

Mapping And Assessing Groundwater Resources Of Vasai In Maharashtra, India, Using GIS

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Abstract

Groundwater is a vital component for sustainable development, particularly in rapidly urbanizing regions where demand often exceeds supply. This study evaluates and maps the groundwater potential zones of Vasai Taluka, Maharashtra (India), employing a Geographic Information System (GIS)-based weighted overlay analysis. The assessment incorporated multiple thematic layers, including slope, soil type, geology, geomorphology, lineament density, drainage density, land use/land cover, and rainfall, each weighted and ranked according to their relative influence on groundwater recharge, determined through expert judgment and literature review. Spatial integration and analysis were performed using ArcGIS 10.5, classifying the study area into high, moderate, and low groundwater potential zones. Results indicated that regions with gentle slopes, permeable soil (Fluvisols), low drainage density (0-57.16 m/km²), and high lineament density (188.02-235.03 m/km²) exhibit higher recharge potential, whereas steep slopes, high drainage density (230.72-428.70 m/km²), and less permeable soils (Cambisols and Nitisols) correspond to lower potential. The GIS-WOA analysis revealed that a significant part of Vasai Taluka falls under moderate groundwater potential, with smaller areas of high- and low-potential zones. The analysis further highlighted the importance of integrated thematic factors, recommending that zones with gentle slopes, high lineament density, and favorable soils be prioritized for conservation, while low-potential areas require targeted artificial recharge interventions.

Keywords: Groundwater potential zones, GIS, Weighted overlay analysis, Spatial analysis, Groundwater recharge, Thematic layers.

1. INTRODUCTION

Groundwater constitutes a critical component of the hydrological cycle and serves as an indispensable source of freshwater for domestic, agricultural, and industrial activities, particularly in regions undergoing rapid population growth and urban expansion. In India, the escalating demand for groundwater, driven by uneven rainfall distribution, overextraction, and increased water consumption, has resulted in the depletion and degradation of groundwater quality in many areas [1]. Consequently, the accurate mapping and assessment of groundwater potential zones are essential for sustainable water resource management. Recent technological advances in Geographic Information Systems (GIS) and remote sensing (RS) have significantly enhanced the capability to delineate groundwater potential zones by integrating multiple thematic parameters, including geology, geomorphology, slope, soil type, lineament density, drainage density, rainfall, and land use/land cover (LULC) [2-5]. Among the various methodologies, the weighted overlay analysis (WOA) technique implemented in GIS provides a systematic framework to combine these diverse layers by assigning weights and ranks based on their relative influence on groundwater occurrence. This approach has been widely validated in numerous regional groundwater studies [6-8]. Chronologically, foundational contributions such as Reddy's comprehensive treatment of geospatial techniques [16] laid the groundwork for modern groundwater management applications using GIS and RS. Early studies like Gupta and Srivastava [7] demonstrated the integration of geological and geomorphological data for groundwater mapping in Pavagarh, Gujarat, while Oh et al. [14] applied frequency-ratio models in Korea to predict groundwater potential using probabilistic approaches.

In Egypt's Central Eastern Desert, Abdalla [1] successfully mapped groundwater zones using hydrological and GIS data; similarly, in India, Sharma et al. [20] and Giri and Bharadwaj [5] enhanced groundwater mapping accuracy through the incorporation of soil, land use, and geoelectrical resistivity data. Multi-criteria decision analysis was effectively utilized by Jose et al. [8] in Kerala, and knowledge-driven GIS models were advanced by

Manap et al. [12] for Malaysia. Furthermore, Jaiswal et al. [21] emphasised the role of RS and GIS in rural water management, while Waikar and Nilawar [24] and Kaliraj et al. [8] showcased weighted overlay and Analytical Hierarchy Process techniques in Indian contexts. Recent studies such as Selvam et al. [17] and Shakak [19] validated these approaches with field investigations and groundwater quality assessments, respectively. The evolution of groundwater potential mapping (GPM) has also embraced machine learning, with ensemble-based predictive models introduced by Mosavi et al. [14], marking a shift toward more sophisticated, data-driven methods. Senanayake et al. [18] applied GIS for recharge site delineation in Sri Lanka, and recent studies [15-17] further refined these techniques in Maharashtra and Pune regions. Despite this extensive work, GPM specific to Mumbai (Vasai Taluka), Maharashtra, is limited. The complex geology, rapid urbanization, and rainfall variability of this region underscore the need for an integrated GIS-based weighted overlay approach. This study aims to develop multiple thematic layers, including slope, soil, geology, geomorphology, lineament density, drainage density, LULC, and rainfall, within a weighted GIS framework to classify groundwater potential into high, moderate, and low zones. The outcomes are expected to provide critical insights for sustainable groundwater management, agricultural planning, and urban water supply strategies while supporting the achievement of Sustainable Development Goals 6 (clean water and sanitation) and 11 (sustainable cities and communities). Building established methodologies and incorporating advanced geospatial techniques, this study assists in improving the precision and reliability of groundwater potential assessments in Vasai Taluka, contributing to regional water security and resource sustainability.

Although groundwater potential mapping using GIS and remote sensing has been widely applied across different parts of India and other regions of the world, there is a lack of comprehensive studies focusing on the **Vasai Taluka region**. This area is unique due to its rapid urban expansion, diverse lithology, and coastal geomorphology, which present distinct challenges for sustainable water resource management compared to inland districts. Previous works (e.g., Abdalla, 2012; Ahmed, 2016; Kaliraj et al., 2014) have successfully applied weighted overlay and AHP techniques in semi-arid and hilly terrains, but their direct transferability to the geomorphologically complex Vasai region has not been adequately tested. Therefore, this study not only fills a regional research gap but also demonstrates how **multi-criteria GIS-based models can be adapted to coastal-urban environments**, where groundwater is under increasing stress. The outcomes provide a replicable framework for similar coastal regions in South Asia, thereby adding value beyond the immediate case study.

2. Area of study

Vasai Taluka, located in Palghar District, Maharashtra, India, lies between 19.47° N latitude and 72.8° E longitude, about 50 km north of Mumbai. It is bounded by the Vaitarna River to the north and Vasai Creek to the south, covering an area of about 544 km². According to the 2024 Census, the taluka supports a population of approximately 1.34 million. The terrain is characterized by a mix of low-lying coastal plains and elevated inland areas, with the highest point at Chinchoti mountain rising above 620 m. The region receives significant monsoonal rainfall, averaging between 2000 mm and 2500 mm annually.

Geomorphologically, Vasai Taluka encompasses coastal alluvial plains, lateritic uplands, and dissected hill ranges. The western part consists largely of alluvial deposits from riverine and marine influences, favouring higher infiltration rates, whereas the eastern highlands are dominated by weathered basalt and laterite. Geologically, the area lies within the Deccan Trap formation, with underlying basaltic flows interspersed with lateritic caps in upland zones. The alluvial tracts along the Vaitarna River and Vasai Creek form shallow unconfined aquifers, while deeper basaltic fractures act as confined to semi-confined aquifer systems in upland regions. Soils range from sandy loams and coastal alluvium in the west to clayey loams and lateritic soils in the elevated east. Drainage is dendritic to sub-dendritic, with low drainage density in the alluvial plains and higher density in the basaltic uplands. This variation in lithology, slope, and drainage strongly influences groundwater recharge and storage potential. Fig. 1 presents the location map of Vasai Taluka, while Fig. 2 depicts the study area map, offering an essential spatial reference for understanding the topography, geomorphology, and hydrogeological framework that underpin groundwater potential assessment in the region.



Fig. 1. Map showing the area of study.

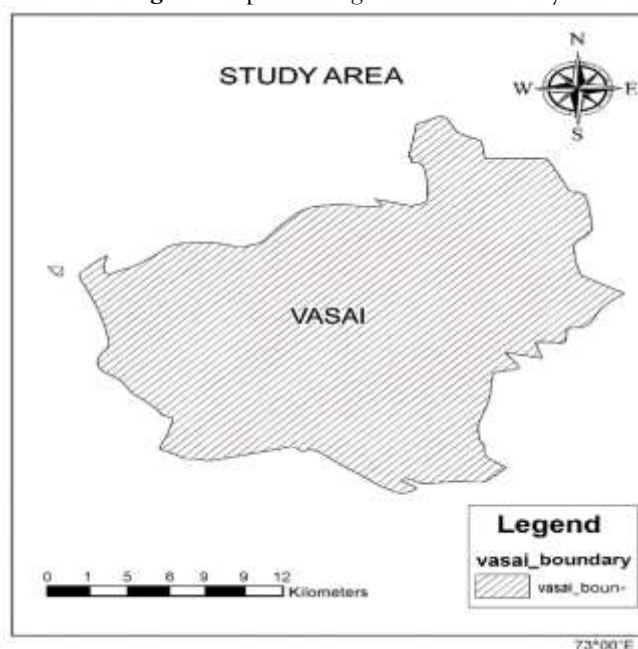


Fig. 2. Map showing the boundaries of the study area in the Vasai region.

3. METHODOLOGY

Due to the demonstrated effectiveness and reliability in GPM, the WOA technique [3, 4, 8, 10, 13, 16] is currently used in this study. The approach involved identifying and evaluating eight key parameters influencing groundwater occurrence, along with environmental factors and associated geospatial analysis tools, such as the Digital Elevation Model (DEM), as shown in Fig. 3. Spatial datasets were obtained from multiple authoritative sources. The DEM from BHUVAN (ISRO's Geoportal) was used to delineate the study area in ArcGIS 10.5 and derive the slope, drainage density, and lineament density layers. The slope was generated using the Surface tool within the Spatial Analyst toolbox. Drainage density was calculated using hydrology tools, while lineament density was derived from hill-shaded DEM imagery. Moreover, line density data were extracted using the ArcToolbox Line Density function.

Geological and geomorphological layers were obtained from BHUKOSH (Geological Survey of India). LULC information was sourced from the USGS Earth Explorer and classified using supervised image classification techniques. Soil data were collected from the FAO (United Nations), while rainfall data for the past decade were acquired from the CHRS Data Portal. Each thematic layer was reclassified based on its influence on groundwater recharge. Weights and ranks were assigned to parameters using expert judgment and literature-based precedence.

The thematic maps were then integrated through the WOA tool in ArcGIS 10.5. Table 1 summarizes the groundwater potential zones and their descriptions. Fig. 4 illustrates the schematic representation of the complete methodological workflow.

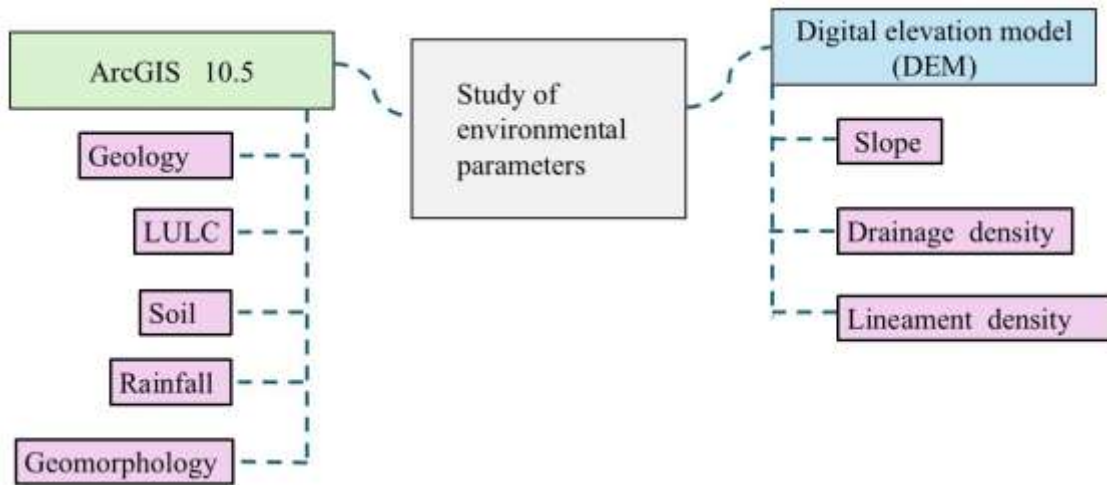


Fig. 3. Environmental parameters and geospatial tools for GPM.

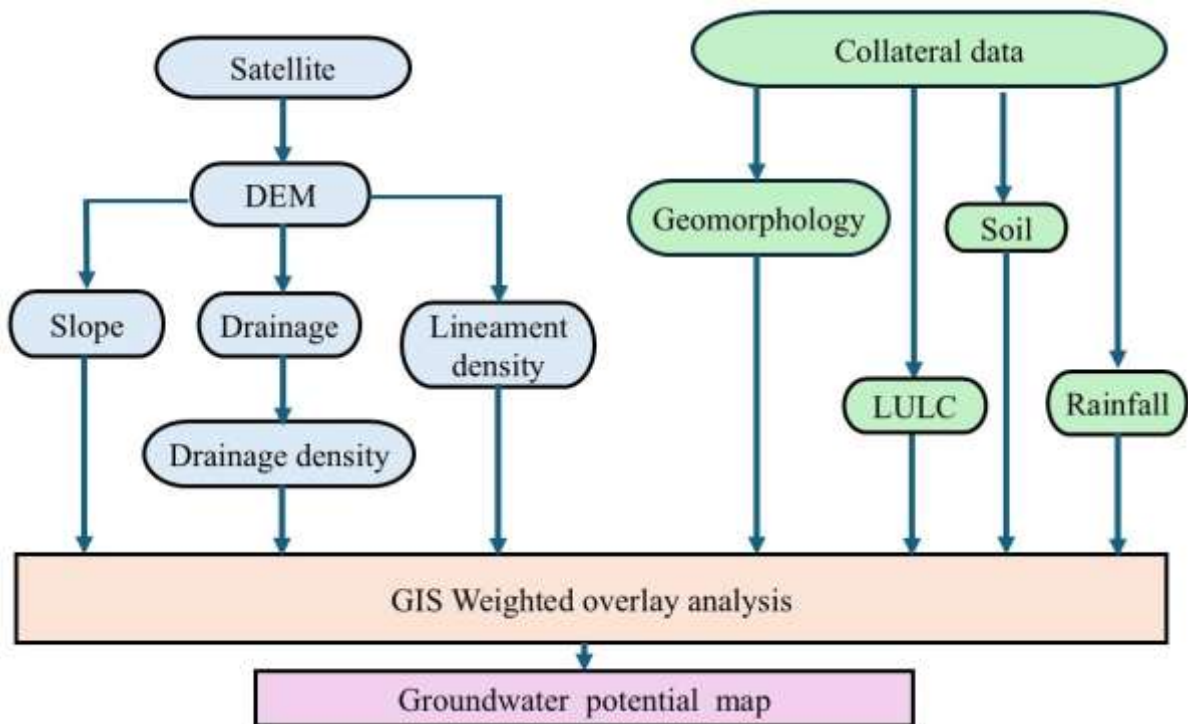


Fig. 4. Schematic representation of the methodological workflow.

Table 1: Classification of groundwater potential zones based on infiltration capacity and recharge potential.

Groundwater potential zone	Description
Excellent	High infiltration capacity and recharge potential
Moderate	Intermediate recharge potential
Poor	Low recharge capacity

4. RESULTS AND DISCUSSIONS

As discussed in the methodology section, ArcGIS 10.5 has been employed to generate eight thematic layers representing the selected parameters. These parameters are vital in determining groundwater potential zones since they include both hydrogeological and environmental factors. The following sections provide a detailed discussion of each parameter related to groundwater occurrence.

4.1 DEM analysis

The DEM provides a three-dimensional representation of terrain elevation, which is a critical factor influencing groundwater recharge. Areas with lower elevation typically exhibit greater water retention capacity due to reduced surface runoff, whereas higher elevations tend to facilitate rapid drainage, limiting infiltration. In the context of Vasai Taluka, located in the Palghar District of Maharashtra, the average elevation is approximately 11 m above sea level. The region lies to the north of Mumbai and is bordered by the Ulhas River estuary and Vasai Creek. The DEM analysis of Vasai Taluka, illustrated in Fig. 4(a), reveals a varied topographic profile with elevations ranging from about 255 m to 603 m. Rugged, mountainous terrain dominates the eastern and northern sectors of Vasai, as evidenced by densely spaced contour lines. These steep slopes are generally unfavorable for groundwater recharge due to rapid surface runoff. Conversely, the southern and western regions, particularly the coastal margins, exhibit gently sloping to flat terrain, which favors infiltration and groundwater storage. The southwestern part of the taluka also contains prominent water bodies and coastal landforms, further enhancing local recharge potential. The maps include a directional compass and scale bar for spatial reference.

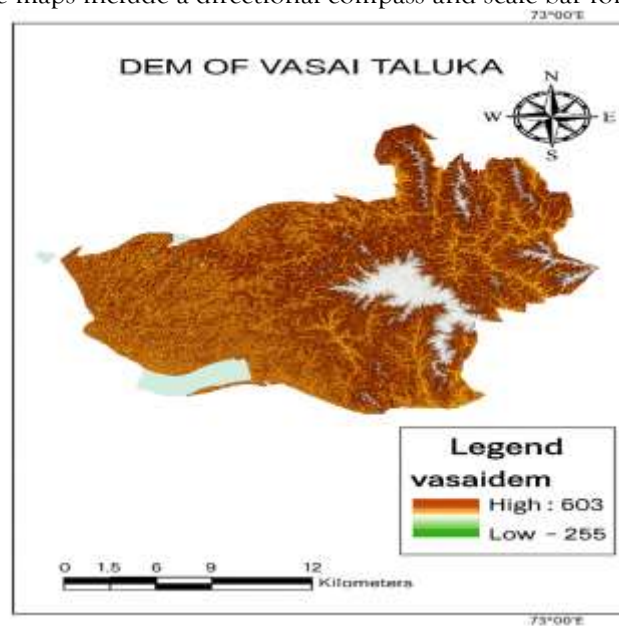


Fig. 4. DEM of Vasai Taluka.

4.2 Factors influencing groundwater potential zones

4.2.1 Drainage density

Fig. 5 illustrates the drainage density map of Vasai Taluka. Drainage density, defined as the total length of stream channels per unit area, shows an inverse relationship with surface permeability. This parameter plays a significant role in influencing both surface and subsurface hydrological characteristics. High drainage density values ($230.72 - 428.70 \text{ m/km}^2$) indicate closely spaced channels, which promote rapid surface runoff and limit infiltration, thereby reducing groundwater recharge potential. In contrast, low drainage density areas ($0 - 57.16 \text{ m/km}^2$) exhibit slower runoff and greater permeability, making them more favorable for infiltration and recharge. The drainage density map generated in ArcGIS (Fig. 5) categorizes values into five classes, highlighting the spatial variation of surface drainage patterns and their influence on groundwater replenishment. Regions exceeding 230.72 m/km^2 are identified as high runoff zones, while those below 57.16 m/km^2 are considered optimal for groundwater recharge.

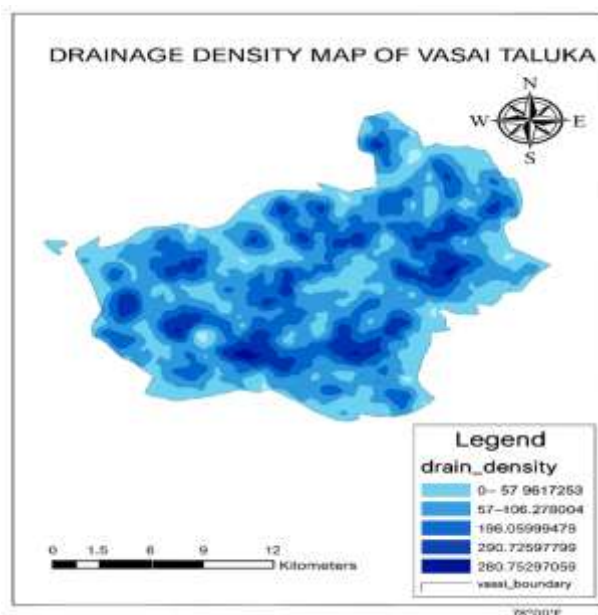


Fig. 5. Drainage density map of Vasai Taluka.

4.2.2 Density of lineaments

Lineaments are linear or curvilinear surface features, commonly associated with tectonic activity, and can be identified in satellite imagery through patterns such as aligned vegetation, straight river courses, or systematically distributed ponds and tanks. These features serve as important indicators of subsurface permeability and are therefore critical in the groundwater potential study. Fig. 6(a) presents the lineament density map of Vasai Taluka. The density of lineaments in a region is positively correlated with groundwater potential, as higher lineament density generally reflects enhanced permeability and greater opportunities for recharge.

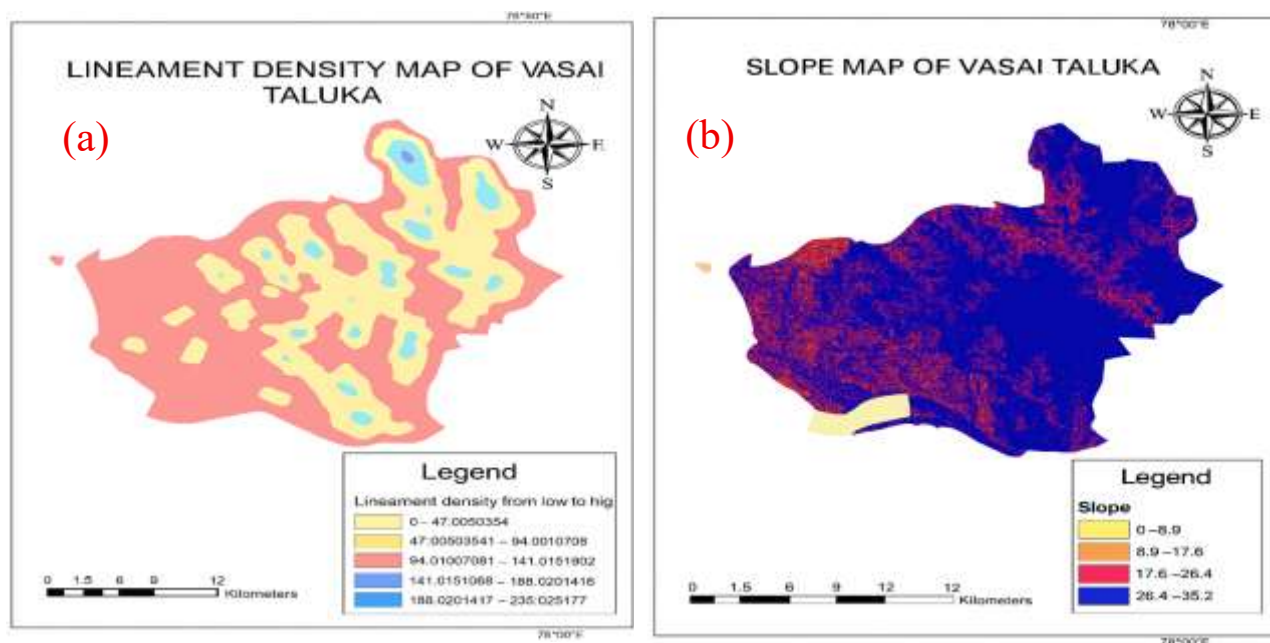


Fig. 6. (a) Lineament density map of Vasai Taluka (b) Slope map of Vasai Taluka.

Slope, an important terrain parameter, is calculated from raster elevation data and represents the rate of elevation change between adjacent cells. It is measured in degrees or percentages, with lower values indicating gentler terrain and higher values indicating steeper gradients. Fig. 6(b) illustrates the spatial variation in slope across Vasai Taluka, categorized into four classes ranging from gentle to steep terrain. Gentle slopes, represented in

yellow and orange, favor groundwater recharge due to slower runoff and higher infiltration capacity, whereas steep slopes, shown in red, purple, and blue, are associated with rapid runoff and reduced recharge potential. Slope thus exhibits an inverse relationship with groundwater recharge: increasing slope reduces infiltration, while flatter terrain promotes recharge. High lineament density zones (188.02–235.03, dark blue in Fig. 6a) occur predominantly in structurally controlled, steeper terrains where the potential for recharge is limited despite fracturing. In contrast, gentle slopes (light yellow to green) provide favorable conditions for infiltration and groundwater recharge.

The lineament density map (Fig. 6(a)) was categorized into five classes, as summarized in Table 2. The analysis indicates that in Vasai Taluka, zones with low lineament density (0–94.01 m/km²) correspond to gentle slopes and flat terrain, making them highly favorable for groundwater recharge. In contrast, areas with very high lineament density (>188.02 m/km²) are typically associated with structurally controlled, steeper terrains where rapid surface runoff limits infiltration and reduces recharge potential.

Table 2: Terrain classification by lineament density and corresponding groundwater recharge potential.

Lineament density (m/km ²)	Terrain characteristics	Groundwater recharge potential
0–47.01	Low density, gentle slopes, flat terrain	Highly favourable for recharge
47.01–94.01	Moderate density, slightly undulating slopes	Supports moderate infiltration
94.01–141.02	Transitional slopes	Reduced recharge due to partial runoff
141.02–188.02	High density, steeper slopes	Low infiltration potential
188.02–235.03	Very high density, steepest slopes	Minimal recharge due to rapid runoff

4.2.3 Rainfall

Rainfall is one of the primary sources of groundwater recharge and is typically measured using rain gauges, which record precipitation depth (mm) over defined time intervals. The contribution of rainfall to groundwater reserves depends on several factors, including topography, vegetation cover, and surface geology, all of which govern infiltration capacity. Fig. 7 shows the spatial distribution of rainfall across Vasai Taluka, while Table 3 summarizes the uniform rainfall characteristics of the region.

Table 3: Summary of rainfall characteristics in Vasai Taluka.

Aspect	Description
Uniform Pattern	Consistent precipitation across the taluka
Spatial Homogeneity	Minimal variation in rainfall intensity
Hydrology	Enhance groundwater recharge in permeable, gentle-slope areas
Agriculture	Supports stable yields and reduces drought risk
Drainage	Requires systems to prevent flooding and waterlogging

Figure 7 and Table 3 together show that rainfall in Vasai Taluka is not only plentiful but also fairly uniform across the region. This even spread of rainfall means that no part of the taluka is left water-stressed, which is encouraging for both groundwater recharge and agriculture. On the positive side, the consistency of rainfall supports reliable farming cycles and ensures that recharge is not restricted by uneven precipitation. At the same time, the data also reminds us that uniform high rainfall can create challenges such as flooding and waterlogging in low-lying and poorly drained areas. Overall, the rainfall pattern emerges as a supportive background factor—providing the necessary input for recharge—while other layers like soil, slope, and drainage determine how effectively this water is absorbed and stored underground.

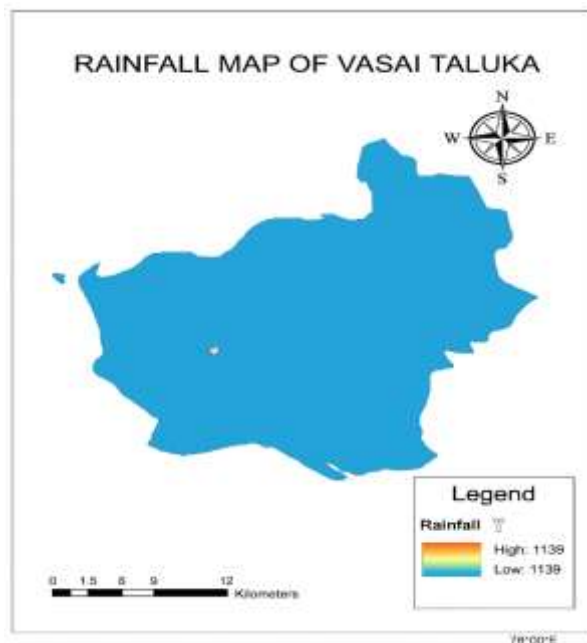


Fig. 7. Rainfall map of Vasai Taluka.

4.2.4 Soil

The soil map of Vasai Taluka (Fig. 8) identifies three dominant soil groups-Cambisols, Fluvisols, and Nitisols-each with distinct physical and chemical properties that influence land-use potential and groundwater dynamics. Strategic land management aligned with these soil characteristics can enhance agricultural productivity and promote sustainable resource utilization. Among soil properties, permeability and porosity are particularly important, as they directly affect groundwater recharge potential. Understanding these parameters is therefore essential for evaluating groundwater prospects in the region. Table 4 provides a summary of the major soil groups. Targeted management practices are essential for optimizing the potential of these soils. Cambisols can benefit from crop rotation and moderate fertilization, Fluvisols require erosion control measures, and Nitisols demand controlled irrigation and aeration strategies. Integrating soil-specific management into land-use planning enhances water conservation, minimizes erosion risks, and supports long-term agricultural sustainability in Vasai Taluka.

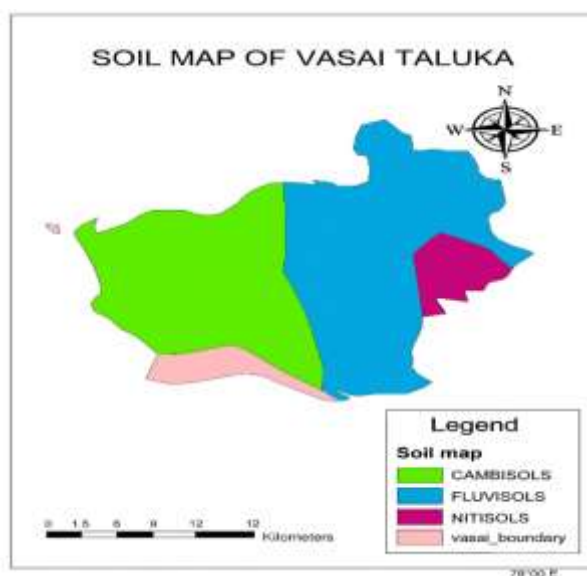


Fig. 8. Soil map of Vasai Taluka.

Table 4: Major Soil Types, Characteristics, and Agricultural Suitability in Vasai Taluka

Soil type	Location	Key traits & suitability	Management needs
Cambisols	West (green)	Moderate fertility, good drainage; suited for general crops	Crop rotation, moderate fertilization
Fluvisols	Central & East (blue)	Mineral-rich, high water-holding; ideal for paddy, moist-crop farming	Erosion control on riverbanks
Nitisols	South & Southeast (pink)	Clay-rich, deep; retains moisture; suited for sugarcane, bananas, vegetables	Controlled irrigation, aeration

4.2.5 Geology

A geological map of Vasai is essential for locating potential groundwater zones. Fig. 9 illustrates the geological framework of Vasai Taluka, highlighting two predominant formations. The pink area represents the Deccan Trap, a volcanic basalt formation characterized by compact, fine-grained basalt rock. This formation is notably resistant to weathering but exhibits low permeability, resulting in limited infiltration and, consequently, reduced groundwater recharge potential. The thin soil cover over these basalts offers moderate fertility but restricts groundwater availability. The southern part of Vasai Taluka, marked in blue, consists of alluvial deposits found along coastal plains, riverbeds, and flood-prone zones. These sediments possess high porosity and permeability, fostering substantial groundwater recharge and supporting a thick, fertile soil layer ideal for agricultural use and moisture retention. The geological distinction plays a crucial role in groundwater potential. While the alluvial deposits favour groundwater accumulation due to their permeable nature and gentle terrain, the Deccan Trap's rugged topography and low permeability limit groundwater recharge. Agricultural productivity is higher in the alluvial regions, whereas the basaltic terrain requires targeted soil management to enhance crop yields.

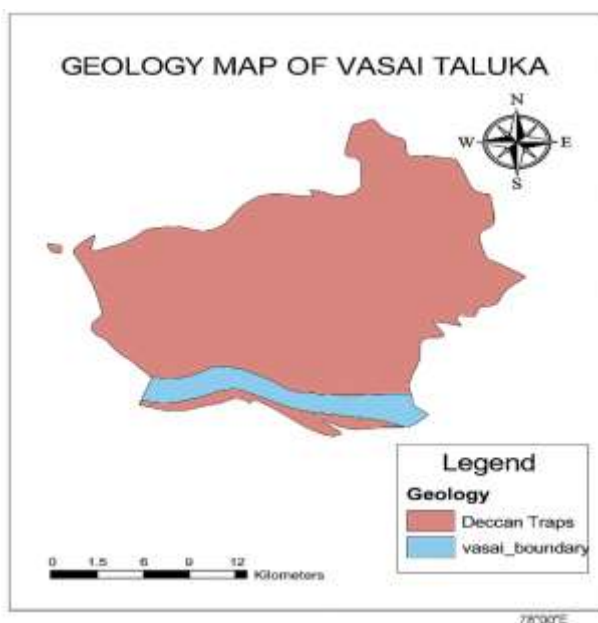


Fig. 9. Geology map of Vasai Taluka.

4.2.6 Geomorphology

Fig. 10 illustrates the geomorphological map of Vasai Taluka, depicting the classification of major landforms and their implications for groundwater potential.

- Low-resected denudational hills and valleys (yellow): Located mainly in the eastern and northeastern parts, these gently sloping areas experience low erosion and moderate surface runoff, resulting in limited groundwater recharge.
- Moderately dissected basaltic hills and valleys (orange): Spread across central and northern zones, these terrains, influenced by Deccan Trap basalts, exhibit moderate erosion and moderate permeability, thereby constraining infiltration.

- **Pedi plains (purple):** Found mainly in southern and central regions, pediplains formed by sustained erosion of hills and valleys are favorable for groundwater recharge.
 - **Coastal plains (grey):** Extending along the western margin, these flat, low-lying tidal landscapes possess good groundwater potential and are suitable for cultivation.
 - **Fluvial plains (green):** Formed by riverine deposition, these fertile units occur near streams and scattered locations, with high permeability that supports significant recharge.
 - **Anthropogenic undifferentiated units (light grey):** Representing urban settlements, industries, and infrastructure, these areas exhibit reduced infiltration and increased surface runoff due to impervious surfaces.
- The geomorphology of Vasai Taluka highlights contrasting groundwater potentials across landforms. Pediplains and coastal plains facilitate recharge and support agriculture, while fluvial plains offer substantial recharge owing to their high permeability. The basaltic hills demonstrate limited infiltration and moderate runoff, necessitating soil and water conservation measures. Although coastal and fluvial plains are favorable for habitation and cultivation, anthropogenic areas disrupt natural hydrological processes, decreasing permeability and altering runoff patterns. Geomorphological mapping thus provides essential insights for sustainable land-use planning, water resource management, and regional development in Vasai Taluka.

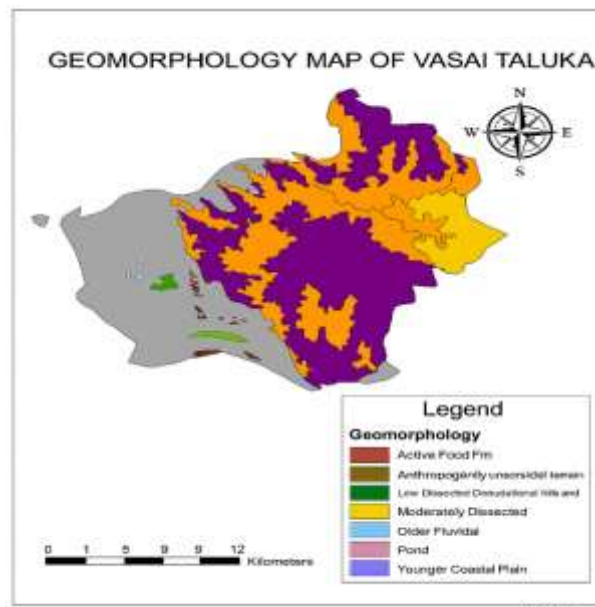


Fig. 10. Geomorphology map of Vasai Taluka.

4.2.7 Land use/land covers (LULCs)

Land use refers to human activities on the land, such as urban development, conservation, or mixed uses, while land cover describes the physical characteristics of the surface, including vegetation, crops, forests, bare soil, and water bodies. Vegetation-rich areas like forests and plantations play a critical role in enhancing water retention through root systems, thereby supporting groundwater recharge. RS technologies provide an effective means to map and monitor LULCs, offering valuable insights into groundwater availability and management strategies.

Fig. 11 illustrates the LULC map of Vasai Taluka, which classifies the region into four major categories: urban areas, water bodies, vegetation, and barren land.

- **Urban land (red zones)** is predominantly located in the western and southern parts, concentrated near the coastline and low-lying areas, reflecting significant human settlements and ongoing urbanization.
- **Water bodies (blue zones)** represent rivers, estuaries, and coastal waters, which sustain marine ecosystems and contribute to the regional hydrological cycle.
- **Vegetation (green zones)** primarily covers the eastern and northern regions, comprising dense forests and agricultural lands that are vital for ecological balance, biodiversity conservation, and groundwater recharge.
- **Barren land (yellow zones)** is scattered mainly in central and western areas, characterized by rocky terrain, degraded soils, or unsuitable conditions for vegetation or agriculture.

The spatial contrast between dense vegetation in the east and expanding urban areas in the west highlights environmental challenges such as green cover loss, flooding risks, and erosion, particularly along coastal zones

under anthropogenic pressure. The extensive water bodies in the south provide crucial hydrological support for both natural ecosystems and human activities. Given these observations, sustainable urban planning in Vasai Taluka should emphasize water resource management and preservation of green zones to mitigate environmental degradation. Additionally, efforts should be directed towards rehabilitating barren lands through afforestation and soil conservation to enhance groundwater recharge. This LULC analysis forms a foundational framework for informed land management, resource allocation, and urban development planning aimed at balancing growth with ecological sustainability.

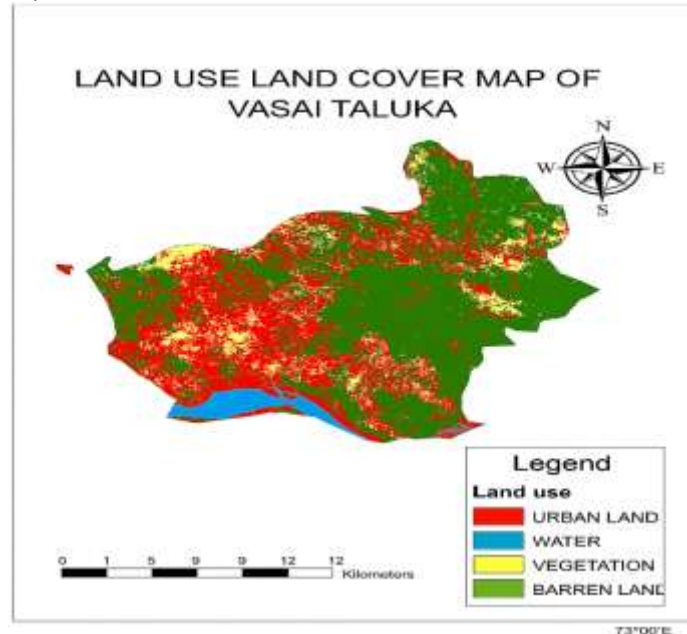


Fig. 11. LULCs map of Vasai Taluka.

4.3 Weighted overlay analysis (WOA)

The WOA was applied to integrate multiple thematic layers influencing groundwater occurrence and recharge. A spatial database was first constructed using satellite imagery and ancillary datasets. Thematic maps representing drainage density, lineament density, slope, rainfall, geology, geomorphology, soil type, and LULC were generated in ArcGIS 10.5. Agricultural and settlement areas were buffered using attribute data, while LULC information was derived from DEM and RS sources. Each thematic layer was assigned a weight according to its relative contribution to groundwater recharge, based on expert judgment and established literature. The groundwater potential index (GPI) was then computed using the following equation [17]:

$$GPI = RF_w RF_r + LG_w LG_r + GG_w GG_r + SG_w SG_r + LD_w LD_r + DD_w DD_r + LC_w LC_r + SC_w SC_r + GC_w GC_r \quad (1)$$

where RF is the rainfall, LG is the lithological index, GG is the geology, SG is the slope gradient index, LD is the lineament density, DD is the drainage density, LC is the land cover, SC is the soil cover, GC is the geomorphology, and w and r are the weight and rank.

Fig. 12(a) illustrates the key components of groundwater potential and their spatial integration, while Fig. 12(b) presents the thematic ranking system used for classification. Fig. 12(a) shows that RF, SG, and DD control surface runoff and recharge availability, whereas LG and LD regulate subsurface water storage and movement. GC determines landform suitability for infiltration, whereas SC and LC influence permeability and retention capacity. A combination of these parameters forms an integrated foundation for mapping groundwater potential zones in Vasai Taluka. Table 5 summarizes the weights and ranks assigned to thematic parameters in the WOA for GPM. Among the parameters, RF (22%) and SC (19%) were assigned to the highest weights, reflecting their strong influence on groundwater recharge, whereas GG (4%) received the lowest weight. The ranking scheme prioritizes favorable conditions with higher scores, thereby enabling a more accurate computation of the GPI.

(a)

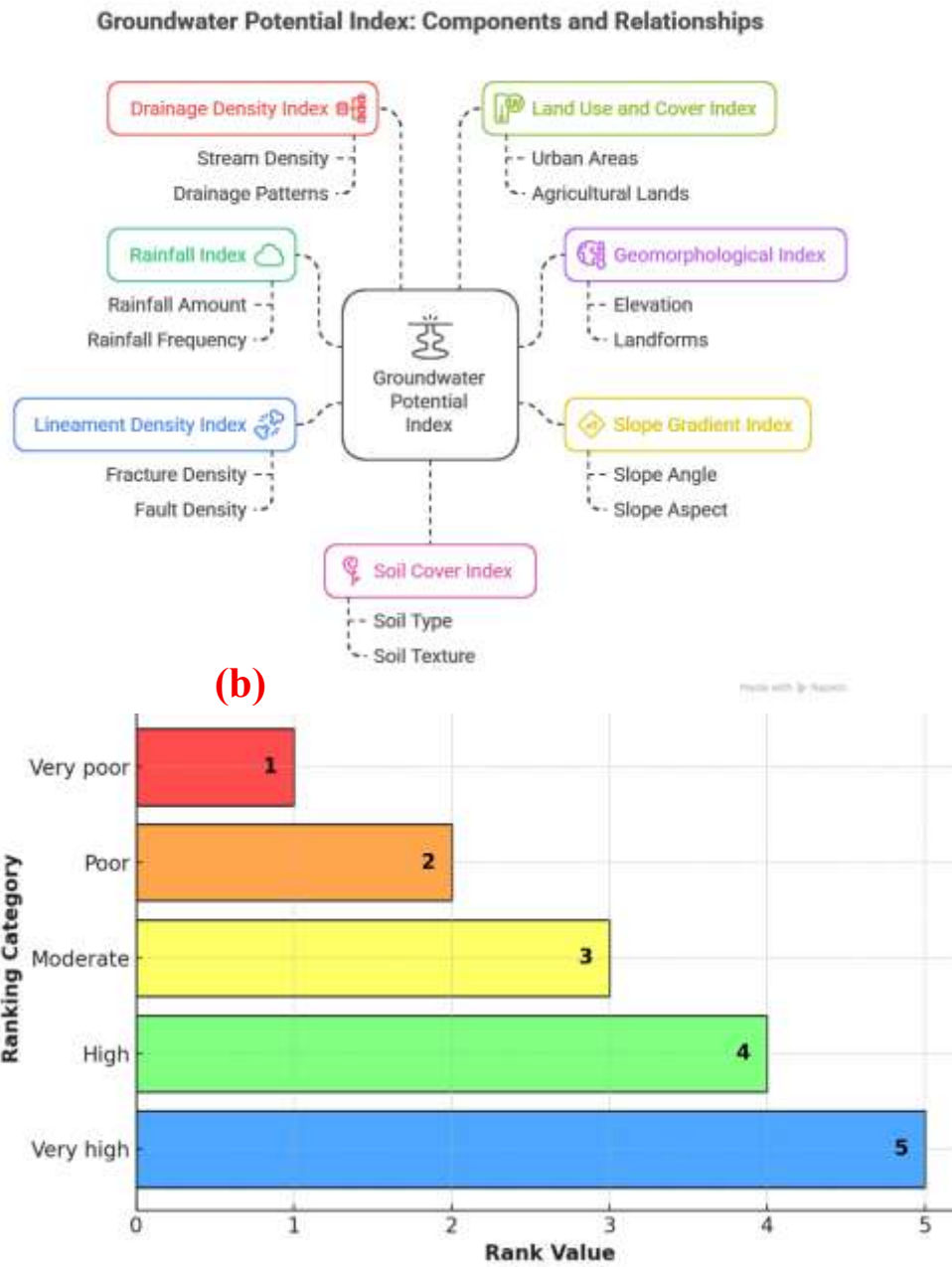


Fig. 12. (a) Components of GPI and (b) Thematic ranking of the map.

Table 5: Ranks and weights given in WOA.

Parameter	Groundwater prospect categories	Weight (%)	Rank
SG	Very good, Good, Moderate, Poor, Very poor	19	5, 4, 3, 2, 1
DD	Very good, Good, Moderate, Poor, Very poor	11	5, 4, 3, 2, 1
LD	Very poor, Poor, Moderate, Good, Very good	9	1, 2, 3, 4, 5
RF	Very good	22	5
SC	Very poor, Poor, Moderate	6	1, 2, 3
GG	Very good	4	5
GC	Very good, Good, Moderate, Poor, Very poor	16	5, 4, 3, 2, 1
LC	Moderate, Good, Poor, Very Poor	13	3, 4, 2, 1

Fig. 13 depicts the groundwater potential zones derived from WOA. The area is divided into three categories: (i) high potential zones with gentle SG, high RF, low DD, and high LD, which improve recharge; (ii) moderate potential zones, which have intermediate suitability across the parameters considered; and (iii) low potential zones characterized by steep SG, high DD, impermeable LC, and unfavorable SC types, which restrict recharge. The analysis indicates that the significant part of Vasai Taluka falls under the moderate potential category, with smaller portions classified as high and low. This GIS-based WOA approach provides a scientifically robust framework for groundwater resource assessment and supports policymakers in sustainable management and planning.



Fig. 13. Groundwater potential zones of Vasai taluka.

5. CONCLUSIONS

The present study identified and delineated prospective groundwater zones in Vasai Taluka, Maharashtra (India), using a GIS-based WOA approach. Amid increasing groundwater demand driven by rapid urbanization and agricultural activities, the integration of multiple thematic layers, weighted according to their relevance to recharge potential, provided a comprehensive spatial assessment of groundwater availability. The findings of this study can be summarized as follows:

- High potential zones are characterized by gentle slopes, low drainage density (0-57.16 m/km²), high lineament density (188.02-235.03 m/km²), permeable soil (Fluvisols), significant rainfall (~1139 mm), and favorable geomorphological features like fluvial and coastal plains that enhance recharge.
- Moderate potential zones cover the majority of the area, featuring moderate slopes, intermediate drainage density (57.16-165.43 m/km²), moderate lineament density, and mixed vegetation/agricultural land that support moderate recharge.
- Low potential zones occur in steep slope areas with high drainage density (230.72-428.70 m/km²), less permeable soils such as Cambisols and Nitisols, and experience rapid runoff that limits infiltration.
- The GIS-WOA analysis indicates that a significant part of Vasai Taluka falls under the moderate groundwater potential zone, with smaller portions classified as high- and low-potential zones.
- The GIS-WOA analysis highlighted the significance of integrated thematic factors, indicating that areas with gentle slopes, high lineament density, and favorable soils need to be prioritized for conservation, whereas low-potential zones require targeted artificial recharge interventions.

This study provides an effective decision-support framework for groundwater management, enabling conservation and recharge strategies, while contributing to SDG 6 (clean water and sanitation) and SDG 11 (sustainable cities and communities).

LIMITATIONS AND FUTURE SCOPE

While the present study successfully delineates groundwater potential zones in the Vasai Taluka using multi-criteria GIS-based analysis, some limitations should be acknowledged. First, the results are dependent on the resolution and accuracy of secondary datasets such as rainfall, soil, and lithology, which may not capture fine-scale variations in highly heterogeneous environments. Second, the methodology is based primarily on weighted overlay analysis and AHP, which rely on expert judgment for assigning weights. This introduces an element of subjectivity that could be refined through the integration of data-driven statistical or machine learning approaches. Third, field validation was limited to available well data, and more extensive hydrogeological surveys would further strengthen the findings.

Future research should explore the integration of **remote sensing time-series data** (e.g., rainfall, vegetation indices), **climate change scenarios**, and **machine learning models** to improve predictive accuracy. Expanding the analysis to incorporate **groundwater quality parameters** alongside potential zones could provide a more holistic view for sustainable groundwater management. Finally, applying the developed framework to other **coastal-urban regions** in India and South Asia would help test its transferability and establish its broader applicability.

Nomenclature

Symbol / Abbreviation	Description
DEM	Digital Elevation Model
GIS	Geographic Information System
GPS	Global Positioning System
LULC	Land Use / Land Cover
RS	Remote Sensing
NDVI	Normalized Difference Vegetation Index
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
SRTM	Shuttle Radar Topography Mission
IRS	Indian Remote Sensing Satellite
WOA	Weighted Overlay Analysis
AHP	Analytical Hierarchy Process
WPI	Weighted Priority Index
UGC	Uniform Grid Cell
SFD	Shear Force Diagram
BMD	Bending Moment Diagram
RA, RB	Reactions at supports A and B (kN)
V	Shear force (kN)
M	Bending moment (kN·m)
θ (theta)	Slope / angle (degrees or radians)
ρ (rho)	Density of soil/rock (kg/m ³)
φ (phi)	Angle of internal friction (degrees)
K	Hydraulic conductivity / permeability (m/s)
W	Uniformly distributed load (kN/m) or weight
P	Point load (kN)
L	Length of beam or watershed (m)
A	Area (m ²)
%	Percentage
M	Metre (unit of length)
kN	Kilonewton (unit of force)

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CRedit authorship contribution statement

Puja Kadam: Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Archanaa Dongre:** Writing –visualization, review & editing **Javed Shaikh** Writing – review & editing **Ajay Radke** Supervising

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