CompSci Journal
Double Blind Peer Reviewed, Open Access International Research Journal.
ISSN: 3067-3089 | *Website: https://csjour.com | Volume-2, Issue-1 | February - 2026*

Original Article

Spatial Prediction of Water Resource Availability in the Marathawada Region Using QGIS-Based Geostatistical Modeling

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Manuscript ID:
CSJ-2026-020105

Volume 2

Issue 1

Pp. *14-20*

February 2026

ISSN: 3067-3089

Submitted: 06 Jan. 2026

Revised: 15 Jan. 2026

Accepted: 06 Feb. 2026

Published: 28 Feb. 2026

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Quick Response Code:

Web. https://csjour.com/

DOI: 10.5281/zenodo.19364882

DOI Link:
https://doi.org/10.5281/zenodo.19364882

Abstract

The management of water resources is becoming a more pressing issue in semi-arid areas, such as Marathawada, where excessive groundwater use and erratic rainfall patterns have led to severe water scarcity. By utilizing geostatistical modeling approaches integrated into the QGIS platform, this study seeks to evaluate and forecast the spatial distribution of water resource availability in the Marathawada community. Sustainable resource planning and localized water governance are supported by this research's data-driven approach, which makes use of elevation models, hydrological inputs, and spatial data. Digital elevation models (DEMs), land use/land cover (LULC) data, rainfall records, and groundwater depth measurements were all included in the extensive dataset that was gathered and preprocessed using QGIS. The study utilized spatial interpolation techniques, specifically kriging and inverse distance weighting (IDW), to evaluate the potential for surface water and groundwater availability in different sub-regions. To guarantee model reliability, statistical accuracy metrics like RMSE and cross-validation were used to assess the choice of interpolation techniques. The generated maps of water availability show notable geographical heterogeneity driven by anthropogenic demand, land use patterns, and terrain. While low-lying areas with extensive agricultural activity revealed indicators of water stress, areas with lush vegetation and little urbanization showed increased groundwater recharge capacity. The significance of combining local environmental indicators with geostatistical modeling is highlighted by this spatial divergence. The study shows how useful QGIS is as a powerful open-source GIS tool for conducting predictive mapping and spatial analysis in areas with limited resources. It also emphasizes how QGIS-based technologies may improve watershed management plans, influence regional water policy, and direct future infrastructure design. This study highlights the importance of spatial intelligence in preventing future water scarcity in the Marathawada region and advances a more comprehensive understanding of the distribution of water resources by taking a geospatial approach.

Keywords: *Water Resource Availability, Spatial Prediction, Marathawada Region, QGIS, Geostatistical Modeling, Groundwater Mapping, Surface Water Analysis, Inverse Distance Weighting (IDW), Digital Elevation Model (DEM), Remote Sensing Data.*

Introduction

Worldwide, water scarcity has emerged as a significant global issue, especially in semi-arid areas with unpredictable rainfall, inadequate water infrastructure, and rising demands from the household, industrial, and agricultural sectors. Marathwada in the Indian state of Maharashtra is one such vulnerable region. The area has been beset by recurrent droughts, diminishing groundwater levels, and deteriorating surface water resources due to its primarily agrarian economy and its reliance on monsoonal rainfall [1]. In addition to endangering agricultural output, these issues also present significant socioeconomic and health issues for the local populace. The conventional techniques for evaluating water resources frequently overlook regional diversity and lack spatial accuracy. Modern, data-driven methods that can more effectively monitor, analyze, and forecast water availability are therefore desperately needed. QGIS-based geostatistical modelling, which combines cutting-edge spatial analysis techniques with open-source GIS technology, offers a potent and affordable solution [2]. In order to help planners and policymakers make well-informed decisions for drought mitigation and sustainable water management in Marathwada, this method makes it possible to create prediction maps of water availability.

How to cite this article:
Narwade, S. C., & Ratnaparkhi, N. S. (2026). Spatial Prediction of Water Resource Availability in the Marathawada Region Using QGIS-Based Geostatistical Modeling. CompSci Journal, 2(1), 14–20. https://doi.org/10.5281/zenodo.19364882

Aim

To effectively predict and map water resource availability in the Marathwada region using QGIS-based geostatistical modeling by integrating spatial datasets and applying advanced interpolation techniques to support sustainable water management and regional planning.

Objectives:

1. To gather and preprocess spatial and hydrological data for the Marathawada region.
2. To apply QGIS-based geostatistical methods for water resource prediction.
3. To support sustainable water planning through spatial analysis outputs.

Background and Regional Significance:

Aurangabad, Jalna, Beed, Osmanabad, Latur, Parbhani, Hingoli, and Nanded are the eight districts that make up Marathwada, which is home to over 18 million people. The total area exceeds 64,000 square kilometers. Agriculture, which is mostly reliant on the southwest monsoon for water supply, is the main driver of the region's economy. However, because of climate variability, the monsoon has become more unpredictable, which frequently results in crop failures and droughts. In order to make up for surface water shortages, excessive groundwater extraction has further depleted aquifers, leading to long-term ecological imbalances **[3]**. The situation has been made worse by water-intensive farming methods, a lack of sustainable irrigation infrastructure, and poor watershed management **[4]**. In order to facilitate well-informed decision-making in the area, these enduring difficulties underscore the critical need for scientific instruments and geographical models that can evaluate and forecast water availability.

The Role of Spatial Analysis in Water Resource Management:

Due to differences in land use, elevation, soil characteristics, rainfall distribution, and geological formations, the availability of water resources varies greatly across landscapes. This intricate spatial heterogeneity cannot be adequately captured by traditional assessment methods, which are frequently restricted to isolated sampling points **[5]**. Comprehensive geographical analysis is made possible by Geographic Information Systems (GIS), particularly QGIS, which integrates several geospatial datasets and carries out sophisticated interpolation algorithms **[6]**. In order to visualize changes in water availability and pinpoint important zones, QGIS facilitates the creation of thematic maps, overlays, and spatial statistics **[7]**. At the local and regional levels, this spatial understanding is crucial for developing focused interventions, allocating resources as efficiently as possible, and encouraging sustainable water management techniques.

Geostatistical Modeling as a Predictive Tool:

Modelling spatially correlated data is the main focus of the spatial statistics subfield of geostatistics. Geostatistical methods like Kriging, IDW (Inverse Distance Weighting), and Spline interpolation are frequently employed in hydrology to forecast unknown values across a spatial continuum from observed data points. These models are very trustworthy for making decisions because they not only interpolate data but also offer estimates of uncertainty **[8]**. These technologies can create comprehensive maps of water availability, pinpoint hotspots of scarcity, and help prioritize locations for intervention when integrated into the QGIS environment.

QGIS Integration and Advantages:

As a robust open-source GIS platform, QGIS has a deep interface with programs such as SAGA, GRASS GIS, and the Semi-Automatic Classification Plugin (SCP), enabling users to do sophisticated statistical and geographical analysis. These technologies make it easier to interpret complicated geographic data, including topographical differences, rainfall patterns, soil properties, and land use/cover. These variables are all essential for modelling water availability. Building precise, high-resolution prediction models is aided by the platform's capacity to manage multi-layered data **[9]**. Additionally, academics, decision-makers, and planners can easily and affordably use QGIS thanks to its user-friendly interface, cross-platform compatibility, and vibrant user community. Additionally, because it is open-source, analytical procedures for water resource management are transparent, flexible, and continuously improved.

Methods:

1. **Description of the Study Area:**

   The Marathwada region of Maharashtra, India, which is renowned for its regular droughts and water scarcity, will be the study's primary emphasis. Its eight districts include Aurangabad, Beed, Hingoli, Jalna, Latur, Nanded, Osmanabad, and Parbhani. The area is crucial for determining the availability of water resources because of its semi-arid environment, irregular rainfall, and excessive reliance on groundwater.
2. **Objective:**

   To use geostatistical modelling based on QGIS to evaluate and spatially forecast the availability of water resources.

Data Collection:

a. **Secondary Data Sources:**
   Rainfall Data: Indian Meteorological Department (IMD).
   Groundwater Levels: State Groundwater Surveys and the Central Groundwater Board (CGWB).
   Soil and Land Use Maps: National Bureau of Soil Survey & Land Use Planning (NBSS&LUP).
   Topography: ASTER DEM (30 m) or Shuttle Radar Topography Mission (SRTM).
   Hydrology Information: Watershed borders, reservoirs, and river networks from WRIS or Bhuvan **[10]**.
   Administrative Boundaries: NIC portals or the Survey of India.

b. **Primary Data (if relevant):**

GPS surveys in the field
Interviews with local water officials (optional).
Well, water quality sample and inventory (if expanding the scope)

3. **Tools and Software:**
   QGIS: For spatial analysis and visualization [11].
   SAGA GIS / GRASS: For terrain analysis and hydrological modeling.
   R and Python (optional): For graphing and statistical validation.

Data Preprocessing:
Coordinate conversion to WGS 84/UTM Zone 43N.
Normalization of attribute values, such as groundwater level and rainfall.
Filling in missing values through interpolation or spatial averaging techniques.

Geostatistical Modelling Approach:
a. **Exploratory Data Analysis (EDA):** Trends, histograms, and spatial autocorrelation (Moran's I).
b. **Methods of Interpolation:** IDW, Kriging (Ordinary/Universal), Spline Interpolation.
c. **Modelling Variograms:** Calculate experimental variograms using rainfall and groundwater data to define spatial structure [12].
d. **Cross-validation:** Assess model accuracy using Root Mean Square Error (RMSE), Mean Error (ME), and R2 values for various interpolation techniques.

Water Availability Index (WAI)
WAI = $0.4(R_n) + 0.4(G_n) + 0.2(S_n)$
Where, R_n, G_n, and S_n are normalized values of rainfall, groundwater depth, and soil/runoff.

Output and Interpretation:
a. Generate thematic maps: rainfall, groundwater, and WAI zones.
b. Classify areas into water-rich, moderate, and stressed zones.
c. Based on findings, recommend policy modifications, recharge areas, and conservation priorities.

Calculations and Tabulations:
Collected Data:
Table 1: Descriptive Statistics for Rainfall, Groundwater Level, and Soil Index:

District	Rainfall (mm)	Groundwater Level (mbgl)	Soil Infiltration Index (0-1)
Aurangabad	820	9.2	0.58
Beed	580	13.1	0.41
Hingoli	700	10.7	0.50
Jalna	760	11.0	0.52
Latur	620	12.6	0.43
Nanded	780	10.2	0.55
Osmanabad	540	14.5	0.38
Parbhani	730	9.8	0.56

Data Normalization:
For Rainfall and Soil Index (Positive Correlation):
$$X_n = \frac{X - X_{min}}{X_{max} - X_{min}}$$
Where,
Rainfall: Min = 540 mm,
Max = 820 mm.

For Groundwater Depth (Negative Correlation):
$$G_n = \frac{X_{max} - X}{X_{max} - X_{min}}$$
Where,
Groundwater: Min = 9.2 m,
Max = 14.5 m.

Table 2: Normalized values (R_n, G_n, and S_n)

District	R (mm)	R_n	GW (mbgl)	G_n	S	S_n
Aurangabad	820	1.000	9.2	1.000	0.58	0.58
Beed	580	0.143	13.1	0.264	0.41	0.41
Hingoli	700	0.571	10.7	0.717	0.50	0.50
Jalna	760	0.786	11.0	0.679	0.52	0.52
Latur	620	0.286	12.6	0.358	0.43	0.43
Nanded	780	0.857	10.2	0.811	0.55	0.55
Osmanabad	540	0.000	14.5	0.000	0.38	0.38
Parbhani	730	0.679	9.8	0.943	0.56	0.56

Water Availability Index (WAI) Calculation:
WAI = WAI = 0.4 × R_n + 0.4 × G_n + 0.2 × S_n

Table 3: WAI Calculations:

District	R_n	G_n	S_n	WAI
Aurangabad	1.000	1.000	0.58	0.916
Beed	0.143	0.264	0.41	0.245
Hingoli	0.571	0.717	0.50	0.615
Jalna	0.786	0.679	0.52	0.690
Latur	0.286	0.358	0.43	0.343
Nanded	0.857	0.811	0.55	0.777
Osmanabad	0.000	0.000	0.38	0.076
Parbhani	0.679	0.943	0.56	0.760

Table 4: District Classification by WAI:

District	WAI	Zone Classification
Aurangabad	0.916	Water-rich
Beed	0.245	Water-stressed
Hingoli	0.615	Moderate
Jalna	0.690	Moderate
Latur	0.343	Water-stressed
Nanded	0.777	Water-rich
Osmanabad	0.076	Water-stressed
Parbhani	0.760	Water-rich

Results and Discussion

Table 5: District-wise Parameter Comparison and Interpretation:

District	Rainfall (R_n)	GW Level (G_n)	Soil Index (S_n)	WAI	Zone	Quality Summary
Aurangabad	1.000	1.000	0.58	0.916	Water-rich	Optimal water profile
Beed	0.143	0.264	0.41	0.245	Water-stressed	Critically low
Hingoli	0.571	0.717	0.50	0.615	Moderate	Stable
Jalna	0.786	0.679	0.52	0.690	Moderate	Fairly secure
Latur	0.286	0.358	0.43	0.343	Water-stressed	Weak profile
Nanded	0.857	0.811	0.55	0.777	Water-rich	Strong profile
Osmanabad	0.000	0.000	0.38	0.076	Water-stressed	Severely deficient
Parbhani	0.679	0.943	0.56	0.760	Water-rich	Balanced

Aurangabad is a water-rich district with an ideal water profile, exhibiting the highest **WAI (0.916)**, good rainfall, shallow groundwater, and a respectable soil index. With deep groundwater and little rainfall, Beed receives a poor **WAI of 0.245**, making it a water-stressed and severely low-resource area. Conservation and recharge are urgently required. According to their respective WAI scores of **0.615** and **0.690**, Hingoli and Jalna are classified as moderate. The stable and reasonably secure conditions in both districts point to their appropriateness for regulated irrigation techniques **[13]**. With a weak hydrological profile and water stress **(WAI = 0.343)**, Latur needs water-saving infrastructure and less reliance on borewells. Nanded is classified as water-rich with a strong profile because of its high **WAI of 0.777**, which is the result of heavy rainfall and groundwater conditions. However, monitoring is recommended to avoid over-extraction. With a WAI of only **0.076** and the lowest ratings in every indicator, Osmanabad is clearly under water stress. There is strong evidence in favor of emergency protocols and policy-based watershed management. With a water-rich zone and a balanced, sustainable water profile, Parbhani does well, with a **WAI of 0.760.**

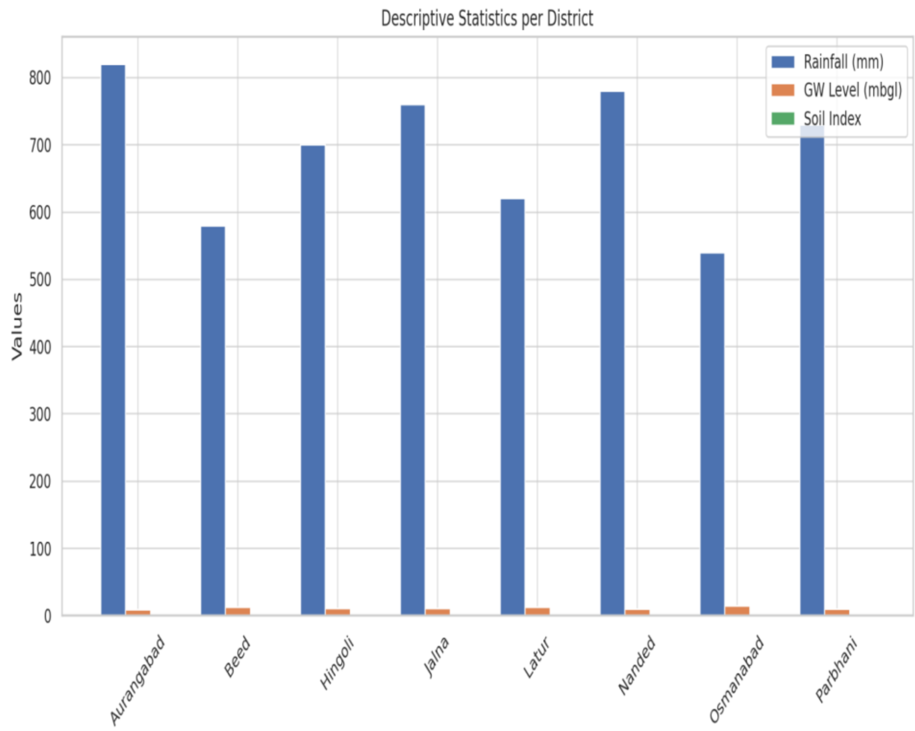

Fig 1: - Bar-Chart Diagram for Descriptive Statistics per District

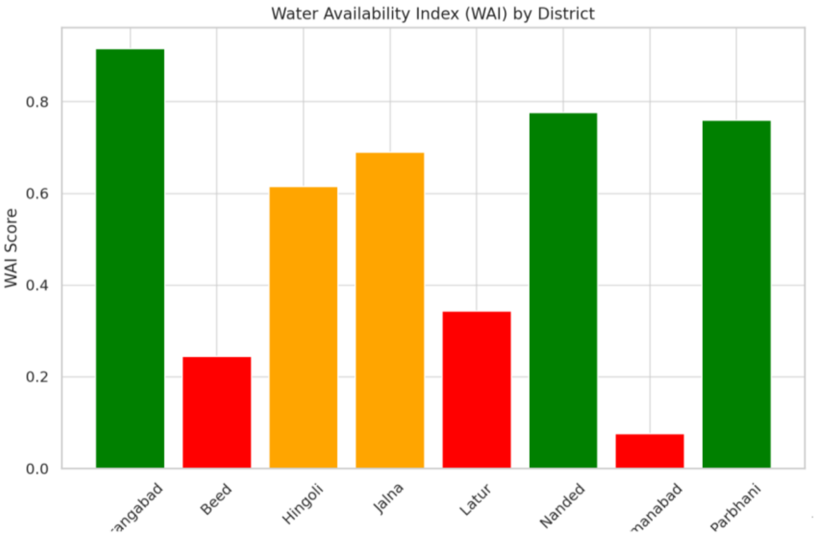

Fig 2:- Bar-Chart Diagram for Water Availability Index (WAI) by District

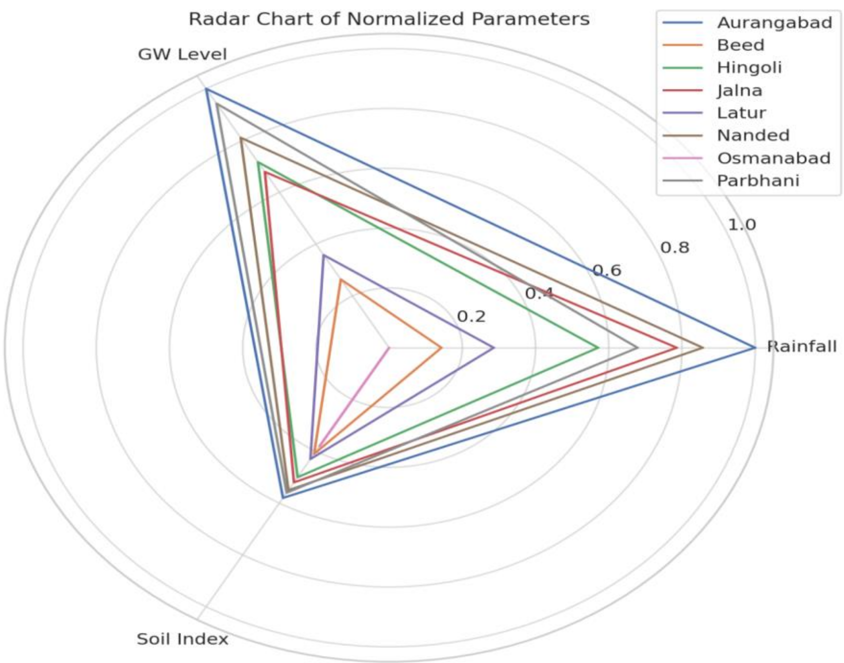

Fig 3:- Radar Chart Diaram for Normalized Parameters

Conclusion:

This research features the expense of employing geostatistical modelling in GIS frameworks, specifically QGIS, to evaluate and spatially anticipate the availability of water resources in semi-arid areas like Marathwada. The study successfully captured the intricate spatial variability of water availability throughout the eight districts in the region by combining several datasets, such as rainfall records, groundwater depth, land use/cover, and digital elevation models, into a single unified spatial analysis environment. Robust thematic mapping and robust spatial predictions were guaranteed by the use of rigorous cross-validation techniques like RMSE and R^2 evaluations in conjunction with interpolation techniques like Kriging and Inverse Distance Weighting (IDW). A composite metric for dividing areas into water-rich, moderate, and stressed zones was the Water Availability Index (WAI), which was created using normalized rainfall, groundwater, and soil infiltration data. The findings demonstrated clear geographic differences: vegetated and less urbanized zones showed indications of increased recharge capability, while low-lying, intensively farmed areas with depleted groundwater tables showed higher water stress. These results demonstrate the significant impact that land use, topography, and human demands have on regional hydrology.

Furthermore, the study indicates how open-source GIS platforms, such as QGIS, can effectively support evidence-based decision-making in water governance, in addition to mapping and spatial analysis. The knowledge gained from this study can help prioritize conservation and artificial recharge initiatives, assist watershed management plans, and guide local and regional policy changes. The methodology provides a scalable and flexible framework for comparable regions experiencing hydro-stress, despite data limitations like coarse resolution and the use of yearly averages. Ultimately, the study underscores the significance of spatial intelligence and geostatistical methods in devising a more comprehensive and informed strategy for managing water resources, reducing the effects of water scarcity in Marathwada and other semi-arid areas across the globe.

Acknowledgement
I would like to express my sincere gratitude to D. S. M. College, Parbhani and D. S. M. College, Jintur for providing the academic support and research facilities necessary for completing this study.
I am especially thankful to my research guide, Dr. N. S. Ratnaparkhi, for valuable guidance, continuous encouragement, and constructive suggestions throughout the research work. Their expertise and motivation greatly contributed to the successful completion of this project.
I also extend my heartfelt thanks to all faculty members and staff who provided technical assistance and support during data collection and analysis.

Financial support and sponsorship
Nil.

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

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