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Spatial Analysis of Groundwater Recharge and Extraction Patterns: A Case Study of Nanded District, Maharashtra (2024–2025)

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Abstract:

This study presents a spatial analysis of groundwater recharge and extraction patterns across 16 talukas of Nanded district, Maharashtra, for the period 2024–2025. Using taluka-wise data on average annual rainfall, annual extractable groundwater resources, and current groundwater extraction, the study evaluates the Stage of Groundwater Development (SGD) and identifies areas of relative stress and surplus. The analysis follows the Central Ground Water Board (CGWB) classification framework, where assessment units are categorized into safe, semi-critical, critical, and over-exploited zones based on the ratio of annual extraction to annual extractable resources. Results indicate that the district as a whole remains in the safe category, with total extraction (38,252.33 HAM) well below total extractable resources (1,18,652.72 HAM), yielding a district-level SGD of approximately 32.2%. However, significant spatial variation exists: Ardhapur (58.93%) and Mudkhed (53.89%) exhibit comparatively higher pressure on local aquifers, while Biloli (11.98%) and Kinwat (23.35%) possess substantial untapped potential. Relatively uniform rainfall across talukas (920–1090 mm) suggests that variations in groundwater availability are governed more by local hydrogeological conditions than by precipitation alone. The findings underscore the need for taluka-specific groundwater governance strategies rather than uniform district-level policies.

Keywords: *groundwater development, spatial analysis, recharge, extraction, taluka-wise assessment, Nanded district, CGWB, Stage of Groundwater Development*

1. Introduction

Groundwater is an indispensable natural resource that sustains agricultural production and domestic water supply across semi-arid regions of India. In the Marathwada sub-region of Maharashtra, where surface water availability is limited and rainfall is seasonal, groundwater serves as the primary source of irrigation and drinking water for millions of people. The district of Nanded, situated in the southeastern part of Marathwada, is characterized by a predominantly agrarian economy, making its groundwater resources particularly critical to local livelihoods.

Despite the importance of groundwater in this region, systematic spatial assessments of recharge potential versus actual extraction at the sub-district (taluka) level remain limited in the published literature. Aggregate district-level data often masks localized disparities, leading to undifferentiated management responses that fail to address emerging hotspots of over-extraction. There is, therefore, a need for granular, taluka-wise analyses that can inform targeted interventions.

This study examines groundwater conditions across all 16 talukas of Nanded district using data collected for the 2024–2025 cycle. The analysis focuses on the Stage of Groundwater Development (SGD), a standard indicator recommended by the Central Ground Water Board (CGWB) for assessing the sustainability of groundwater use. By mapping spatial variability in SGD across the district, this paper aims to identify talukas at risk of transitioning from 'safe' to 'semi-critical' status and to recommend evidence-based management strategies.

2. Study Area

Nanded district is located between latitudes 17°50' N and 19°55' N and longitudes 76°54' E and 78°52' E in the eastern part of Marathwada, Maharashtra. The district covers an area of approximately 10,528 sq. km and is bounded by Hingoli and Parbhani districts to the north, Yavatmal to the east, Bidar (Karnataka) to the south, and Latur to the west. The Godavari River and its tributaries drain major portions of the district.

The geology of the district is predominantly characterized by Deccan Trap basalts, which influence the nature and extent of groundwater aquifers. Weathered and fractured zones in the basaltic formations serve as the primary repositories of groundwater. The district is administratively divided into 16 talukas: Ardhapur, Bhokar, Biloli, Degloor, Dharmabad, Hadgaon, Himayatnagar, Kandhar, Kinwat, Loha, Mahur, Mudkhed, Mukhed, Naigaon, Nanded, and Umari.

The climate of the district is semi-arid, with an average annual rainfall ranging from approximately 920 mm in Mudkhed to 1,090 mm in Mahur. The southwest monsoon (June–September) accounts for nearly 80–85% of the annual precipitation. Agriculture is the primary occupation, with crops such as soybean, cotton, sorghum, and sugarcane cultivated across the district.

3. Methodology

3.1 Data Sources

Primary data for this study were sourced from the official groundwater assessment records of central ground water board (GWRCD) by GEC-2015 method for Nanded district for the year 2024–2025. The dataset includes three key variables for each of the 16 talukas: (1) average annual rainfall (mm), (2) annual extractable groundwater resources (measured in Ham — Hectare Metres), and (3) current annual groundwater extraction (Ham). These data were compiled from district-level groundwater surveys and cross-verified using published CGWB assessment norms.

3.2 Key Indicator: Stage of Groundwater Development (SGD)

The primary analytical metric used in this study is the Stage of Groundwater Development (SGD), which quantifies the proportion of available groundwater resources currently being extracted. It is computed as follows:

$$\text{SGD (\%)} = (\text{Annual Groundwater Extraction} / \text{Annual Extractable Groundwater Resource}) \times 100$$

(Equation 1)

This indicator is widely used by the CGWB and state groundwater agencies to assess sustainability and classify assessment units into the following categories:

SGD (%)	Classification Category
< 70%	Safe
70 – 90%	Semi-Critical
90 – 100%	Critical
> 100%	Over-Exploited

Table 1: CGWB Classification of Assessment Units by SGD

3.3 Analytical Approach

SGD values were calculated for each of the 16 talukas using Equation 1. Talukas were then ranked by SGD and classified according to CGWB norms (Table 1). Additionally, aggregate district-level SGD was calculated using total extraction and total extractable resources. The relationship between rainfall and extractable resources was examined to determine the relative influence of precipitation versus hydrogeological factors on groundwater availability.

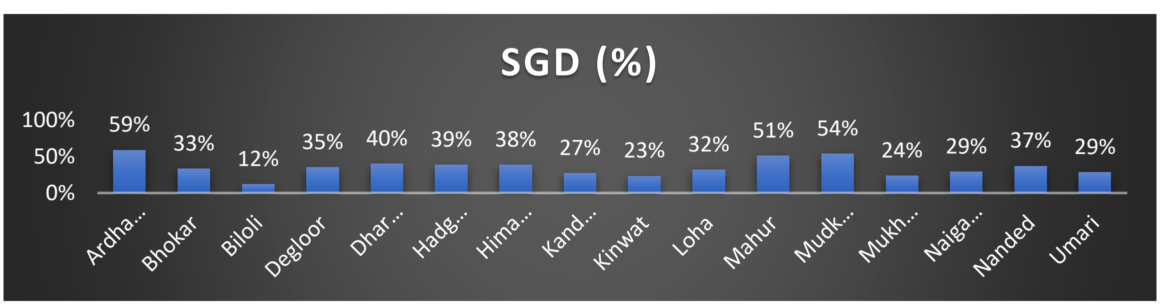
4. Results

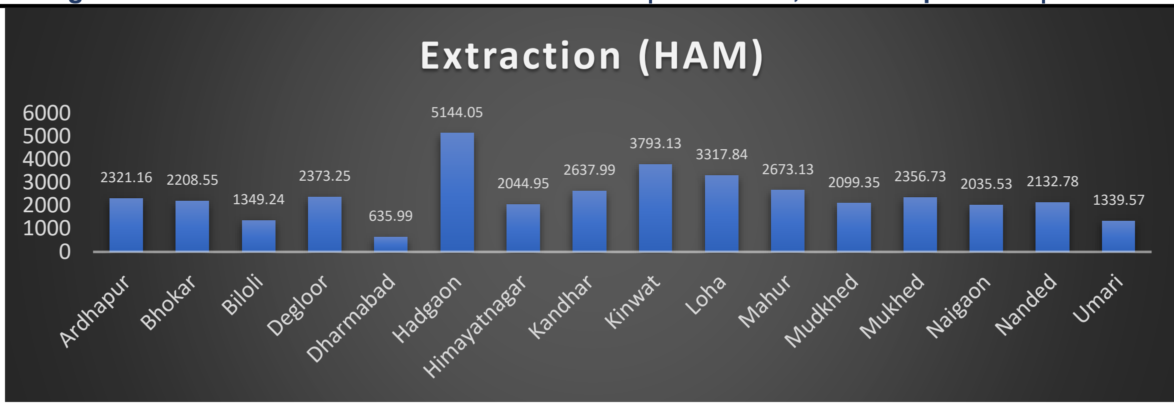
4.1 Taluka-wise Groundwater Data and SGD

Table 2 presents the complete dataset for all 16 talukas, including annual rainfall, annual extractable groundwater resources, current extraction volumes, and calculated SGD values for 2024–2025.

Taluka	Rainfall (mm)	Extractable Resource (HAM)	Extraction (HAM)	SGD (%)	Status
Ardhapur	982.57	3,938.89	2,321.16	58.93%	Safe
Bhokar	1022.20	6,652.49	2,208.55	33.20%	Safe
Biloli	1078.36	11,428.57	1,349.24	11.98%	Safe
Degloor	958.70	6,755.55	2,373.25	35.13%	Safe
Dharmabad	1066.59	4,094.83	635.99	39.95%	Safe
Hadgaon	1022.94	13,348.63	5,144.05	38.54%	Safe
Himayatnagar	1024.61	5,514.03	2,044.95	38.48%	Safe
Kandhar	1042.32	9,903.65	2,637.99	26.64%	Safe
Kinwat	1083.47	16,195.11	3,793.13	23.35%	Safe
Loha	984.72	10,380.77	3,317.84	31.96%	Safe
Mahur	1090.80	5,241.09	2,673.13	51.00%	Safe
Mudkhed	995.45	3,895.31	2,099.35	53.89%	Safe
Mukhed	920.34	9,872.36	2,356.73	23.63%	Safe
Naigaon	1063.04	7,009.17	2,035.53	29.04%	Safe
Nanded	989.98	5,763.55	2,132.78	37.00%	Safe
Umari	1024.76	4,662.90	1,339.57	28.71%	Safe
Total / Average	**1,023.69**	**1,18,652.72**	**38,252.33**	**32.24%**	**Safe**

Table 2: Taluka-wise Groundwater Data and Stage of Groundwater Development (SGD), Nanded District, 2024–2025





4.2 Spatial Variation in SGD

All 16 talukas fall within the 'Safe' category (SGD < 70%), indicating that current extraction levels do not exceed the sustainable yield of local aquifers. However, the data reveal substantial spatial heterogeneity. Ardhapur records the highest SGD at 58.93%, followed closely by Mudkhed (53.89%) and Mahur (51.00%). These talukas are approaching the semi-critical threshold and warrant closer monitoring. In contrast, Biloli (11.98%), Kinwat (23.35%), and Mukhed (23.63%) demonstrate very low development levels, indicating that large portions of their extractable resource remain unutilized.

At the district level, the total annual extractable groundwater resource stands at 1,18,652.72 HAM, against a total annual extraction of 38,252.33 HAM, yielding a district-wide SGD of 32.24%. This aggregate figure places Nanded district firmly within the safe zone; however, this district-level average conceals the localized pressure experienced in talukas such as Ardhapur and Mudkhed.

4.3 Relationship Between Rainfall and Extractable Resources

Average annual rainfall across the 16 talukas ranges from 920.34 mm (Mukhed) to 1,090.80 mm (Mahur), representing a variation of approximately 170 mm. Despite this relatively narrow range, extractable groundwater resources vary dramatically — from 3,895.31 HAM in Mudkhed to 16,195.11 HAM in Kinwat, a difference of more than fourfold. This pattern indicates that inter-taluka differences in groundwater availability are not primarily driven by rainfall but are instead governed by local geology, aquifer depth, thickness, and hydraulic properties. The Deccan Trap basalt formations in the district exhibit significant spatial heterogeneity in weathering and fracture intensity, which likely explains the observed disparities in extractable resources.

5. Discussion

The findings of this study align with the broader literature on groundwater dynamics in Deccan Trap terrain, where geological heterogeneity plays a dominant role in determining aquifer productivity (Kulkarni et al., 2000; CGWB, 2022). The uniformity of rainfall across Nanded district, combined with the wide variation in extractable resources, reinforces the conclusion that recharge processes are strongly mediated by subsurface geological conditions rather than surface hydrology alone.

The comparatively high SGD values in Ardhapur (58.93%) and Mudkhed (53.89%) are a cause for concern. These talukas have limited extractable reserves — 3,938.89 HAM and 3,895.31 HAM respectively — yet sustain extraction volumes exceeding 2,000 HAM per year. If current extraction trends continue without compensatory recharge augmentation, these talukas could transition into the semi-critical category within a few years. This is particularly noteworthy given that climate projections for the Marathwada region indicate potential future reductions in monsoon rainfall reliability (Kulkarni et al., 2020).

On the other end of the spectrum, Biloli and Kinwat exhibit very low SGD values (11.98% and 23.35% respectively) despite possessing the largest extractable reserves in the district. This under-utilization may reflect lower agricultural intensity, land use patterns, or limited irrigation infrastructure in these talukas. Biloli's extractable resource of 11,428.57 HAM, with extraction of only 1,349.24 HAM, suggests considerable scope for regulated expansion of groundwater use, provided such expansion is accompanied by appropriate monitoring and sustainable governance frameworks.

The high extraction volumes in Hadgaon (5,144.05 HAM) — the largest in absolute terms among all talukas — may be attributed to the prevalence of water-intensive cash crops, potentially including sugarcane, in that region. Promoting crop diversification toward less water-intensive alternatives such as pulses and oilseeds, along with the adoption of micro-irrigation technologies (drip and sprinkler systems), could substantially reduce pressure on groundwater in Hadgaon.

6. Conclusion and Recommendations

6.1 Conclusion

This study demonstrates that while Nanded district as a whole maintains a safe groundwater status in 2024–2025, the spatial pattern of groundwater development is highly uneven across its 16 talukas. The uniformly safe district-level aggregate masks localized stress in Ardhapur, Mudkhed, and Mahur, where SGD values are approaching 60%. These findings highlight the inadequacy of aggregate, district-level groundwater management and make a strong case for taluka-specific policies.

6.2 Recommendations

Based on the analysis, the following recommendations are proposed:

- Priority monitoring for Ardhapur and Mudkhed: These talukas, with SGD values exceeding 50%, should be designated 'Priority 1' zones. Regulatory restrictions on new deep-bore well approvals and mandatory water audits should be introduced.
- Artificial recharge augmentation: Investment in check dams, percolation tanks, and nala bunding in low-extractable-resource talukas (Mudkhed, Dharmabad, Ardhapur) would enhance monsoon recharge and improve the long-term groundwater budget.

- Demand-side management in Hadgaon: Given its highest absolute extraction volume (5,144 HAM), promoting micro-irrigation and crop diversification in Hadgaon is essential to reduce unsustainable demand growth.
- Regulated development in Biloli and Kinwat: These talukas have significant untapped potential. Planned, scientifically managed agricultural groundwater use in these areas could be permitted, subject to continuous monitoring to prevent future over-exploitation.
- Community-led water budgeting: Village-level water security plans that track local extraction and recharge can build grassroots accountability and complement top-down regulatory frameworks.
- Long-term hydrogeological mapping: Investment in detailed aquifer mapping across the district is recommended to better understand the spatial distribution of recharge zones and inform future groundwater governance.

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