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^{1,2,3}Department of Applied Geology,
Vijayanagara Sri Krishnadevaraya
University, Post-Graduation Centre
Nandihalli-SANDUR, Karnataka, India
Email: basavaraj24hatti@gmail.com

Address for correspondence:

Basavaraj Hatti
Department of Applied Geology,
Vijayanagara Sri Krishnadevaraya
University, Post-Graduation Centre
Nandihalli-SANDUR, Karnataka, India
Email: basavaraj24hatti@gmail.com

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Geospatial Assessment of Surface Runoff Dynamics in the Hutti-Maski Schist Belt, Dharwar Craton, South India

Mahesh Babu N.¹, Rekha S.², Basavaraj Hatti³

Abstract

The Hutti-Maski schist belt (HMSB) within the archaean Dharwar Craton of South India is a semi-arid, mineral-rich region where surface water availability is a critical constraint for mining operations, agriculture, and ecosystem sustainability. Accurate assessment of surface runoff, governed by the complex interplay of geomorphology, lithology, and land use, is essential for effective water resource management and flood risk mitigation in this terrain. This study employs an integrated geospatial approach to model and analyze the spatiotemporal dynamics of surface runoff in the HMSB. The Soil Conservation Service Curve Number (SCS-CN) method, widely recognized for its efficacy in ungauged basins, is implemented within a Geographic Information Systems (GIS) environment. The model integrates key spatial parameters including a high-resolution digital elevation model (DEM) for hydrological conditioning, soil texture and hydrologic group mapping derived from field and legacy data, and land use/land cover (LULC) classification from multispectral satellite imagery. These inputs are used to generate a runoff curve number grid and compute peak runoff estimates for dominant storm events. The results delineate the watersheds of the HMSB and reveal significant spatial heterogeneity in runoff potential. Areas with exposed bedrock, mining operations, and sparse vegetation exhibit high runoff coefficients due to low infiltration capacity, while zones with residual soil cover and deciduous forests show moderate to high infiltration, attenuating surface flow. The study produces a validated runoff potential zonation map, classifying the terrain into low, moderate, high, and very high runoff zones. The findings conclusively demonstrate that the geospatial CN model is a robust tool for hydrological assessment in archaean greenstone belts. This work provides a critical scientific basis for designing site-specific water harvesting structures, managing sediment transport from mining areas, and formulating sustainable watershed management plans to enhance water security in the HMSB and analogous semi-arid cratonic regions.

Keywords: Geospatial analysis, Surface runoff, SCS–Curve Number (SCS-CN), GIS and Remote Sensing, Runoff potential zonation, Land use/land cover (LULC), Hydrologic soil groups, Digital Elevation Model (DEM), Semi-arid hard-rock terrain

Introduction

Sustainable water resource management in semi-arid, geologically complex terrains is a persistent global challenge. In the Archaean cratons of peninsular India, such as the Dharwar Craton, the availability of surface water is highly variable, governed by a fragmented drainage network, erratic rainfall, and a shallow regolith profile overlying impervious bedrock (Kale & Rajaguru, 1987; Sajinkumar et al., 2017; Hutti and Nijagunappa, 2011). The Hutti-Maski schist belt (HMSB), a prominent auriferous greenstone belt within this craton, epitomizes this hydro-climatic stress. Its economy is dominated by mining and subsistence agriculture, both of which are critically dependent on a finite and seasonally contingent surface water supply (Srinivasan et al., 1989). Furthermore, land cover alterations from mining and associated activities exacerbate surface runoff, leading to reduced groundwater recharge, increased erosion, and heightened flood risks during intense monsoon events a trend observed in similar mining-affected watersheds globally (Mishra et al., 2021).

Quantifying surface runoff dynamics in such data-scarce regions is therefore paramount for strategic water harvesting, pollution mitigation, and ecosystem preservation. Traditional hydrological gauging is often impractical across these rugged terrains, creating a compelling need for robust, spatially explicit modeling approaches. Geospatial technology, integrating Remote Sensing (RS) and Geographic Information Systems (GIS), has emerged as a transformative tool for hydrological assessment, enabling the parameterization of landscape variables like topography, soil, and land use at a catchment scale (Jain et al., 2012; Hutti and Nijagunappa, 2015). The Soil Conservation Service Curve Number (SCS-CN) method, when embedded within a GIS framework, provides a standardized and effective model for estimating runoff from rainfall, particularly in ungauged or poorly monitored basins (USDA-SCS, 1972; Gajbhiye, 2015).

Against this backdrop, this study aims to execute a comprehensive geospatial assessment of surface runoff dynamics in the HMSB. The specific objectives are to: (1) delineate the watersheds and model the terrain's hydrological parameters using a high-resolution digital elevation model (DEM); (2) generate an integrated runoff curve number map by synthesizing data on soil hydrologic groups and land use/land cover (LULC); and (3) quantify the spatial distribution of runoff potential to produce a zonation map for targeted water resource management interventions.

Study Area

The Hutti-Maski Schist Belt is actually known as India's main gold field. This region is famously known as the "Gold field of India". The study area is located in northern Karnataka state, India and covers an 1149 km². There is also the Hutti-Maski Schist Belt of Dharwar Craton present in this region as well. Essentially, this area is bounded by 15°10' to 15°30' North and 76°30' to 77°15' East which covers the same geographical region. Also it is certainly deprives North Raichur and South Ballari this district. In addition, Koppal district is situated on its west side and Yadgir district to the east of it. Furthermore, the Hutti-Maski Schist Belt is essentially a mineral area and it also has well known Hutti Gold Mines. Besides, this area is definitely semi-arid with annual precipitation ranges from 650 to 1000 mm per year. Furthermore, these weather conditions are the cause of an excessively dry climate in this land for most part of the year. The region's geology is dominated by schist and quartzite rocks which in turn offer high groundwater storage (and transmission) potential. These rock formations itself are known for their good water-holding properties.

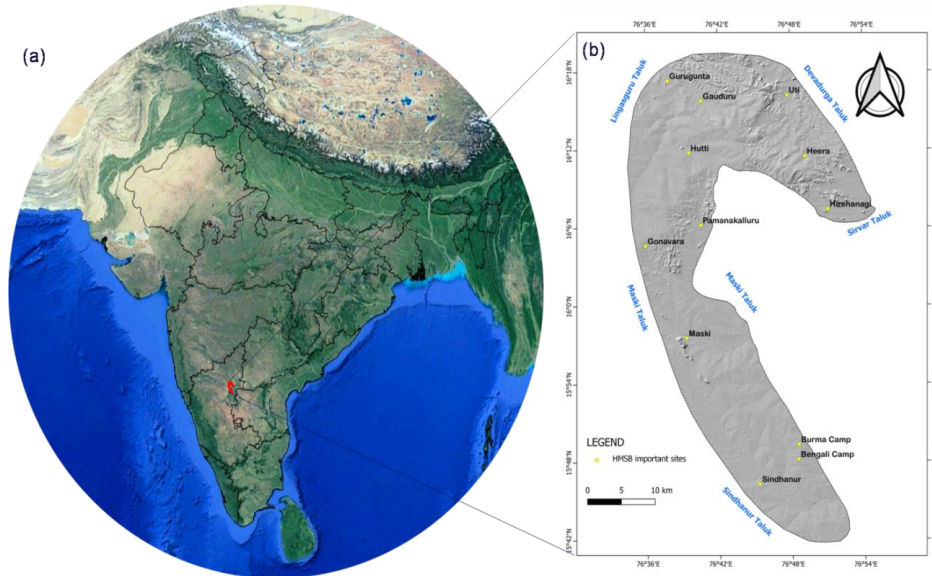


Fig.1 Study area (a) Hutti-Maski Schist belt location in India; (b) with its important sites

Research Methodology

This study utilize a GIS-based SCS-CN model, integrating multi-source geospatial data to analyze the Hutti-Maski schist belt (1149 km²), defined by administrative and watershed boundaries sourced from the Survey of India. Data acquisition method was primary inputs included a 30m resolution Cartosat-1 A multi-source data framework was implemented, incorporating an NRSC (2018) DEM for topography, a Sentinel-2A (2023) based LULC map created in QGIS 3.28, and soil data for texture and Hydrologic Soil Group (HSG) classification is processed in QGIS 3.28. HSG map was derived by digitizing and reclassifying the 1:250,000 scale soil map from the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP, 1990). Long-term average annual rainfall data (2000-2024) was obtained from the India Meteorological Department (IMD) for 15 stations within and adjacent to the belt.

The runoff modeling (SCS-CN) method was implemented, where runoff depth (Q) is calculated as $Q = (P - I_a)^2 / (P - I_a + S)$ for $P > I_a$. The initial abstraction (I_a) was taken as $0.2S$, and the potential maximum retention (S) was derived from the curve number (CN), which was assigned per hydrologic soil cover complex using standard lookup tables (Mishra & Singh, 2003). A weighted CN grid was created by overlaying HSG and LULC layers in QGIS. Runoff was computed pixel by pixel using the Raster Calculator, and the output was validated against limited historical streamflow reports from the State Water Resources Department.

Results and Discussions

1. Geology

The lithology of the Hutti-Maski belt comprises metamorphosed volcanic and sedimentary sequences of the Dharwar Supergroup, including schist, phyllite, and quartzite, intruded by granites and pegmatites. Figure 2 illustrates that the belt is primarily composed of these units alongside mafic-ultramafic rocks such as metabasalt and metaperidotite (Chatterjee et al., 2017). The dominant schistose and quartzitic rocks are recognized for their significant groundwater storage and transmission potential, a characteristic well-documented in similar terrains (Naha et al., 2020; Jha et al., 2021).

Geomorphology

The landscape features gentle hills underlain by the tectonically deformed rocks of the Hutti-Maski Greenstone Belt. These rocks, originally submarine basalts and volcanic sediments, have been folded and faulted over time. This structural

complexity, shown in Figure 2, has created the fracture-dominated aquifer framework of the region. Surface drainage is provided by seasonal streams with highly variable flow. The surface runoff exists primarily as confined aquifers in deeper bedrock and as unconfined aquifers in the shallow weathered zone. Recharge is almost exclusively derived from rainfall, with the monsoon season providing the most significant input.

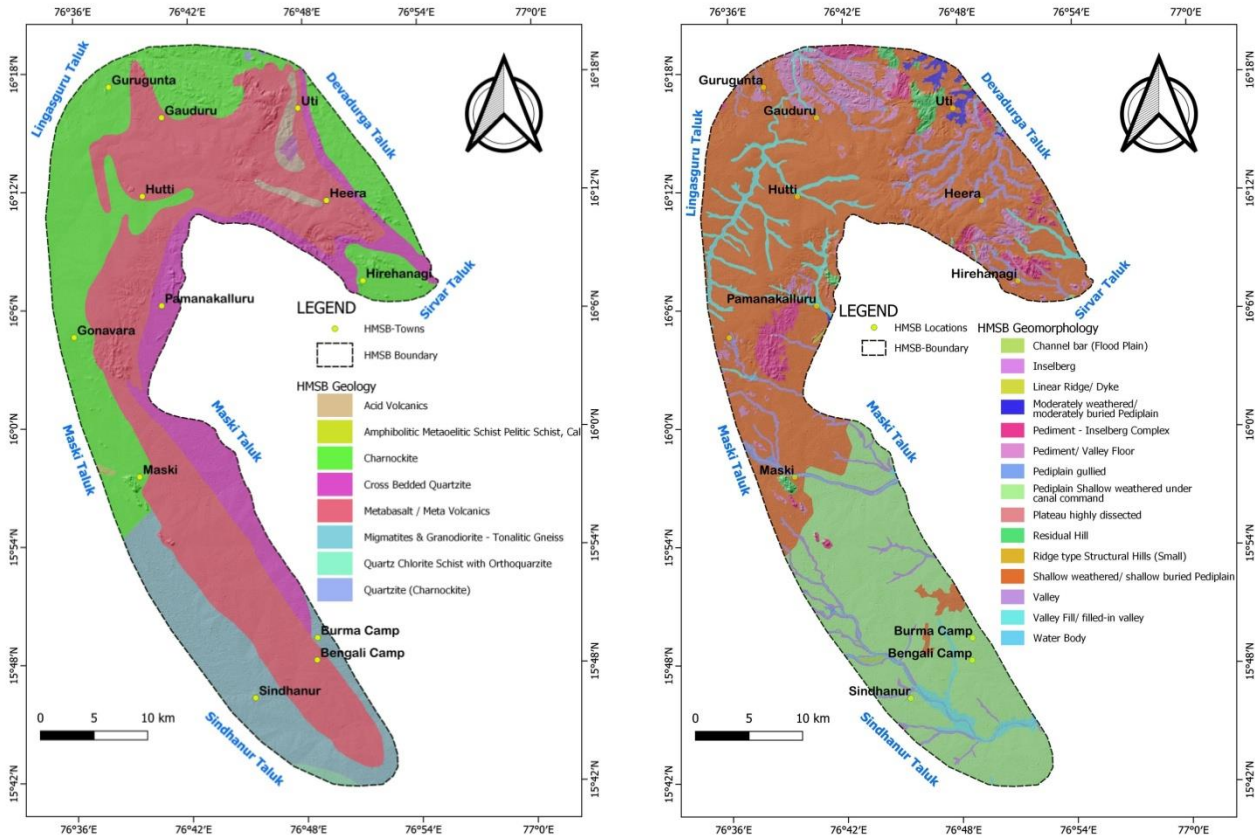


Fig.2 Geology and Geomorphology map of the study area

Soil Type

The characteristics of Hutti-Maski soils are a product of their parent material and the regional hydroclimate. A critical determinant of soil function is permeability, which increases with greater and better-connected porosity (Hatti & Ibomcha, 2022). The size and arrangement of soil particles further dictate water retention and transmission dynamics (Li et al., 2021). When soils are compacted, pore spaces are reduced, creating a physical barrier to water movement and decreasing overall permeability (Nkonya et al., 2022). Ultimately, these physical attributes porosity, texture, and structure directly influence where and how much groundwater can be recharged and stored within the region (Yang et al., 2021; Hutti and Nijaganappa, 2015).

Land Use and Land Cover

As demonstrated in studies, land use change critically controls surface runoff infiltration, potentially reducing groundwater recharge by 60%. The soil and land cover parameters governing this process in the study area are mapped in Fig. 3.

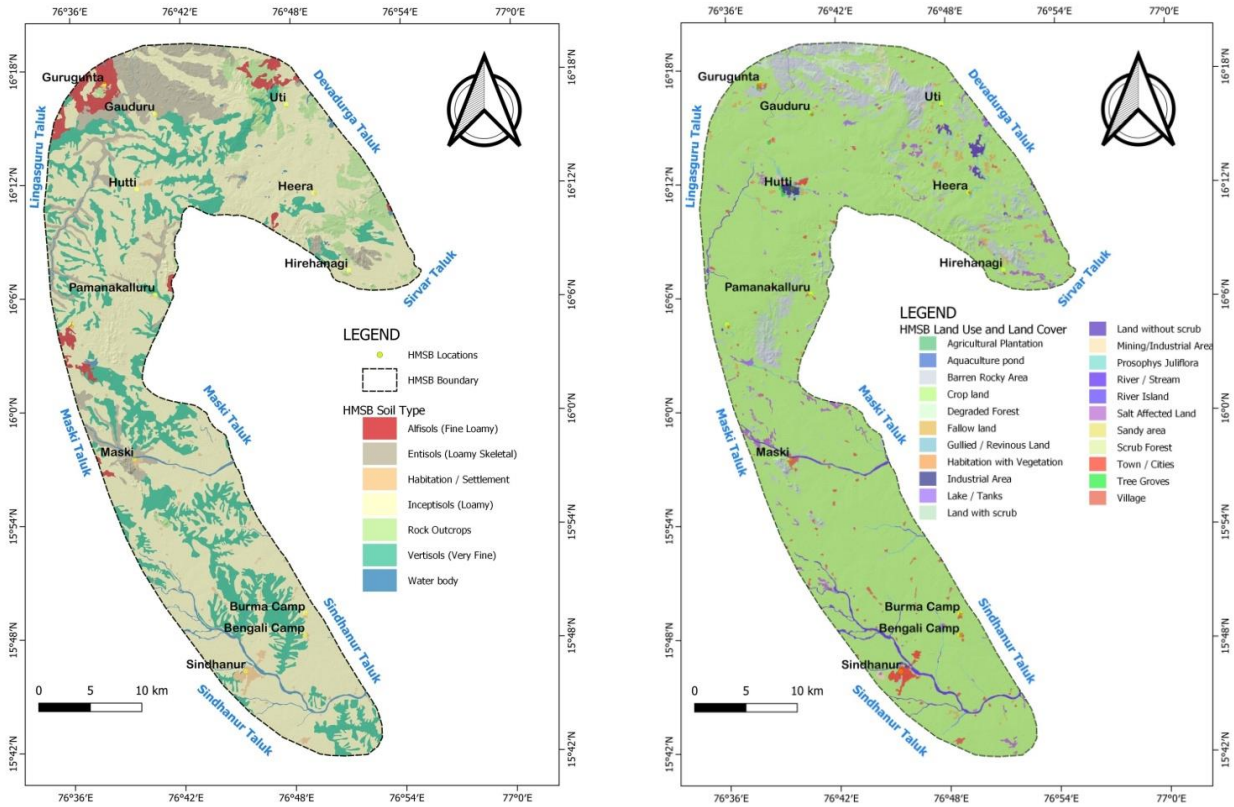


Fig.3 Soil type and LULC map of the study area

Drainage Density

Based on the drainage network shown in the attached image (Fig. 4), a geospatial analysis was performed to calculate the drainage density (Dd) for the Hutti-Maski Schist Belt (HMSB). Drainage density, a critical morphometric parameter defined as the total stream length per unit area (Horton, 1945), was computed using the line density tool in a GIS environment. The analysis reveals a moderate to high drainage density across the belt, particularly in the central and eastern sectors near Hutti, Maski, and Lingasugur. This pattern indicates a well-developed, branching stream network that efficiently conveys surface runoff. The higher density in these areas suggests a combination of impermeable lithology, moderate to steep slopes, and lower infiltration capacity, which promotes quicker channel formation and enhanced surface flow response to rainfall events (Strahler, 1964). The presence of several water bodies/tanks, as shown on the map, often coincides with lower-order stream confluences in this dense network, indicating natural sites for surface water accumulation.

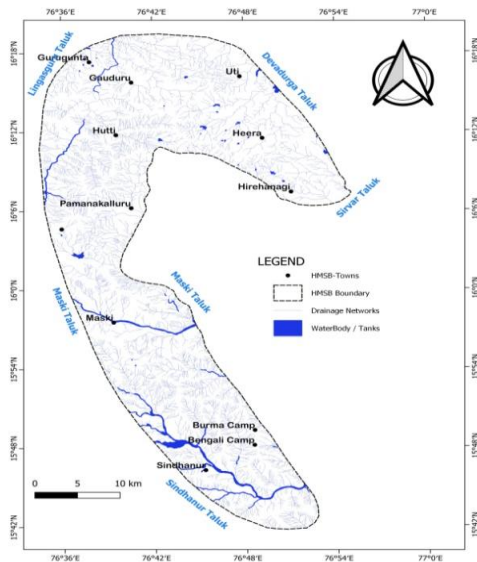


Fig.4 Drainage density map of the study area

Slope and Elevation Characteristics

The terrain morphology, derived from a 30m resolution Digital Elevation Model (DEM), is a primary control on runoff velocity and accumulation. The Hutti-Maski Schist Belt exhibits a moderate topographic relief, with elevations ranging approximately from 450 to 650 meters above mean sea level. Slope analysis, performed using the spatial analyst tool in QGIS, classifies the area predominantly into gentle to moderate slopes (0° to 15°), with steeper gradients (15° to 30°) localized along dissected hill slopes and ridge lines. This slope distribution facilitates moderate overland flow velocities, influencing the concentration time and peak discharge of generated runoff within the watersheds (Moore et al., 1991).

Elevation

According to the research, the height of a region plays a critical role in water processes such as filling and releasing of ground water. In the aspect of hydrological research, different water movement mechanisms are observed in high land and low land areas (Hou et al., 2021). Terrain dictates how water will flow and spread on land, but also influences the way that water is distributed in various environments. What happens is, the water stays there more in low and flat areas and it also travels down to recharge groundwater further.

Rainfall Data Analysis

The precipitation regime was analyzed using a 25-year dataset (2000–2024) from 15 stations within and surrounding the Hutti-Maski Schist Belt (HMSB), obtained from the India Meteorological Department (IMD). Statistical analysis reveals significant spatiotemporal variability in annual rainfall across the study area. The mean annual rainfall for the period from 2000 to 2024, at every five, ten, fifteen, twenty and twenty-five years interval mean rainfall images are shown in the following figures and ranges from approximately 547 mm at Budihal Camp to 624 mm at Pathapur, with an overall basin average of ~592 mm. This confirms the region's semi-arid classification. Temporally, the data exhibits high inter-annual variability, a characteristic of monsoonal climates, with coefficients of variation exceeding 30% at several stations. Notably, extreme years are evident, such as the high rainfall recorded at Sindhanur (1190 mm in 2009) and consistent deficits in years like 2002 and 2003. The 5-year mean (2020–2024) shows a slightly increasing trend compared to the 25-year mean at most stations, with current averages around 610–720 mm, potentially indicating a shift in rainfall patterns. This high variability and the occurrence of intense, short-duration storms are critical drivers of flash runoff events in the region, directly influencing the Curve Number (CN) model's initial abstraction and runoff computations (Mishra & Singh, 2003). The spatial interpolation of this station data using techniques like Inverse Distance Weighting (IDW) provided the essential precipitation input for the SCS-CN model across the watershed.

Table.1 Mean rainfall of every five, ten, fifteen, twenty and twenty-five years interval

Station No.	RG-Station	Latitude	Longitude	5yrs-Mean (2020-24)	10yrs-Mean (2015-24)	15yrs-Mean (2010-24)	20yrs-Mean (2005-24)	25yrs-Mean (2000-24)
1	Hutti	16.19	76.66	719.82	642.92	611.07	587.59	552.54
2	Maski	15.95	76.65	718.96	630.96	630.69	617.41	572.58
3	Gurgunta	16.28	76.63	690.90	624.82	595.12	619.60	618.89
4	Sindhanur	15.76	76.75	610.17	566.95	591.51	626.48	592.15
5	Javalgera	15.86	76.81	610.17	569.48	593.19	627.72	583.82
6	Buddinni	16.03	76.64	719.82	642.92	629.11	601.12	563.37
7	Uti	16.26	76.77	693.21	643.34	629.31	636.95	610.29
8	Pathapur	16.12	76.87	693.49	637.53	629.20	645.99	624.17
9	Kurukunda	16.17	76.88	693.49	637.53	629.20	645.99	624.17
10	Heera	16.18	76.82	693.49	637.53	629.20	645.99	624.17
11	Hosuru	16.2	76.74	719.84	642.93	629.11	601.12	563.36
12	Yalaghatta	16.27	76.72	693.86	626.30	594.10	624.53	622.83
13	Budihal Camp	15.71	76.8	561.97	535.60	551.25	557.87	547.49
14	Balaganur	15.95	76.75	610.17	569.48	593.19	627.72	583.84
15	Honnahalli	16.21	76.56	719.84	642.93	629.11	613.72	573.44

Rainfall-Runoff Temporal Dynamics (2000–2024)

The temporal analysis of monthly rainfall-runoff relationships from 2000 to 2024, derived from the SCS-CN model outputs, reveals the pronounced seasonality and inter-annual variability of the hydrological regime in the Hutti-Maski Schist Belt. Runoff generation is overwhelmingly confined to the monsoon months (June–September), exhibiting a strong, non-linear correlation with precipitation intensity. The time-series graphs for representative years (e.g., 2009, 2018, 2022) demonstrate sharp, lagged runoff peaks directly following major precipitation events, with runoff coefficients (runoff/rainfall) varying significantly between events. High-intensity, short-duration storms, even in otherwise drier years, trigger disproportionate runoff responses due to the rapid saturation of the region's shallow soils and low-infiltration bedrock, a characteristic of semi-arid, hard-rock terrains (Sharma et al., 2010).

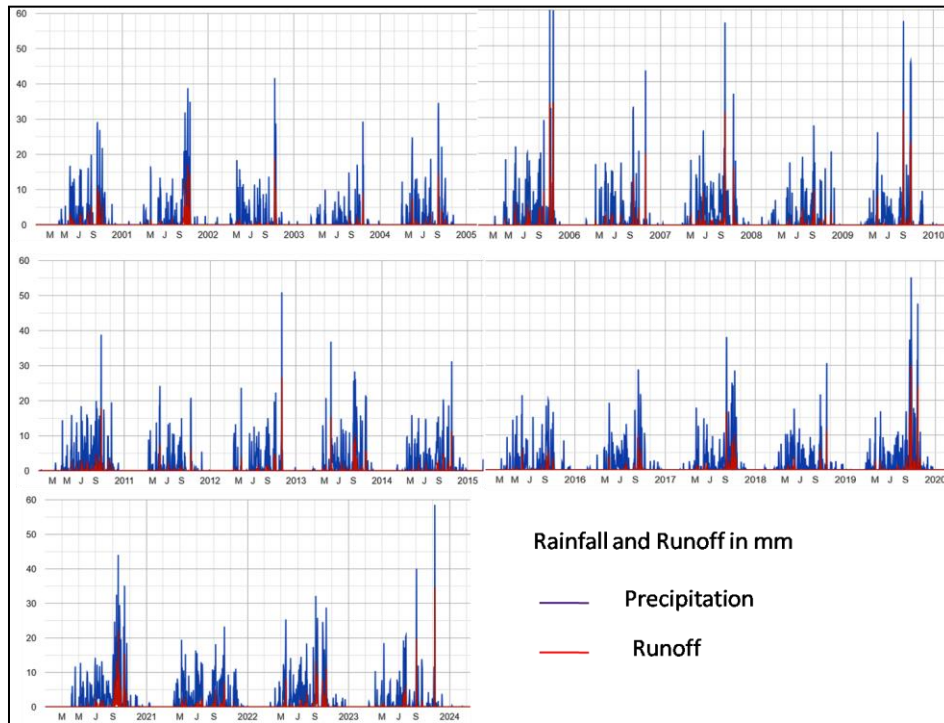


Fig.5 From year 2000 to 2024 rainfall runoff time series charts of the study area

The long-term trend shows considerable volatility, with some years (e.g., 2002, 2003, 2015) exhibiting low cumulative runoff due to rainfall deficits, while others (e.g., 2009, 2020, 2022) record substantial runoff volumes corresponding to high-rainfall years. Notably, the latter period (2018–2024) appears to feature more frequent high-runoff events, aligning with the observed increase in the 5-year mean rainfall. The runoff response is highly sensitive to antecedent moisture conditions; a major storm occurring after initial monsoon rains generates a significantly higher and faster runoff peak than one of similar magnitude on dry soil, validating the dynamic abstraction loss accounted for in the SCS-CN methodology (Mishra & Singh, 2003). This analysis confirms that while total annual rainfall dictates the overall water yield, the intensity and distribution of storm events within the monsoon season are the critical determinants of peak discharge, flood risk, and ephemeral streamflow in the HMSB. The decoupling of rainfall and runoff during the dry months (October–May) is nearly absolute, with negligible baseflow, highlighting the region's dependency on managed surface water storage and monsoon recharge.

Conclusion:

This study successfully implemented a GIS based SCS-CN model to assess the spatiotemporal dynamics of surface runoff in the semi-arid Hutti-Maski Schist Belt (HMSB). The integrated geospatial analysis of key parameters including terrain morphology, soil hydrologic groups, land use/land cover, and a 25-year rainfall record revealed significant spatial heterogeneity in runoff generation potential. The results demonstrate that areas of exposed bedrock, active mining, and sparse vegetation exhibit very high runoff coefficients due to minimal infiltration, contrasting with forested zones and residual soils that promote greater percolation. The findings underscore the primary control of intense, short-duration monsoon rainfall on the region's ephemeral hydrology, with runoff response being highly sensitive to storm intensity and antecedent moisture. The production of a validated runoff potential zonation map provides a critical planning tool, clearly identifying priority areas for interventions. Zones of high and very high runoff potential are prime candidates for targeted water harvesting structures to capture and conserve surface flow, thereby enhancing water security. Conversely, these same areas require focused erosion and sediment control measures, especially near mining operations, to mitigate downstream impacts. In conclusion, this research affirms the robustness of the geospatial SCS-CN methodology for hydrological assessment in data scarce, hard rock terrains. The outputs offer a scientifically grounded framework for sustainable watershed management in the HMSB. Implementing site specific strategies based on this runoff zonation such as constructing check dams, promoting afforestation in critical areas, and regulating land use can significantly improve water resource resilience, support economic activities, and protect the local ecosystem in this vital mineral rich region of the Dharwar Craton.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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