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Integrated AHP and GIS-Based Delineation of Groundwater Potential Zones in the Tipan River Basin, India: A Multi-Criteria Decision and Sensitivity Analysis Approach

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Abstract

The Tipan River, a tributary of Son River in Madhya Pradesh, India, is characterized by diverse geomorphic features such as pediment-pediplain complexes, low to moderately dissected hills, and an intricate river network. The soil of region ranges from clayey to loamy, underlain by geological formations including basalt, granite gneiss, limestone, and fine-grained sandstone. To address urgent need for sustainable groundwater management, this study integrates the Analytical Hierarchy Process (AHP) with Geographic Information System (GIS) tools to delineate groundwater potential zones (GWPZs). Eight hydrological parameters - rainfall, geology, geomorphology, soil, land use/land cover (LULC), slope, drainage density, and lineament density—were selected based on their relevance to groundwater occurrence and recharge. These were weighted through AHP using Saaty's 1–9 scale, with consistency verified (CI = 0.055, CR = 0.039). A weighted overlay analysis in ArcGIS Pro produced a GWPZ map, classifying basin into four classes: Poor (3.58%), Moderate (20.62%), Good (47.59%), and Very Good (28.21%). High groundwater potential was found in areas with gentle slopes, loamy soils, pediment-pediplain features, and high rainfall. The map's accuracy was validated using Receiver Operating Characteristic (ROC). Area Under Curve (AUC) value of 0.789, indicates strong predictive performance. Sensitivity analysis through the map removal method highlighted geology, geomorphology, and soil as the most influential parameters, while LULC showed minimal impact. This AHP-GIS approach offers a robust and replicable framework for groundwater assessment, supporting sustainable water resource planning in Tipan River Basin.

Keywords: Tipan River Basin, Analytical Hierarchy Process, Geographic Information System, Groundwater Potential Zones, Sensitivity Analysis

Introduction

Groundwater, a critical natural resource, serves as a basic source of potable water, irrigation, as well as industrial use in many regions worldwide, particularly in semi-arid and arid environments (Magesh *et al.*, 2012; Pal *et al*., 2020; Sherin *et al*., 2023; El-Sorogy *et al*., 2024). In India, groundwater accounts for approximately 50% of irrigation needs and over 80% of rural and urban water supplies, underscoring its significance for sustainable development and food security (Das, 2019). However, the increasing demand for groundwater, coupled with overexploitation, climate variability, and inadequate management, has led to significant depletion of aquifers, posing challenges to water security (Machiwal *et al*., 2011; Kumar *et al*., 2021; Shinde *et al*., 2024). The Tipan River Basin, located in central India, exemplifies these challenges, with its diverse geological settings and growing anthropogenic pressures necessitating precise and reliable methods for assessing groundwater potential.

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Delineating zones of groundwater potential (GWPZs) is essential for planning and management of groundwater resources as it enables informed management and planning of water resource (Oh *et al.*, 2011; Manap *et al.*, 2013; Nagarajan and Singh, 2009; Hasanuzzaman *et al.*, 2022; Masroor *et al.*, 2023). Traditional methods like geophysical surveys are often expensive, time-consuming, and offer limited spatial coverage. (Tiwari and Kushwaha, 2020; Shimpi and Rokade, 2021; Takele *et al.*, 2025). In contrast, combination of geospatial techniques, including Geographic Information Systems (GIS) and remote sensing, with multi-criteria decision-making methods such as Analytical Hierarchy Process (AHP), offers a robust, cost-effective, and spatially comprehensive approach to mapping groundwater potential (Echogdali *et al.*, 2022; El Sherbini *et al.*, 2025; Sarkhel, 2025). These methods leverage spatial data, including topography, lithology, land use/land cover (LULC), rainfall, and drainage patterns, to model groundwater potential with high accuracy (Chatterjee *et al.*, 2023; Verma and Mirajkar, 2024).

AHP scale developed by Saaty (1980), is a broadly used MCDA method that assigns weights to influencing factors, with sensitivity analysis enhancing the reliability and robustness of