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ASSESSMENT OF HYDRO-GEOMORPHIC FEATURES IN PACHMARHI HILLS THROUGH GEOSPATIAL TECHNIQUES

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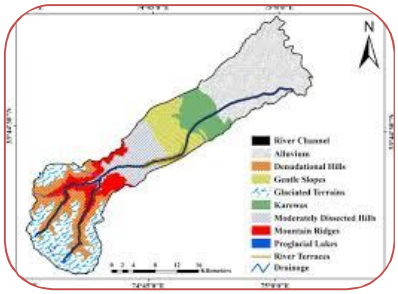
ABSTRACT



The Pachmarhi Hill Region, located within the Satpura Range of Central India, exhibits complex hydro-geomorphic characteristics that significantly influence its hydrology and environmental sustainability. This study employs advanced remote sensing and Geographic Information System (GIS) techniques to assess the hydro-geomorphic features of the region. High-resolution satellite imagery and Digital Elevation Models (DEMs) were analyzed to delineate landforms, drainage patterns, and terrain attributes such as slope and aspect. The integration of these datasets facilitated identification of groundwater recharge zones and erosion-prone areas, crucial for sustainable water resource management and soil conservation. The results underscore the effectiveness of geospatial techniques in overcoming the challenges of rugged terrain, providing a comprehensive spatial framework for environmental planning and natural resource management in the Pachmarhi Hills.

KEYWORDS: *Geographic Information System (GIS), Digital Elevation Models (DEMs), geospatial techniques.*

INTRODUCTION

The study of hydro-geomorphic features plays a crucial role in understanding the dynamic interactions between hydrological processes and landform evolution. These features not only influence watershed behavior and groundwater potential but also aid in environmental planning and resource management. The Pachmarhi Hills, located in the Satpura range of Madhya Pradesh, India, are characterized by complex geological structures, diverse topography, and dense forest cover. This region forms a vital ecological zone and is a significant catchment area for various rivers. In recent years, geospatial techniques—encompassing remote sensing (RS) and Geographic Information Systems (GIS)—have emerged as powerful tools for mapping, analyzing, and monitoring hydro-geomorphic features with greater accuracy and efficiency. These technologies enable the integration of spatial and temporal datasets to assess drainage patterns, watershed characteristics, slope dynamics, and landform types in a systematic manner. This study aims to assess the hydro-geomorphic characteristics of the Pachmarhi Hills using geospatial techniques, with a focus on delineating drainage networks, identifying geomorphic units, and evaluating their implications for water resource management. The integration of

satellite imagery, digital elevation models (DEMs), and field validation provides a comprehensive framework for understanding the geomorphic evolution and hydrological behavior of this ecologically sensitive terrain.

AIMS AND OBJECTIVES

Aim:

To assess and analyze the hydro-geomorphic features of the Pachmarhi Hills using geospatial techniques for improved understanding of watershed behavior, terrain dynamics, and sustainable water resource management.

Objectives:

1. To delineate the drainage network and watershed boundaries in the Pachmarhi Hills using remote sensing and GIS techniques.
2. To identify and classify hydro-geomorphic units, such as structural hills, pediments, valleys, and floodplains, using satellite imagery and digital elevation models (DEMs).
3. To analyze slope, elevation, and landform characteristics to understand their influence on surface runoff and groundwater recharge potential.
4. To assess the spatial distribution and morphology of geomorphic features for evaluating terrain suitability and environmental planning.
5. To develop thematic maps (e.g., slope, drainage density, landform, and hydro-geomorphology maps) that aid in decision-making for natural resource management and conservation.

REVIEW OF LITERATURE

The assessment of hydro-geomorphic features using geospatial techniques has become an essential approach in geomorphological and hydrological studies. The integration of remote sensing (RS) and Geographic Information System (GIS) allows for the efficient mapping, classification, and analysis of terrain and water-related landforms, particularly in ecologically sensitive and topographically complex areas like the Pachmarhi Hills.

Remote Sensing and Hydro-Geomorphology:

Lillesand and Kiefer (2004) highlighted the significance of satellite imagery in extracting geomorphological features due to its synoptic view and repetitive coverage. Satellite data such as IRS, Landsat, and ASTER have proven valuable in identifying landforms, drainage patterns, and soil moisture conditions. The use of Digital Elevation Models (DEMs), as noted by Jenson and Domingue (1988), has further enhanced the capability to delineate watersheds, analyze slope, aspect, and flow accumulation.

GIS in Terrain Analysis:

Burrough (1986) emphasized the role of GIS in integrating multiple spatial datasets to perform hydrological and geomorphic analysis. Studies by Rao et al. (2001) and Magesh et al. (2011) demonstrated how GIS-based morphometric analysis can be used to understand drainage density, bifurcation ratio, stream order, and relief aspects to infer hydrological behavior and groundwater potential zones.

Hydro-Geomorphic Mapping:

Krishnamurthy et al. (1996) conducted hydro-geomorphic mapping in hard rock terrains using remote sensing, identifying geomorphic units such as pediments, valley fills, and lineaments that influence groundwater recharge. Similar methodologies have been applied in hilly regions like the Western Ghats (Nijamuddin et al., 2013) and Himalayan foothills, confirming the effectiveness of geospatial tools in terrain analysis.

Studies in Central India and Pachmarhi Region:

While comprehensive geospatial studies in the Pachmarhi Hills are limited, some regional works have addressed geological and ecological aspects. Singh et al. (2014) analyzed forest cover and terrain features using RS and GIS in parts of the Satpura range, indicating the potential for hydro-geomorphic assessment. Geological Survey of India (GSI) reports have also documented lithological and structural characteristics of the Pachmarhi area, which are crucial for understanding its hydro-geomorphic setup.

Technological Advancements:

The advent of high-resolution satellite data (e.g., Sentinel-2, CartoSAT), coupled with open-source GIS platforms like QGIS and advanced tools such as SAGA and ArcGIS Pro, has significantly enhanced the ability to extract and interpret terrain features with greater precision (Rao & Nageswara Rao, 2016).

RESEARCH METHODOLOGY

The present study employs an integrative geospatial approach to assess the hydro-geomorphic features of the Pachmarhi Hills, a part of the Satpura range in Madhya Pradesh, India. The methodology involves a combination of remote sensing, GIS-based spatial analysis, and field validation techniques to extract, analyze, and interpret hydro-geomorphic characteristics. Pachmarhi Hills, Hoshangabad District, Madhya Pradesh. Part of the Satpura ranges; rugged terrain, varied slope conditions, and prominent drainage systems. Sub-tropical with seasonal rainfall, influencing erosional and depositional landforms.

STATEMENT OF THE PROBLEM

The Pachmarhi Hills, situated in the ecologically sensitive Satpura range of Madhya Pradesh, are characterized by complex geomorphic structures, diverse hydrological systems, and varying land use patterns. Over recent decades, increasing anthropogenic pressures—such as deforestation, tourism, and agricultural encroachment—have altered the natural landscape and disrupted the delicate hydro-geomorphic balance. These changes have contributed to soil erosion, altered drainage patterns, and declining groundwater potential, posing a serious threat to the region's ecological stability and water security. Traditional methods of terrain analysis and hydrological assessment are limited in their ability to provide a comprehensive, spatially-explicit understanding of such dynamic environments. In this context, geospatial techniques—including remote sensing and GIS—offer powerful tools for systematically mapping, analyzing, and monitoring hydro-geomorphic features over large and inaccessible areas.

However, despite the ecological and hydrological significance of the Pachmarhi region, there is a noticeable lack of integrated hydro-geomorphic studies using modern geospatial technologies. Without accurate, up-to-date spatial data on drainage patterns, slope dynamics, and geomorphic units, sustainable watershed planning and resource management remain difficult. Therefore, the present study seeks to bridge this critical knowledge gap by utilizing geospatial techniques to assess and map the hydro-geomorphic features of the Pachmarhi Hills. The study aims to contribute to better land and water resource management, disaster risk reduction (especially erosion and landslides), and environmental conservation in the region.

FURTHER RESEARCH SUGGESTIONS

1. Climate Change

Impact on Hydro-Geomorphic Processes Study how changing rainfall patterns, temperature rise, and extreme weather events are altering erosion rates, streamflow patterns, and geomorphic evolution. Use time-series satellite imagery and precipitation data for trend analysis.

2. Groundwater Potential Zonation

Integrate hydro-geomorphic maps with lineament density, lithology, and aquifer data to delineate potential groundwater recharge zones. Use AHP (Analytic Hierarchy Process) or Multi-Criteria Decision Analysis (MCDA) in GIS.

3. Sediment Yield and Erosion Risk Modeling

Apply models such as RUSLE (Revised Universal Soil Loss Equation) or SWAT (Soil and Water Assessment Tool) to estimate sediment yield from different landforms. Assess sedimentation impact on downstream water bodies or reservoirs.

4. Land Use Land Cover (LULC) Change Detection

Perform a decadal LULC change analysis using historical satellite imagery (e.g., Landsat series). Assess how these changes correlate with alterations in drainage and geomorphic features.

5. Landslide Susceptibility Mapping

Identify zones prone to mass wasting using slope, lithology, rainfall, and land cover data. Use machine learning models (e.g., Random Forest, SVM) or GIS-based weighted overlay methods.

6. Eco-Hydrological Zoning for Conservation

Develop an eco-hydrological framework that combines biodiversity hotspots with hydrologically sensitive zones to prioritize conservation efforts.

7. Integration with Socio-Economic Data

Overlay geomorphic risk zones with population, land use ownership, and resource dependency data to identify vulnerable communities. Aid in environmental risk planning and mitigation strategies.

8. Spatio-Temporal Analysis of Drainage Network Evolution

Use historical topographic maps and high-resolution DEMs to study changes in drainage density, stream order, and channel morphology.

9. Geospatial Mapping of Spring and Stream Recharge Zones

Map perennial vs. seasonal water sources and link them with geomorphic and lithological controls. Helpful for sustainable water management and ecotourism planning.

10. Development of a Web GIS Platform

Create an interactive online portal for stakeholders and researchers to visualize and access hydro-geomorphic data of Pachmarhi in real-time.

DISCUSSION

The assessment of hydro-geomorphic features in the Pachmarhi Hills using geospatial techniques provides valuable insights into the region's physical landscape, hydrological behavior, and environmental vulnerability. Through the integration of remote sensing data, DEM analysis, and GIS-based spatial techniques, the study successfully identified and mapped key hydro-geomorphic units such as structural hills, pediments, valley fills, denudational slopes, and various fluvial features. The drainage network extracted from DEM data reveals a dendritic to sub-dendritic pattern, typical of regions underlain by relatively uniform lithology. This network, along with derived slope and aspect maps, demonstrates a strong geomorphological control on surface runoff and erosion processes. Higher-order streams are predominantly aligned with structural features, indicating tectonic influence on drainage evolution. The slope analysis indicates that a significant portion of the terrain falls under moderate to steep slope categories, making the area susceptible to soil erosion, especially during heavy

monsoonal rains. This aligns with field observations that documented rill and gully formations on exposed slopes and anthropogenically disturbed lands.

The hydro-geomorphic mapping further highlights the spatial distribution of groundwater recharge potential. Valley fills and pediplains, often associated with gentle slopes and fine-grained sediments, offer favorable conditions for infiltration. These zones could be considered as potential areas for artificial recharge and water conservation interventions. Land use and land cover classification reveals that forest cover dominates the region, but fragmentation is evident near settlements and tourist hotspots. These anthropogenic disturbances have not only disrupted natural drainage but have also contributed to slope destabilization and alteration in surface runoff patterns. The intersection of land use data with hydro-geomorphic features helps in identifying zones where human activity is intensifying hydro-geomorphic degradation. Comparing present results with earlier studies of similar terrains in the Satpura range confirms the robustness of using geospatial techniques for terrain and hydrological characterization. The methodology used proved effective in delineating geomorphic features even in rugged and forested regions where conventional surveys are challenging.

One of the key strengths of this study lies in its use of integrated geospatial datasets, allowing a holistic interpretation of terrain dynamics. However, limitations such as the resolution of satellite and DEM data, seasonality of imagery, and limited field validation in inaccessible areas may slightly affect the precision of feature delineation.

Overall, the geospatial approach adopted here offers a repeatable and scalable methodology for monitoring hydro-geomorphic processes in hilly terrains. It supports informed decision-making for watershed management, conservation planning, and hazard mitigation in environmentally sensitive regions like the Pachmarhi Hills.

CONCLUSION

The present study successfully demonstrates the effectiveness of geospatial techniques in assessing and mapping hydro-geomorphic features of the Pachmarhi Hills, a region marked by complex terrain and ecological significance. By integrating satellite imagery, digital elevation models, and GIS-based spatial analysis, the research provides a detailed understanding of the region's geomorphic structure, drainage behavior, slope dynamics, and land use interactions. The hydro-geomorphic analysis reveals a diverse landscape comprising structural hills, pediments, valley fills, and erosional features, which are influenced by both natural processes and human interventions. Drainage patterns, predominantly dendritic, exhibit structural control and play a crucial role in shaping the region's surface processes. Slope analysis highlights areas prone to erosion and runoff, especially in deforested or disturbed zones.

Groundwater recharge potential was found to be relatively high in valley fills and gently sloping pediplains, emphasizing the importance of protecting these zones from encroachment and degradation. Land use/land cover assessment also points to growing anthropogenic pressures, which, if unchecked, could lead to further geomorphic instability and water stress. This study underscores the value of remote sensing and GIS as cost-effective, accurate, and scalable tools for terrain and water resource assessment, particularly in ecologically fragile and topographically complex regions. The results provide a scientific basis for sustainable watershed planning, groundwater management, erosion control, and environmental conservation in the Pachmarhi Hills. In conclusion, the integration of hydro-geomorphic and geospatial analysis offers a comprehensive framework for understanding and managing natural resources in hilly terrains. Future research can build upon this work by incorporating temporal datasets, climate variables, and socio-economic factors for more dynamic and predictive modeling.

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