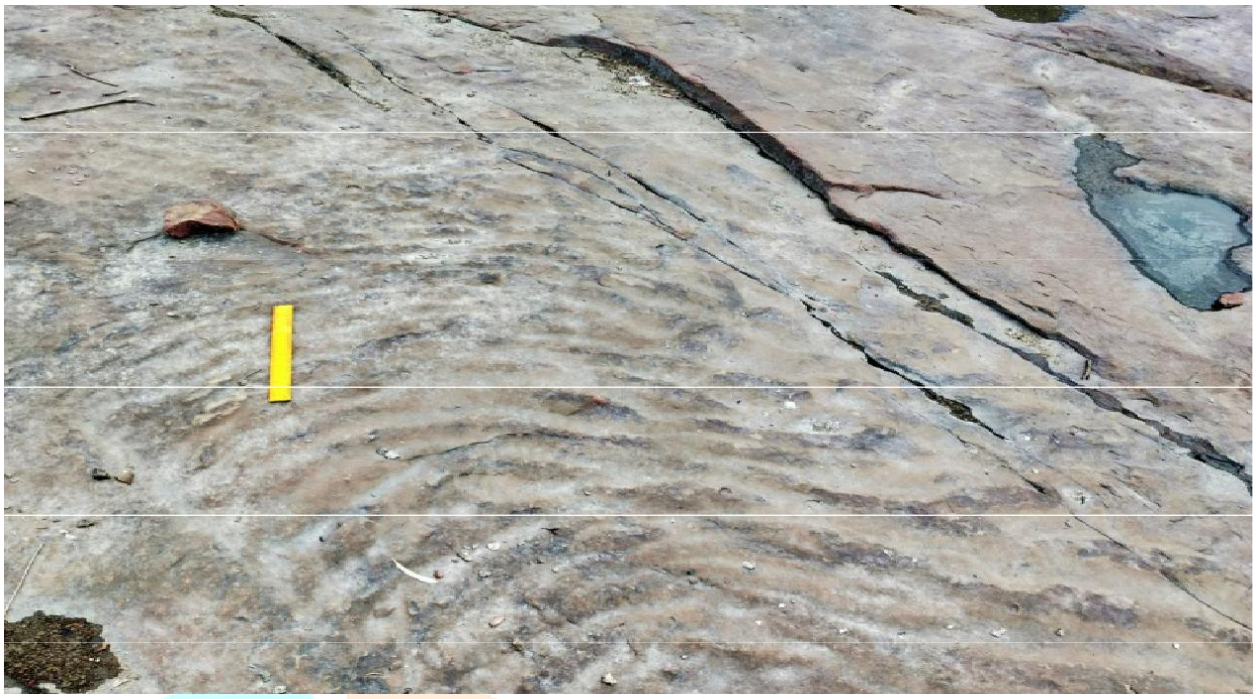

Fig. 3.4 Field Photograph showing current ripples in Sandstones near Bhadbhada

Fig. 3.5 (a) Field photograph showing ferruginous nodules seen at an expouser at shyamla hills, (b) Field photograph showing Nodules at the surface of sandstone at ManuabhanTekri

3.4 Hydrogeology and Groundwater Conditions

Groundwater in Bhopal occurs under phreatic to semi-confined conditions. Aquifer characteristics are directly influenced by lithology and structure:

- **Basalt Aquifers**: Yield moderate to good quantities of water, especially where weathered and fractured. Columnar joints and vesicular layers serve as critical water-bearing zones.
- **Sandstone Aquifers**: In the Upper Bhander Formation, joints, bedding planes, and lithologic variation create moderately productive aquifers. These are important for domestic water supply in hilly zones.
- **Alluvial Aquifers**: Exhibit high transmissivity due to sandy-gravelly textures. Located in low-lying areas and along river channels, these are the most productive zones.

Seasonal groundwater fluctuation is notable, with significant recharge during monsoon months. However, continuous abstraction in urban areas has resulted in declining water tables and deteriorating water quality.

3.5 Environmental and Urban Challenges

The growing population and expansion of Bhopal's urban boundary have direct consequences on its hydrogeological regime:

- **Recharge Reduction**: Construction over natural recharge zones (e.g., lake catchments) has led to reduced infiltration.
- **Groundwater Contamination**: Leachate from solid waste dumps and untreated wastewater affects aquifer quality.

- **Drainage Alteration and Urban Flooding**: Channel modifications, blockage of nalas, and impervious urban surfaces have increased flood risk during heavy rains.

These challenges necessitate urban planning that incorporates geoscientific assessments, zoning of recharge areas, promotion of artificial recharge techniques, and sustainable land-use policies.

4. Conclusion

Bhopal's geology is a blend of stable Proterozoic formations and younger volcanic and alluvial sequences. The complex interplay between geology, structure, and human activity determines groundwater availability. Detailed geological mapping, structural analysis, and sedimentological studies reveal that the Upper Bhander Sandstone plays a pivotal role in shaping the hydrogeological system. Sustainable water management in Bhopal requires geoscientific inputs at the planning and implementation stages of development projects.

Acknowledgments

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