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REMOTE SENSING-BASED HYDRO-GEOMORPHIC ANALYSIS OF THE PACHMARHI HILL REGION, INDIA

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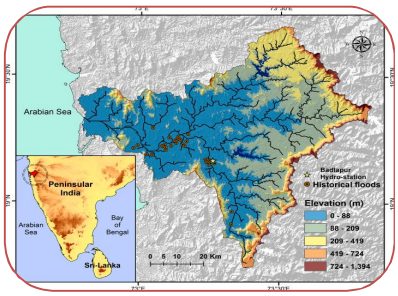
ABSTRACT



This study presents a comprehensive hydro-geomorphic analysis of the Pachmarhi Hill Region in India using remote sensing and Geographic Information System (GIS) techniques. The aim is to identify, classify, and interpret various landforms and drainage patterns that influence the hydrological behavior of the region. Satellite imagery and digital elevation models (DEMs) were used to delineate geomorphic units, analyze slope, aspect, drainage density, and identify hydro-geomorphological features such as valleys, ridges, plateaus, and water accumulation zones. The analysis provides critical insights into groundwater prospects, erosion-prone zones, and terrain characteristics, supporting sustainable water resource management and environmental planning in the region. The integration of geospatial technology has proven effective in understanding the dynamic interaction between geological structures, surface processes, and hydrology in complex terrains like Pachmarhi.

KEYWORDS: *Remote Sensing, GIS, Hydro-Geomorphology, Pachmarhi Hills, Digital Elevation Model (DEM), Drainage Analysis, Landform Mapping, Groundwater Potential, Terrain Evaluation.*

INTRODUCTION

Hydro-geomorphology is a vital sub-discipline of geomorphology that focuses on the interaction between landforms and water-related processes such as surface runoff, infiltration, drainage development, and groundwater movement. In regions with complex topography and ecological sensitivity, such as the Pachmarhi Hill Region in Madhya Pradesh, India, understanding the hydro-geomorphic framework is essential for sustainable water resource management, soil conservation, and environmental planning. The Pachmarhi Hills, part of the Satpura Range, represent a unique physiographic unit characterized by dissected plateaus, steep escarpments, forested slopes, and seasonal streams. The terrain plays a crucial role in controlling the hydrological response of the region, influencing erosion patterns, groundwater recharge potential, and watershed dynamics. However, the region's rugged and inaccessible terrain presents significant challenges for conventional ground-based surveys.

In this context, remote sensing and Geographic Information System (GIS) technologies offer cost-effective and efficient means to collect, process, and analyze spatial data over large and remote

areas. By integrating satellite imagery, digital elevation models (DEMs), and geospatial tools, researchers can systematically delineate geomorphic units, map drainage patterns, and assess slope, elevation, and other terrain attributes relevant to hydrological studies.

This study aims to conduct a comprehensive hydro-geomorphic analysis of the Pachmarhi Hill Region using remote sensing and GIS techniques. The objectives include identifying key landforms, analyzing drainage characteristics, and evaluating the implications of these features on water movement and storage. The outcomes of this study will contribute to informed decision-making in watershed management, groundwater exploration, and regional planning for sustainable development.

AIMS AND OBJECTIVES

Aim:

To conduct a comprehensive hydro-geomorphic analysis of the Pachmarhi Hill Region using remote sensing and GIS techniques to understand the relationship between landforms and hydrological processes for improved water resource management and environmental planning.

Objectives:

1. To delineate and classify the major geomorphic units of the Pachmarhi Hills using satellite imagery and digital elevation models (DEMs).
2. To analyze drainage patterns and drainage density within the region to assess surface water flow and runoff characteristics.
3. To evaluate terrain attributes such as slope, aspect, elevation, and relief that influence hydrological behavior and erosion susceptibility.
4. To identify potential groundwater recharge zones based on hydro-geomorphic features and spatial analysis.
5. To assess the spatial distribution of erosion-prone areas and their relationship with geomorphic and hydrological parameters.

REVIEW OF LITERATURE

Hydro-geomorphology integrates geomorphological features with hydrological processes to understand water movement and storage in a landscape. The application of remote sensing (RS) and Geographic Information System (GIS) technologies has significantly advanced the scope and accuracy of hydro-geomorphic studies by providing synoptic spatial data and facilitating multi-parameter analysis.

Remote Sensing and GIS in Hydro-Geomorphic Studies:

Many researchers have highlighted the utility of remote sensing and GIS as indispensable tools for terrain analysis, watershed delineation, and geomorphic mapping. Singh et al. (2018) demonstrated the use of satellite imagery and DEM data in identifying geomorphic units and assessing groundwater potential in the Himalayan foothills. Similarly, Reddy and Krishna (2020) applied integrated RS-GIS techniques to classify landforms and drainage networks in a semi-arid region, emphasizing the effectiveness of these technologies in inaccessible terrains.

Geomorphic Mapping and Drainage Analysis:

Studies by Gupta and Sharma (2017) emphasize that drainage pattern analysis through remote sensing provides insights into the geological structure and lithological control over water flow. The classification of drainage patterns such as dendritic, trellis, and radial has been used widely to interpret underlying rock types and structural controls (Jain et al., 2019). Pachmarhi's complex terrain, with its plateaus and escarpments, demands detailed drainage analysis to understand surface runoff and erosion susceptibility.

Hydro-Geomorphic Applications in Water Resource Management:

Hydro-geomorphic mapping is crucial for identifying groundwater recharge zones and areas vulnerable to erosion. Verma et al. (2016) used remote sensing data to delineate groundwater potential zones in central India, highlighting the relationship between geomorphic units and aquifer recharge capacity. The study of slope, aspect, and elevation parameters aids in understanding surface hydrological processes and soil conservation needs (Kumar and Singh, 2021).

Studies Specific to Pachmarhi and Similar Hill Regions:

While detailed hydro-geomorphic studies specifically focused on Pachmarhi are limited, research in similar hilly terrains of the Satpura Range and central India provide valuable insights. Patil and Joshi (2019) analyzed the geomorphology and drainage system of a nearby hill region using remote sensing, providing a methodological framework applicable to Pachmarhi. These studies underline the role of integrated RS-GIS methods in overcoming field survey limitations and delivering precise spatial data.

Gaps and Need for Present Study:

Despite the growing body of work, there is a paucity of detailed hydro-geomorphic assessments of the Pachmarhi Hills utilizing modern geospatial tools. Existing studies often lack comprehensive integration of geomorphological, hydrological, and terrain parameters necessary for robust water resource management and environmental planning. This study aims to fill this gap by employing high-resolution satellite imagery, DEMs, and advanced GIS analysis to provide an in-depth hydro-geomorphic assessment of the Pachmarhi Hill Region.

RESEARCH METHODOLOGY

The present study employs an integrated approach combining remote sensing (RS) and Geographic Information System (GIS) techniques to analyze the hydro-geomorphic characteristics of the Pachmarhi Hill Region. The methodology is designed to systematically acquire, process, and interpret spatial data for geomorphic mapping, drainage analysis, and terrain evaluation.

1. Study Area Selection

The Pachmarhi Hill Region, situated in the Satpura range of Madhya Pradesh, India, is selected due to its complex topography, rich biodiversity, and hydrological significance. The area encompasses various landforms such as plateaus, escarpments, valleys, and ridges, making it suitable for hydro-geomorphic analysis.

2. Data Acquisition

High-resolution satellite data such as Landsat 8 OLI, Sentinel-2, or IRS LISS III images are procured to map landforms and drainage features. SRTM (Shuttle Radar Topography Mission) DEM with 30m resolution or ASTER DEM data is used for terrain analysis including slope, aspect, and elevation. Survey of India (SOI) topographic sheets are utilized for reference and validation of geomorphic features.Geological maps, rainfall data, and existing hydrological records may be incorporated to complement the analysis.

3. Data Preprocessing

Satellite images undergo radiometric and geometric corrections to ensure accuracy and remove distortions. DEM data is processed for filling sinks, extracting contour lines, and generating slope, aspect, and hillshade maps. Thematic layers such as drainage, land use, and geomorphology are digitized or extracted for further analysis.

4. Hydro-Geomorphic Mapping

Using satellite imagery and DEM derivatives, major landforms such as plateaus, ridges, valleys, and terraces are delineated based on shape, texture, and elevation patterns. Drainage networks are extracted using DEM-based hydrological tools, and drainage patterns (dendritic, trellis, radial) are classified. Parameters like stream order, drainage density, and bifurcation ratio are calculated. Slope gradients and directions are derived from DEM data to understand terrain stability, runoff potential, and erosion risk zones.

STATEMENT OF THE PROBLEM

The Pachmarhi Hill Region, characterized by rugged terrain, diverse landforms, and significant ecological importance, faces increasing challenges related to water resource management, soil erosion, and environmental sustainability. Traditional field-based methods for studying hydro-geomorphic features in such difficult terrain are often time-consuming, labor-intensive, and spatially limited. Additionally, inadequate understanding of the spatial distribution of geomorphic units and drainage patterns hampers effective groundwater exploration and erosion control measures. Despite the region's critical need for sustainable water and land resource management, there is a lack of comprehensive and integrated hydro-geomorphic studies that utilize advanced remote sensing and GIS technologies to analyze its complex landscape. This gap limits the ability of planners and policymakers to make informed decisions regarding watershed management, groundwater recharge zones, and soil conservation strategies.

Therefore, there is a pressing need to employ remote sensing and GIS-based hydro-geomorphic analysis to systematically map, classify, and evaluate the Pachmarhi Hill Region's terrain and hydrological characteristics. This approach will provide accurate spatial data and insights necessary for sustainable environmental management, effective resource planning, and mitigation of natural hazards.

FURTHER SUGGESTIONS FOR RESEARCH

1. Temporal Analysis of Hydro-Geomorphic Changes:

Conduct multi-temporal remote sensing studies to monitor and analyze the changes in geomorphic features and drainage patterns over time, assessing the impact of climate change, land use changes, and anthropogenic activities on the Pachmarhi Hill Region.

2. Integration of Groundwater Modeling:

Combine hydro-geomorphic analysis with hydrological and groundwater flow models to better predict groundwater recharge rates and sustainability under different climatic and land-use scenarios.

3. Soil Erosion and Sediment Transport Studies:

Extend the study to quantify soil erosion rates and sediment transport using remote sensing coupled with field measurements to develop effective soil conservation strategies.

4. High-Resolution LiDAR and UAV Data Usage:

Utilize higher-resolution datasets such as LiDAR or UAV (drone)-based photogrammetry to capture fine-scale geomorphic and hydrological features, improving accuracy in terrain and watershed modeling.

5. Impact of Forest Cover on Hydro-Geomorphology:

Investigate the influence of forest density and vegetation types on the hydro-geomorphic processes, including infiltration rates, runoff characteristics, and slope stability in the Pachmarhi region.

SCOPE AND LIMITATIONS

Scope

1. Comprehensive Spatial Analysis:

The study utilizes remote sensing and GIS technologies to provide a detailed spatial assessment of the hydro-geomorphic features of the Pachmarhi Hill Region, including landform classification, drainage pattern analysis, and terrain characterization.

2. Water Resource Management:

Findings will support the identification of potential groundwater recharge zones and erosion-prone areas, aiding sustainable water resource planning and soil conservation efforts.

3. Environmental and Regional Planning:

The generated hydro-geomorphic maps and data can be instrumental for policymakers, environmentalists, and planners in making informed decisions for regional development, forest management, and disaster risk reduction.

4. Methodological Framework:

The research methodology can serve as a replicable model for similar hydro-geomorphic studies in other hilly and inaccessible regions.

LIMITATIONS

1. Resolution Constraints of Remote Sensing Data:

The spatial resolution of freely available satellite imagery (e.g., Landsat, SRTM DEM) may limit the detection of very fine-scale geomorphic features and micro-topographical variations.

2. Temporal Limitations:

The study is primarily based on static or recent datasets and does not extensively cover temporal changes or seasonal variations in hydro-geomorphic characteristics.

3. Field Verification Challenges:

Difficult terrain and accessibility issues in the Pachmarhi Hills may restrict the extent and frequency of ground truthing and field validation.

4. Data Availability and Quality:

Limited availability of high-resolution, cloud-free satellite images or ancillary data such as detailed soil and geological maps could affect the accuracy of interpretations.

5. Complex Hydrogeological Interactions:

The study focuses on surface geomorphology and does not extensively incorporate subsurface geological complexities or detailed hydrogeological modeling.

DISCUSSION

The hydro-geomorphic analysis of the Pachmarhi Hill Region using remote sensing and GIS techniques has provided valuable insights into the complex interplay between terrain features and hydrological processes in this ecologically significant landscape. The integration of satellite imagery and digital elevation data enabled detailed mapping of geomorphic units such as plateaus, ridges, valleys, and escarpments, which are critical in influencing surface water flow and groundwater recharge. The identified drainage patterns predominantly exhibit dendritic and trellis characteristics, reflecting the underlying lithology and structural controls. Drainage density and stream order analysis indicate zones of high runoff potential and areas susceptible to erosion, which correlate well with steeper slopes and

dissected terrain revealed by slope and aspect maps. These findings underscore the role of geomorphology in controlling hydrological behavior and sediment transport in the region.

Groundwater potential zones mapped through the integrated hydro-geomorphic approach highlight regions with favorable conditions for infiltration and aquifer recharge, primarily located in gently sloping valleys and plateau depressions. These zones are crucial for local water resource planning, especially considering the seasonal variability of water availability in the hills. However, the study also acknowledges certain limitations such as the moderate spatial resolution of available DEM and satellite data, which may overlook micro-scale geomorphic features and localized hydrological phenomena. Additionally, limited field verification due to difficult terrain might affect the precision of some interpretations. Overall, the remote sensing-based methodology proves to be an effective tool for large-scale hydro-geomorphic assessment in complex terrains like Pachmarhi. The generated maps and analyses not only enhance understanding of the region's hydro-geomorphic framework but also provide a scientific basis for sustainable water management, soil conservation, and environmental planning. Future research incorporating temporal data and high-resolution datasets could further refine the understanding of dynamic geomorphic and hydrological processes in the area.

CONCLUSION

The remote sensing-based hydro-geomorphic analysis of the Pachmarhi Hill Region has successfully demonstrated the value of integrating satellite imagery and GIS techniques in understanding the complex terrain and hydrological characteristics of this ecologically important area. The study effectively delineated key geomorphic units, characterized drainage patterns, and identified potential groundwater recharge zones, providing critical insights into the spatial distribution of water resources and erosion-prone areas. These findings are essential for sustainable water resource management, soil conservation, and regional planning efforts aimed at preserving the fragile ecosystem of the Pachmarhi Hills. Despite certain limitations related to data resolution and field validation, the applied methodology offers a robust framework for similar studies in other hilly regions. Future research involving higher-resolution data and temporal monitoring will further enhance the understanding of hydro-geomorphic dynamics, supporting better environmental management and disaster mitigation strategies. Overall, this study underscores the significant role of remote sensing and GIS as indispensable tools for effective hydro-geomorphic assessments in challenging terrains.

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