

Mapping Managed Aquifer Recharge (MAR) Suitability for Climate Adaptation in Odisha, India

Syed Adil Mizan, Mohammad Faiz Alam, Shivam Chaudhary, Alok Sikka, and Giriraj Amarnath

February 2026



Authors

Syed Adil Mizan, (Former) Researcher, International Water Management Institute (IWMI), New Delhi, India
Mohammad Faiz Alam, Senior Regional Researcher, IWMI, New Delhi, India
Shivam Chaudhary, Research Officer – Water Resources Management, IWMI, New Delhi, India
Alok Sikka, Country Representative – India & Bangladesh, and Senior Fellow, IWMI, New Delhi, India
Giriraj Amarnath, Research Group Leader - Water Data for Climate Resilience (WDCR), and Principal Researcher – Disaster Risk Management and Climate Resilience, IWMI, Colombo, Sri Lanka

Acknowledgement

This work was carried out under the CGIAR Climate Action Program, CGIAR Sustainable Farming Program, and the CGIAR Accelerator for Digital Transformation. We would like to thank all funders who support this research through their contributions to the CGIAR Trust Fund (www.cgiar.org/funders).

CGIAR Climate Action Program

The science program aims to drive science, innovation, and collaboration to transform food, land, and water systems for a climate-resilient, net-zero, and equitable future. in Bangladesh, Cambodia, Côte d'Ivoire, Ethiopia, Honduras, India, Kenya, Nepal, Nigeria, Pakistan, Philippines, Senegal, Sri Lanka, Sudan, Tanzania, Zambia, Zimbabwe.

Citation

Mizan, S. A.; Alam, M. F.; Chaudhary, S.; Sikka, A.; Amarnath, G. 2026. *Mapping Managed Aquifer Recharge (MAR) suitability for climate adaptation in Odisha, India*. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Climate Action Program; CGIAR Sustainable Farming Program; CGIAR Accelerator for Digital Transformation. 25p.

© 2026 International Water Management Institute. Some rights reserved. This work is licensed under a Creative Commons Attribution 4.0 International License (CC by 4.0).

Front and back cover photo: Tanmoy Bhaduri/IWMI

Disclaimer

This publication has been prepared as an output of the CGIAR Climate Action Program and has not been independently peer reviewed. Responsibility for editing, proofreading, layout, opinions expressed, and any possible errors lies with the authors and not the institutions involved. Boundaries used in the maps do not imply the expression of any opinion whatsoever on the part of CGIAR concerning the legal status of any country, territory, city, or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Borders are approximate and cover some areas for which there may not yet be full agreement.

Contents

1. Introduction	3
2. Study Area	4
3. Methodology	5
4. Results	10
5. Conclusion and Way Forward	11
6. References	11

1. Introduction

Groundwater resources in large parts of India are under stress from unsustainable use, and the stress is further compounded by impacts of climate change and rapid population growth, leading to heightened demand and reduced natural recharge (Gale and Dillon, 2005). In several high-demand regions, groundwater development has reached a critical threshold, leading to severe resource depletion and scarcity, with alarming declines in water levels, disruptions in water supply, saline water intrusion in coastal aquifers, and increased pumping depths necessitating the construction of deeper and more costly groundwater extraction structures (Rodell et al., 2009). To tackle the issue of de-saturation of aquifer zones and consequent deterioration of ground water quality, Managed aquifer recharge (MAR) is being advocated for building resilience to climate change (Dillon et al., 2009; Ringleb et al., 2016).

MAR involves strategically recharging aquifers with excess surface water through infrastructures such as check dams, recharge wells, etc. It is a strategy used to combat groundwater depletion and improve water security for irrigation (Zhang et al., 2020, Alam & Pavelic 2020, Zheng et al. 2021). This process helps increase groundwater storage during dry seasons and droughts (Dillon et al 2019 & Zhang et al 2020), supporting irrigation and mitigating aquifer depletion. The success of MAR depends on having a reliable source of water to harvest, such as floodwater or treated wastewater (Alam et al., 2025). India, the world's largest groundwater user, has long championed MAR initiatives to counteract the adverse impacts of extensive groundwater use, exemplified by ambitious national Master Plans for aquifer recharge (CGWB, 2021a). Recent government efforts have evidenced encouraging results in increased recharge and decrease in number of overexploited units (CGWB, 2025).

In the eastern state of Odisha (Figure 1) importance of groundwater is increasing. Odisha receives an average annual rainfall of approximately 1452 mm (GoO 2020a), but still a large portion of the state's agriculture remains rainfed and vulnerable to climatic uncertainties. Currently, surface water supports nearly 80% of irrigation, however the state possesses substantial untapped groundwater potential (Mitra et al. 2024). In the last decade, Odisha has seen increase in groundwater use with overall groundwater development at 46% in 2023 increasing from 28% in 2011. In this context, the strategic development and management of groundwater resources become increasingly important for managing risks of climate change. Managed Aquifer Recharge (MAR) presents a promising approach for enhancing groundwater availability, improving irrigation security, and ensuring sustainable water management for climate adaptation in Odisha.

A range of spatial MAR suitability assessments have been carried out globally, most commonly using GIS-based approach; however, published studies show considerable variability in selected criteria and weighting schemes, and there is no single standardized protocol (Sallwey et al., 2019). Recent applications commonly integrate hydrogeological and terrain factors with decision frameworks (e.g., weighted overlay/AHP-type structures), and in some cases extend screening with additional feasibility constraints or ranking steps (Rahman et al., 2013; Hani et al., 2023). Building on this literature, this analysis is used to provide a state-scale, decision-oriented screening for Odisha that combines suitability of hydrogeology with the practical context of available supply and demand, so that identified zones are not only physically suitable

for recharge, but are also aligned with where harvested water is likely to be available and where irrigation-related groundwater demand is most relevant for climate risk management.

This study carries out a spatial suitability assessment to identify and characterize potential areas suitable for MAR implementation in Odisha based on suitable hydrogeology along with available supply and demand situation. It compiles and harmonizes spatial layers describing recharge feasibility together with indicators of water availability to harvest and the prevailing groundwater use context and integrates these through a GIS-based framework to delineate priority MAR zones. The outputs include a spatial suitability map and a characterization of candidate areas to support planning of MAR interventions, enabling comparison across districts/blocks and supporting a more targeted, sustainable and equitable approach to groundwater development in Odisha.

2. Study Area

The state of Odisha (Figure 1a) experiences a subtropical climate, marked by three distinct seasons: a hot summer from March to June, a monsoon season from June to October, and a mild winter from November to February. Approximately 85% of the annual rainfall is received during the southwest monsoon, with July and August recording the highest precipitation. Rainfall is heaviest in the northeastern coastal region, ranging between 1,271 mm to 1,698 mm. In contrast, a low-rainfall zone extends from Keonjhar in the north to Gopalpur in the south, passing through Angul and Phulbani. Summers are typically hot, with daytime temperatures reaching up to 45°C.

The state exhibits a diverse and scenic range of landforms. The southern and central districts—such as Rayagada, Kalahandi, Phulbani, and Gajapati—feature rugged hilly terrains, while the northern districts of Sundargarh, Keonjhar, and Mayurbhanj, along with parts of Nawarangpur in the southwest, are characterized by plateau regions. Major river valleys are defined by gently undulating plains, and a narrow coastal belt stretches along the Bay of Bengal. Physiographically, the state can be broadly classified into five distinct units: (i) Coastal Plains, (ii) Northern Uplands, (iii) Erosional Plains of the Mahanadi Valley, (iv) Southwestern Hilly Region, and (v) Subdued Plateaus.

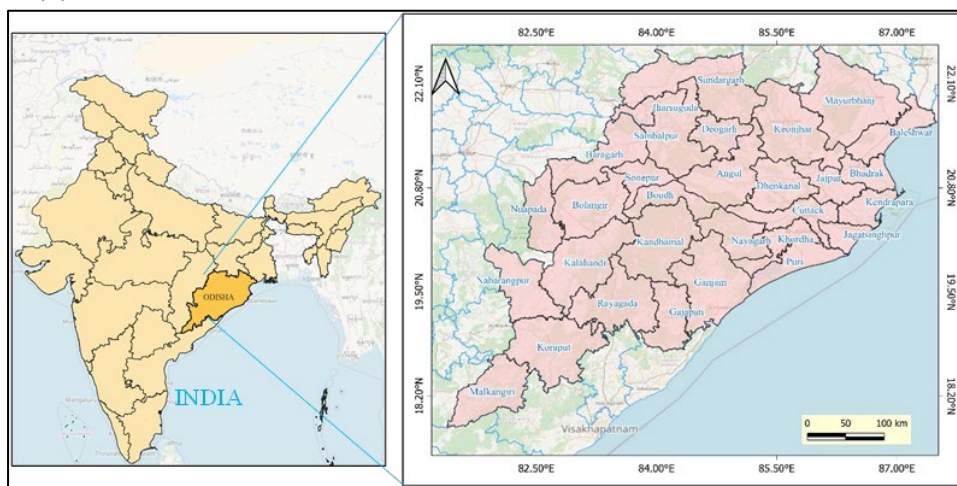


Figure 1. (a) Study Area: State of Odisha

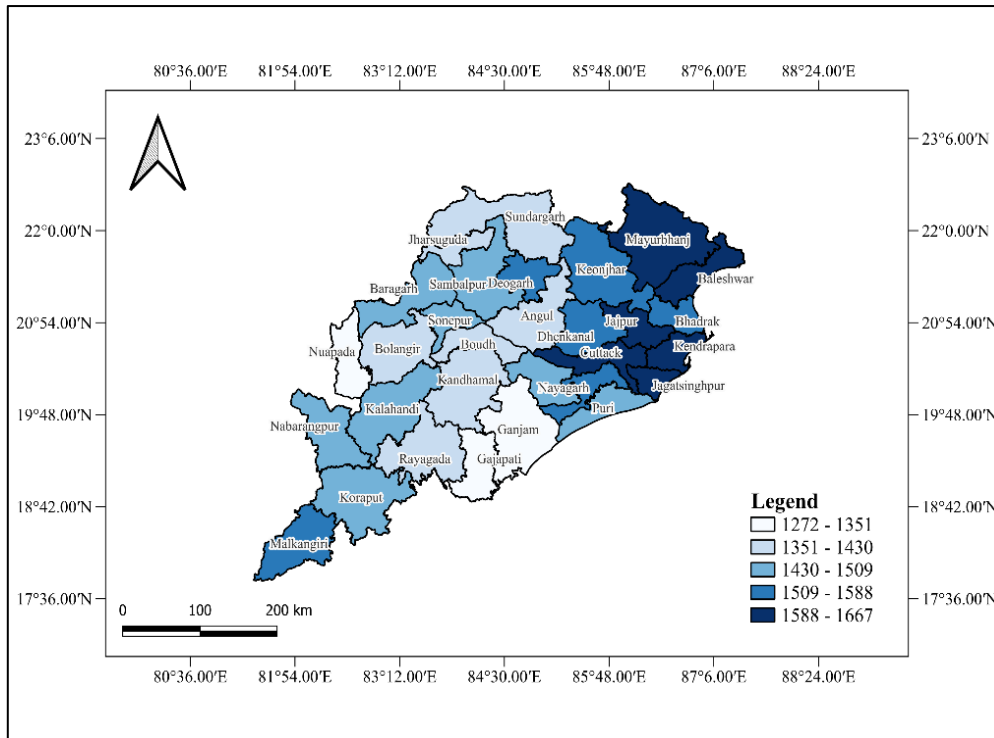


Figure 1. (b) Annual Precipitation among all districts of Odisha

3. Methodology

A GIS-based multi criteria approach (Alam and Pavelic, 2020) has been applied to identify and map the suitability of MAR, combining hydrogeological, hydrological, environmental, and socio-economic assessments to ensure effective site selection, design, and implementation. This approach involves identifying suitable recharge zones using remote sensing and GIS-based multi-criteria analysis, combining soil and aquifer properties along with the availability and quality of water available for recharge. This is followed by a brief assessment of appropriate MAR techniques based on site-specific conditions.

Figure 2 represents an integrated, multi-criteria decision-making approach for MAR site selection. There are three primary categories used to evaluate MAR suitability:

- **Water Supply Suitability:** This focuses on whether a reliable water source is available for recharge. It assesses the quantity of water to ensure its suitability. Key considerations include the seasonal availability and overall reliability of the source.
- **In-situ Suitability:** This evaluates the physical characteristics for implementing MAR. It examines the geology, hydrogeology, geomorphology and topography to see if the hydrogeology can effectively store water. This helps ensure the site is physically capable of supporting MAR without unintended consequences.
- **Groundwater (GW) Demand:** This analyses the local need for groundwater. It considers current usage and future demand to determine if MAR is necessary and how large it should be. This ensures that the project is addressing a real need, such as an

area with existing water shortages/future demands and/or declining groundwater levels.

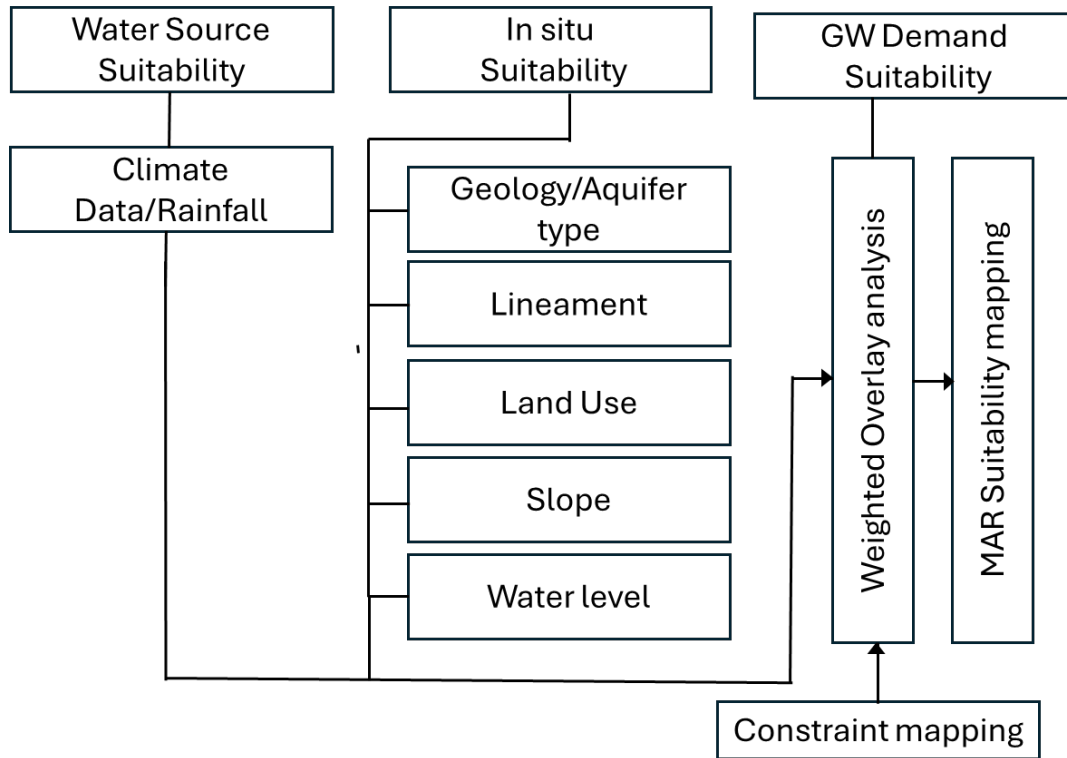


Figure 2. A framework for the MAR suitability mapping in Odisha.

Table 1 gives the data used for analysis. Each thematic layer was first standardized on a common suitability scale ranging from 1 (low) to 4 (very high) as mentioned in Table 2, to ensure comparability across diverse datasets. The standardized criteria were then combined using a weighted linear overlay approach, where equal weightage was assigned to each layer to avoid bias toward any single factor. The overall suitability index for each location was calculated as:

$$S(x, y) = \prod_{i=1}^n (R_i(x, y))^{w_i}$$

where $S(x,y)$ is the suitability score at pixel (x,y) , w_i is the weight assigned to the i^{th} layer, and n is the total number of criteria (here, $n=9$).

The resulting continuous suitability surface was further classified into four categories—Low, Moderate, High, and Very High—by rounding off the computed suitability values to the nearest integer on the standardized scale (1–4). The final MAR suitability map thus represents an integrated decision layer that accounts for water availability, groundwater stress, and site-specific physical conditions, providing a systematic and replicable framework for identifying priority zones for MAR interventions.

Table 1. Data used in this study.

Data set	Sources	Derived data
Rainfall	IMD	Average and seasonal rainfall, deficit and surplus rainfall years
SRTM DEM	USGS	Slope
Land Use/Land Cover	Roy et al 2018	Land Use
Geology	GSI (www.bhukosh.gsi.in)	Geology map
Lineament	GSI (www.bhukosh.gsi.in)	Lineament density map
GW development stage	CGWB	GW stage map
GW level	CGWB	Water level maps

Data set	Sources	Derived data	Spatial resolution	Time period
Rainfall*	IMD	Average and seasonal rainfall, deficit and surplus rainfall years	1.0° x 1.0°	1999-2020
SRTM DEM	USGS	Slope	30m	2000
Land Use/Land Cover	Roy et al 2018	Land Use	56m	2015-16
Geology	GSI (www.bhukosh.gsi.in)	Geology map	1:50,000	Static
Lineament*	GSI (www.bhukosh.gsi.in)	Lineament density map	1:50,000	2012
GW development stage*	Central Ground Water Board (CGWB)	GW stage map	Block scale	1999-2020
GW level*	CGWB	Water level maps	Block scale	1999-2020

NOTE: *: Prepared thematic layers (all standardized to 30 m × 30 m and reclassified into 4 classes)

Table 2. Criteria and Justification for Aquifer Recharge Suitability

Factor	Indicator	Value	Score (C)	Suitability for MAR	Justification
Supply	Average Rainfall (mm)	>1200 mm	4	V High	Higher rainfall increases recharge potential, while low rainfall limits surplus for recharge.
		800-1200 mm	3	High	
		500-800 mm	2	Moderate	
		<500 mm	1	Low	
	Monsoonal rainfall (% of annual rainfall)	>90 %	4	V High	Higher rainfall with greater seasonal and yearly variability increases runoff, enhancing recharge potential but also flood risk.
		75-90 %	3	High	
		60-75 %	2	Moderate	
		<60 %	1	Low	
	% Excess rainfall years in the last 25 years (> 20 % of average rainfall)	>30 %	4	V High	More excess rainfall years increase surplus water for recharge but also raise flood risk.
		20-30 %	3	High	
		10-25 %	2	Moderate	
		<10 %	1	Low	
Demand	% Deficit	≥30 %	4	V High	The higher the deficit years, the greater the need for recharge and irrigation and need to enhance groundwater storage.
		20 – 30 %	3	High	
		10 – 20 %	2	Moderate	
		<10 %	1	Low	
	Groundwater demand (groundwater development)	> 80 %	4	V High	Higher groundwater development, higher the groundwater use (mostly for irrigation) suggests the need to augment groundwater storage.
		60 – 80 %	3	High	
		40 – 60 %	2	Moderate	
		< 40 %	1	Low	
In-situ					Post monsoon level > 3 m reflects that recharge space if available.
	Groundwater level	> 3 mbgl	1	Feasible	
< 3 mbgl		0	Not Feasible		

Landuse	Bare areas	4	V High	Recharge is higher in bare areas and croplands but reduced in forests and least in urban/water bodies due to limited infiltration.
	Cropland & Grass land	3	High	
	Sparse vegetation/dense Forest	2	Moderate	
	Urban areas/Water bodies	1	Low	
Slope	0-5 degree	4	V High	Flatter slopes reduce runoff and enhance infiltration, making them more suitable for recharge than steep slopes.
	5 - 10 degree	3	High	
	10 - 20 degree	2	Moderate	
	> 20 degree	1	Low	
Geology	Alluvium	4	V High	Recharge is highest in alluvium due to high porosity, moderate in semi-consolidated rocks, and lowest in hard rocks where it depends on weathering and fractures
	Weathered Sandstone/Quartzite	3	High	
	Fractured Granites	2	Moderate	
	Gabbro/Volcanic rocks/Unclassified granites	1	Low	

4. Results

There are nine thematic layers used to evaluate MAR suitability for Odisha. Each map layer contributes critical information to assess groundwater recharge potential. A brief interpretation of each layer is discussed below.

Supply Suitability

Rainfall: Figure 3 illustrates that nearly every district in Odisha is classified as having "Very High" rainfall suitability, indicating a sufficient supply of water throughout the state. This shows the water availability for recharge is generally not a constraint.

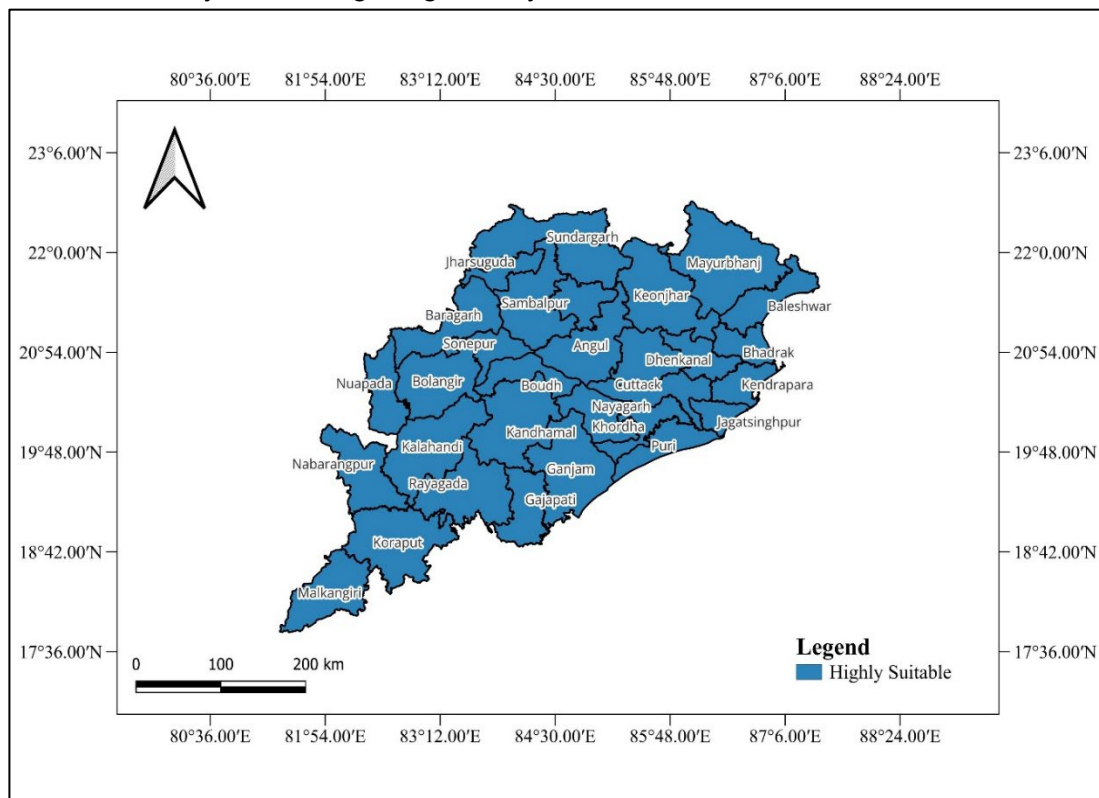


Figure 3. Rainfall-Based Suitability for MAR over the Study Area Source: ()

South West monsoon: The spatial distribution of monsoonal rainfall contribution (Figure 4) demonstrates that most districts are classified as "High" to "Moderately" suitable, with a few districts displaying "Very High" dependency on monsoon rains. This represents the seasonal concentration of precipitation, which increases surface runoff and improves recharging opportunities.

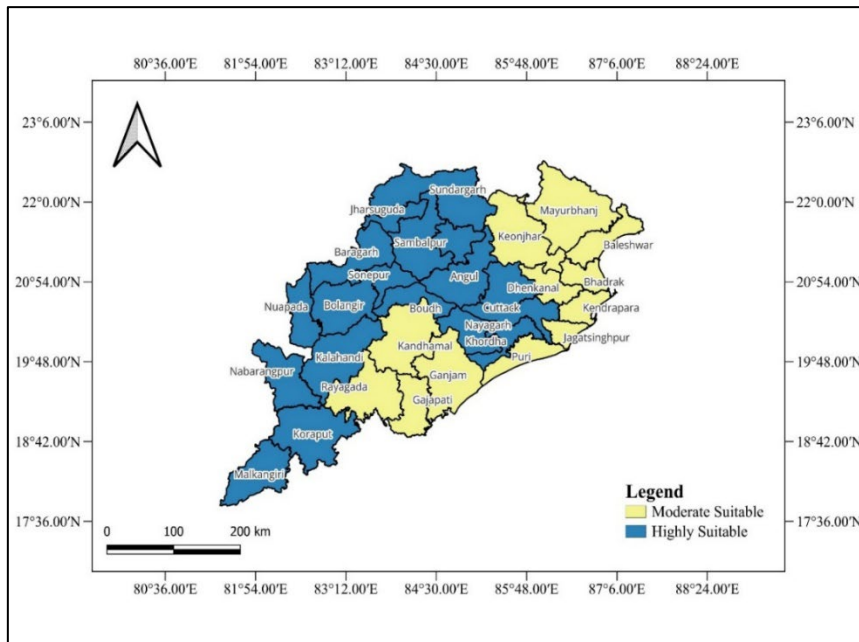


Figure 4. SW Monsoon Rainfall-Based Suitability for MAR over the Study Area.

Excess Rainfall years: The excess rainfall frequency (Figure 5) varies considerably across districts, ranging from “Low” to “High” suitability. Some districts, like Cuttack, Dhenkanal, Keonjhar, and Koraput, are in the "Low" suitability class, meaning there are fewer excess rainfall years, whereas other districts, like Angul, Bolangir, and Kalahandi, show a high frequency of excess rainfall years, providing surplus water for recharge. The necessity for location-specific recharge planning for MAR treatments is highlighted by this diversity.

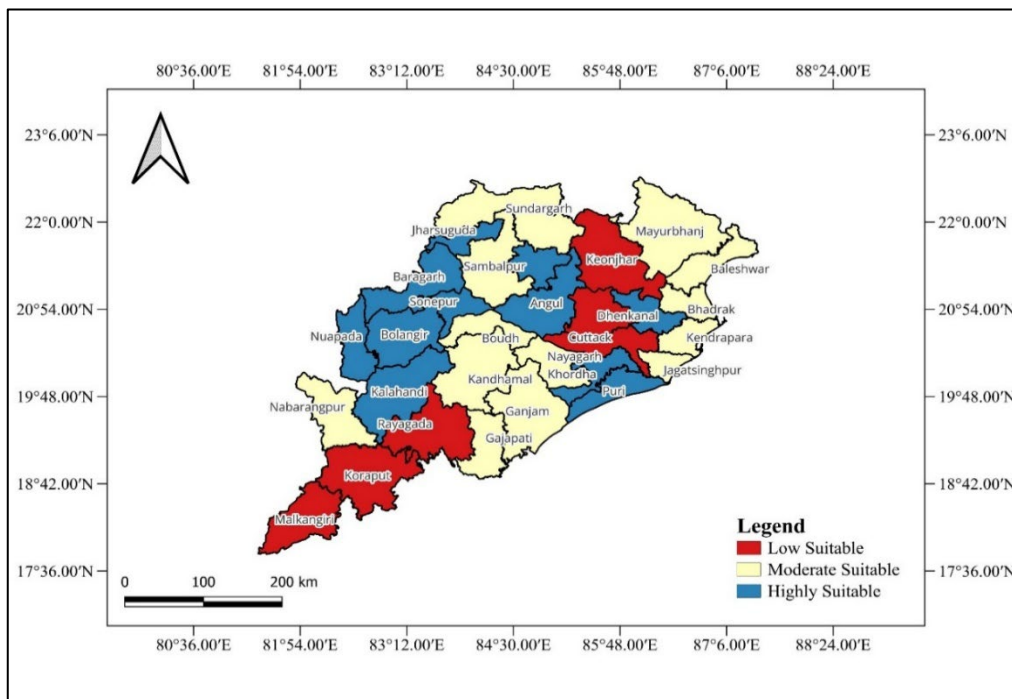


Figure 5. Excess Rainfall-Based Suitability for MAR over the Study Area.

In-situ Suitability

Slope: The slope map (Fig.6) shows its suitability for recharge across Odisha. The areas highlighted in blue (Very Highly Suitable) and light green (Highly Suitable) indicate flatter regions with low slopes. These regions are widespread, particularly in the central and coastal parts of the state. Conversely, the areas with steeper slopes are marked in orange (Moderate Suitable) and red (Low Suitable). These are concentrated primarily in the central and western parts of the state, corresponding to the hilly and mountainous terrains. Flatter slopes are crucial for successful MAR because they allow water to remain on the surface for a longer time, increasing the opportunity for it to infiltrate into the ground. When the slope is steep, water runs off quickly, reducing the opportunity time to seep into the soil thus necessitating land management interventions such as terracing, contour bunding etc to slow runoff and increase infiltration time. Therefore, areas with low to moderate slopes are considered more favorable for implementing MAR projects. The widespread presence of flatter regions in Odisha makes a significant portion of the state highly feasible for recharge development.

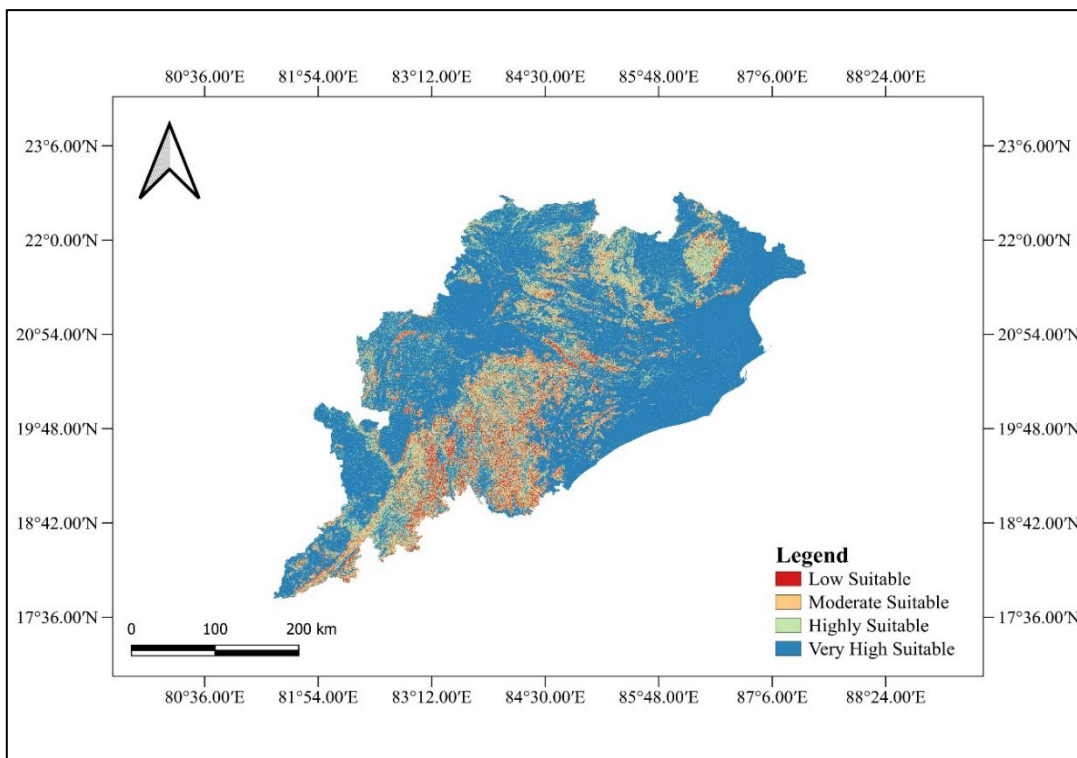


Fig.6. Slope-Based Suitability for MAR over the Study Area. (Source:)

Geology: The Geology & Lineament Map (Fig. 7) highlights the diverse hydrogeological landscape of the state, which directly influences groundwater recharge potential:

- **Alluvium/Sand (Green):** Found along the eastern coastal belt, particularly in the Mahanadi River delta, these unconsolidated formations are highly porous with significant storage and transmission capacity, making them the most favourable zones for Managed Aquifer Recharge (MAR).
- **Fractured Granites/Quartzite:** Dominating the central, southern, and western regions, these consolidated hard rocks generally have low primary porosity but become

moderately suitable for recharge where fractures and weathered layers are present. Recharge efforts here are most effective when focused on small-scale interventions like recharge pits and trenches that enhance infiltration into the shallow fractured zones.

- **Highly Fractured/Weathered Consolidated Rocks:** Present in patches across the northern and western parts of the state, these formations benefit from extensive fracturing and weathering. The secondary porosity created by these features provides good pathways for infiltration, making them highly favourable for MAR development compared to other hard rock settings.
- **Unclassified Granites/Volcanic Rocks:** Scattered across the state and often interspersed with fractured granites, these rocks have uncertain recharge potential. Their suitability depends largely on the degree of weathering and fracturing; in general, where such features are limited, they are considered to have low recharge suitability.

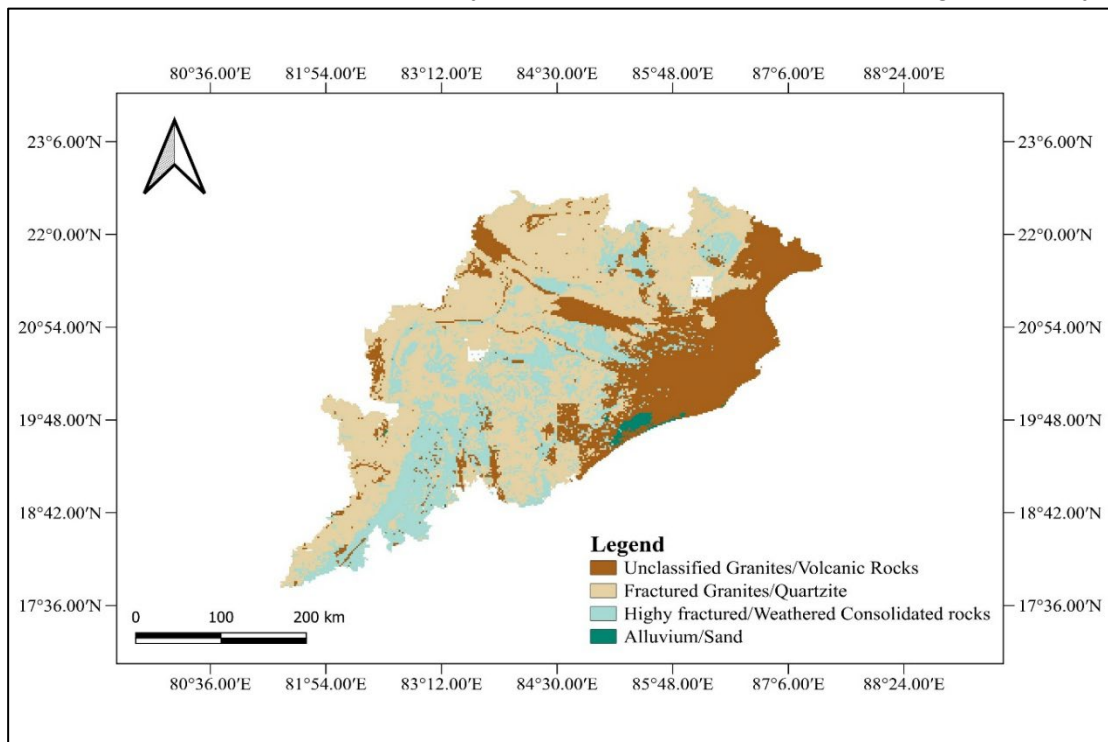


Figure 7. Geology-Based Suitability for MAR over the Study Area. (Source:)

LULC: The Land Use and Land Cover (LULC) map (Fig 8) illustrates a diverse land use pattern across the state. Highly Suitable (light green) and Very Highly Suitable (blue) areas are widespread, covering most of the state. These regions, likely characterized by agricultural land and natural vegetation, are conducive to water infiltration. Moderate Suitable (orange) areas are also extensive, particularly in the central and northern parts of the state. Low Suitable (red) areas are limited and appear in scattered pockets. These likely correspond to urban centers or areas with impervious surfaces, which hinder natural water seepage. LULC patterns significantly influence the effectiveness of Managed Aquifer Recharge (MAR), making them essential considerations in sustainable water resource planning. For example, urban landscapes are often dominated by impervious features such as buildings and paved roads, which hinder natural water infiltration and lead to greater surface runoff with reduced groundwater recharge potential. Conversely, areas covered

with crop land and vegetation enhance infiltration processes, thereby supporting groundwater replenishment (Hammouri et al., 2014; Siddik et al., 2022).

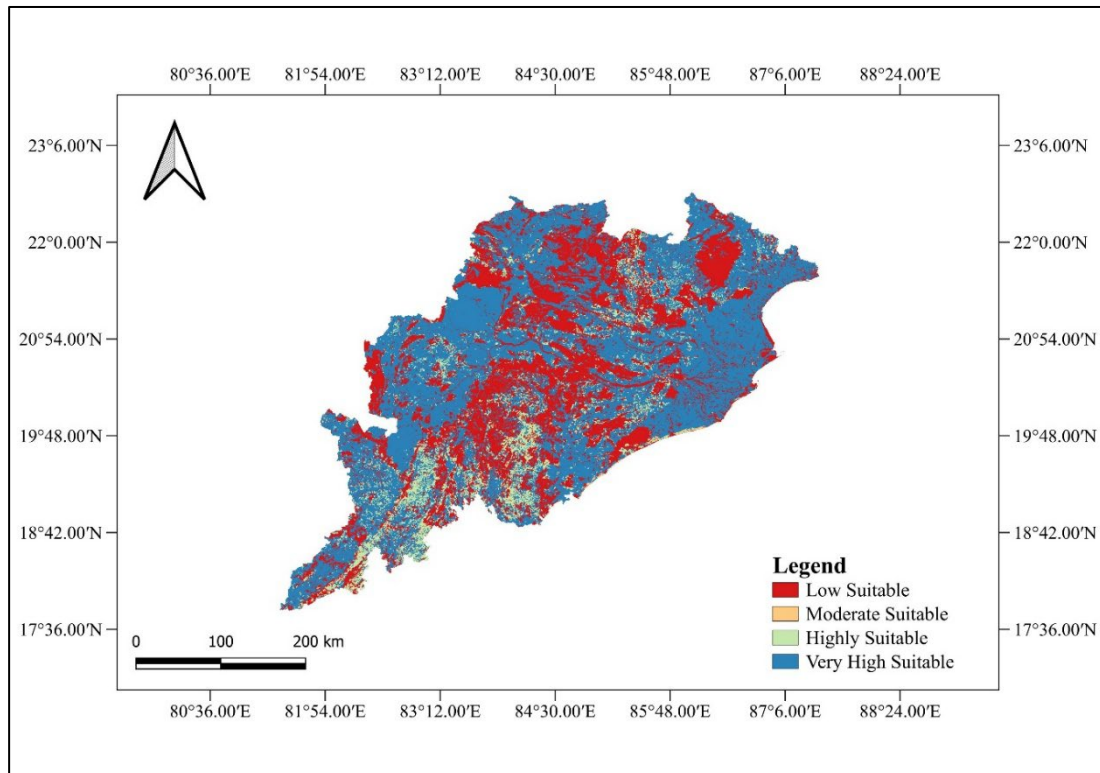


Figure 8. LULC-Based Suitability for MAR over the Study Area. (Source:)

Groundwater levels: The groundwater levels (Fig. 9) in Odisha vary significantly, with much of the state having a water table deep enough to be feasible for Managed Aquifer Recharge (MAR). The map shows the feasibility of recharge based on the depth of the groundwater table after the monsoon season. Feasible areas (blue): These regions, where the groundwater table is deeper than 3 meters post-monsoon, are spread across the central, southern, and western parts of the state. These deep-water levels mean there's sufficient space in the underground aquifer to store more water, making these areas highly suitable for recharge. Not Feasible areas (yellow): These areas, where the water table is shallower than 3 meters post-monsoon, are concentrated in the eastern coastal plains and north central. A shallow water table means the ground is already saturated with water, leaving little to no space for additional recharge.

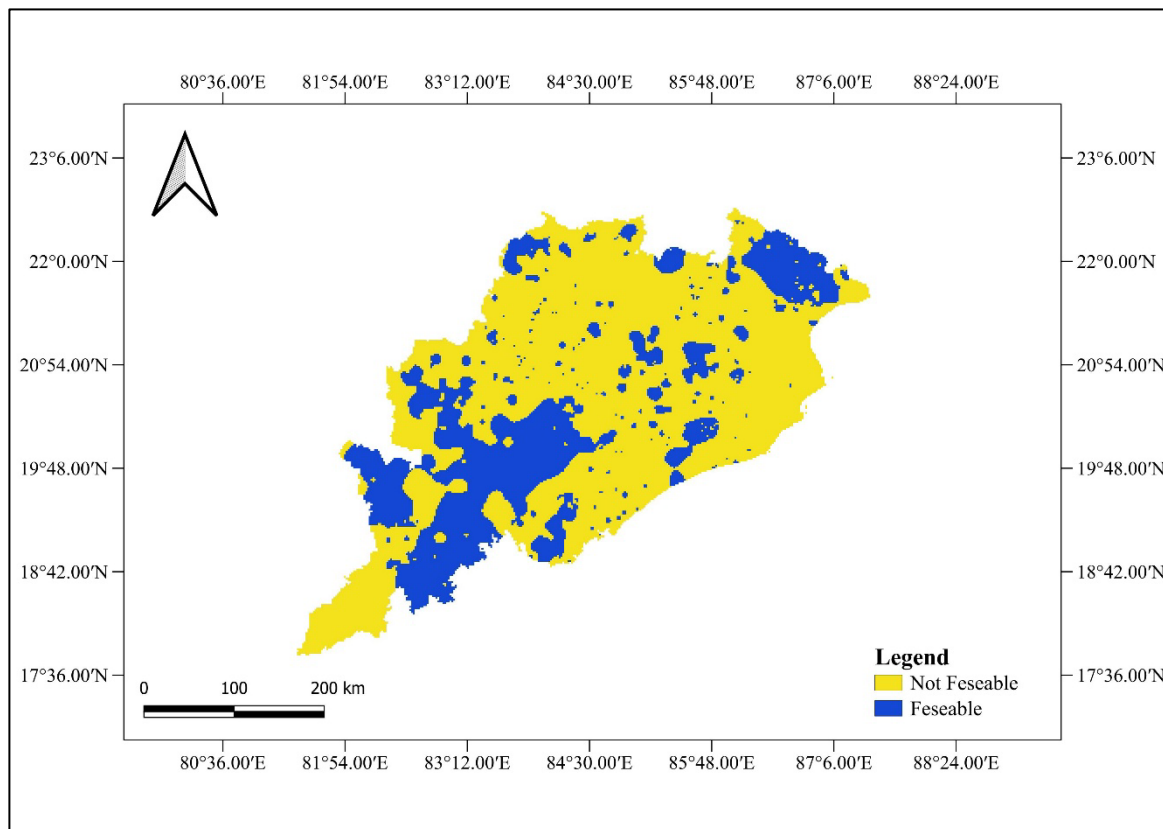


Figure 9. GWL-Based Suitability for MAR over the Study Area. (Source:)

Demand Suitability

Groundwater abstraction: The groundwater development stage (Fig. 10) in Odisha varies significantly across the state, indicating different levels of groundwater use and potential for new development. The map shows the level of groundwater utilization across Odisha.

Low to Moderate Groundwater Use (grey and green): These areas cover a large portion of the state, particularly in the western and southern regions. A low development stage signifies that groundwater extraction is well below the available resources, suggesting these areas have a surplus. These regions "present opportunities for strategic groundwater development.

High to Very High Groundwater Use (blue and brown): These areas are scattered across the state, with notable concentrations in the central and northern parts, as well as along the coast. A high development stage means that groundwater is being utilized at or near its maximum sustainable limit. These areas require focused attention for sustainable management including exploring opportunities to implement MAR.

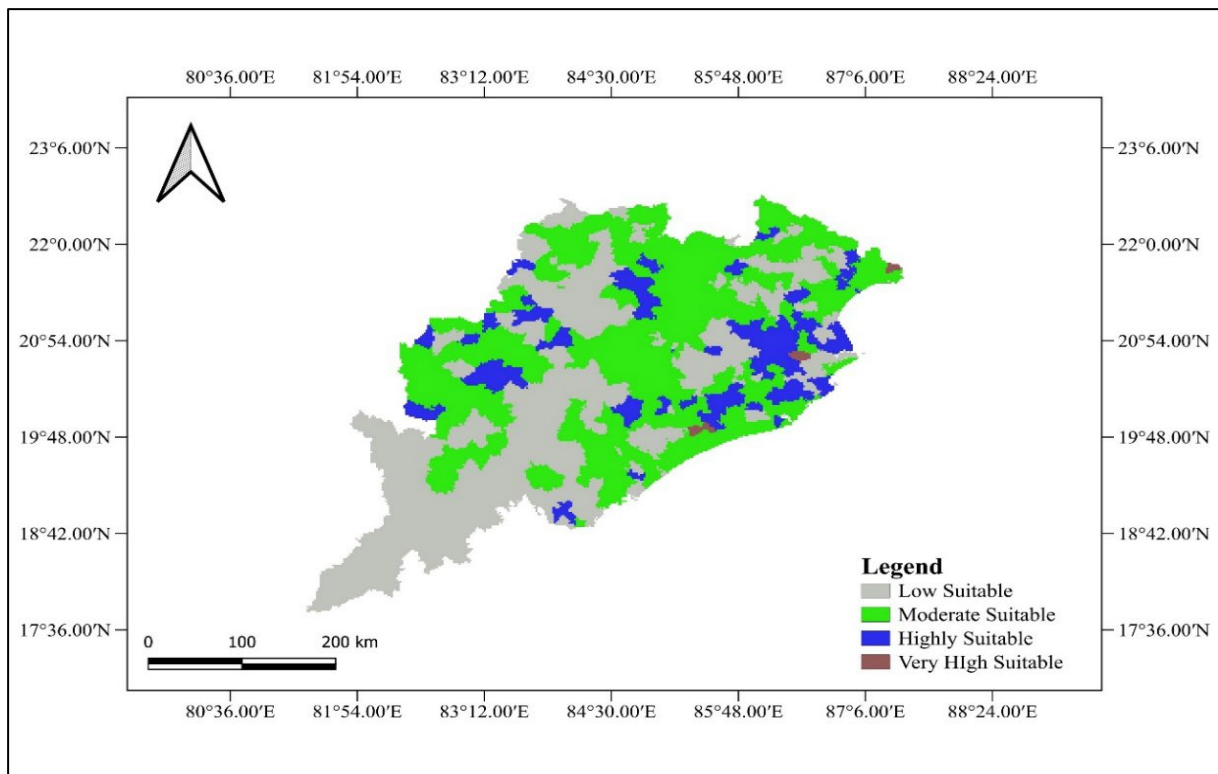


Figure 10. Groundwater Demand-Based Suitability for UTFI over the Study Area.

Supplemental Irrigation Requirement: Irrigation needs are determined based on the frequency of deficit rainfall years. The frequency of rainfall deficits varies throughout Odisha, as seen in Figure 11. The "High" to "Very High" rainfall deficit suitability classes include districts like Bolangir, Baragarh, Deogarh, and Jharsuguda. These districts frequently experience shortages that increase water stress and underscore the necessity of more intensive recharge initiatives. Districts in the "Low" suitability class, on the other hand, such as Baleshwar, Cuttack, and Dhenkanal, have comparatively lower irrigation because there are fewer deficit years in these areas.

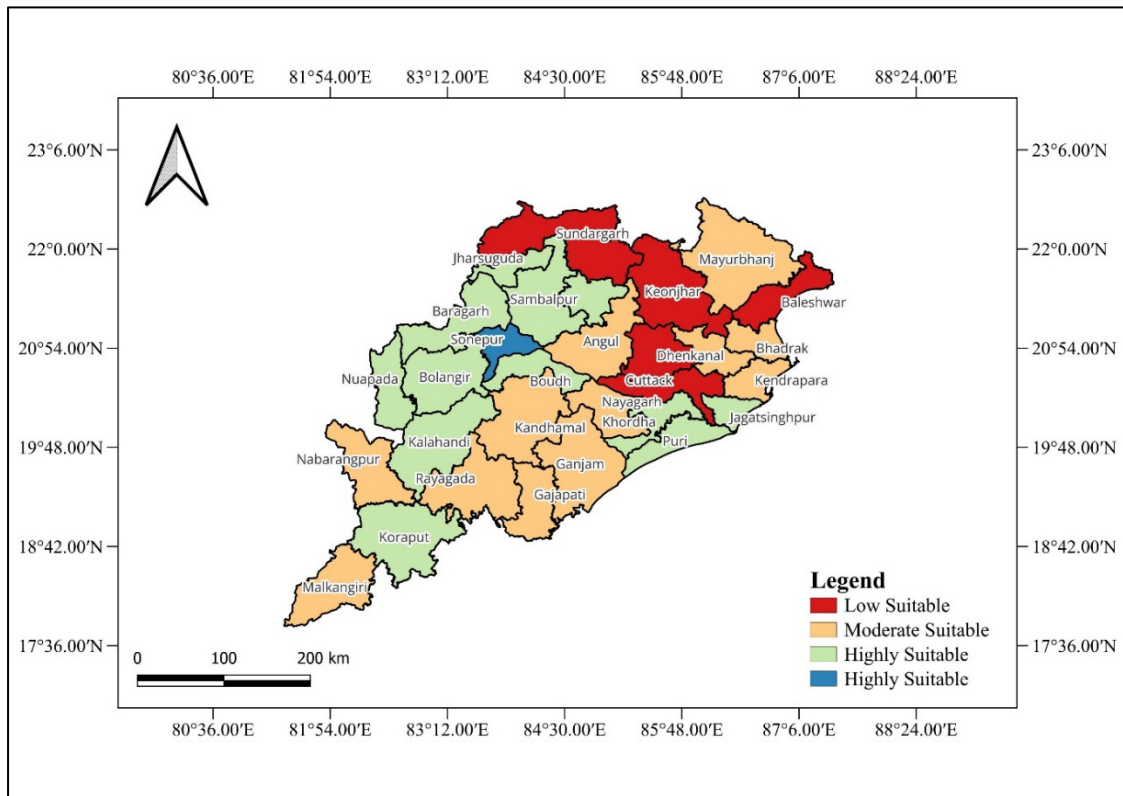


Figure 11. Deficit Rainfall-Based Suitability for UTFI over the Study Area.

MAR Suitability Map

Figure 12 gives the MAR suitability map based on the combination of supply, in-situ and demand suitability. MAR suitability (Figure 12) of Odisha varies significantly across the state. A substantial portion of the state, approximately 30%, is considered highly to very highly suitable for MAR, with the remaining 70% being moderate and low suitable. Figure 12 shows the spatial distribution across the state based on their suitability for MAR, categorized into four classes:

- **Low Suitability (Red):** The majority of Odisha, including extensive parts of Koraput, Malkangiri, Rayagada, Kandhamal, Ganjam, Gajapati, Sundargarh, Deogarh, Keonjhar, Mayurbhanj, Cuttack, and Khordha, falls under the low suitability zone. These areas are less favourable for recharge interventions.
- **Moderate Suitability (Orange):** Pockets within districts such as Kalahandi, Nabarangpur, parts of Kandhamal, and limited areas in Gajapati and Rayagada exhibit moderate suitability. These regions offer some recharge opportunities where slope and fractured rock formations provide localized infiltration potential.
- **Highly Suitable (Light Green):** Districts like Bargarh, Bolangir, Sonapur, Boudh, and parts of Angul, Nayagarh, and Sambalpur show highly suitable conditions for MAR. The combination of agricultural dominance, moderate slopes, and fractured aquifers enhances recharge prospects in these areas.

- **Very High Suitability (Dark Green):** Scattered patches within central and coastal Odisha, notably in Baleshwar, Bhadrak, Jajpur, Kendrapara, Jagatsinghpur, Puri, and parts of Cuttack and Nayagarh, fall in the very high suitability category. These zones benefit from favourable geology, groundwater levels, and rainfall, making them ideal for recharge interventions.

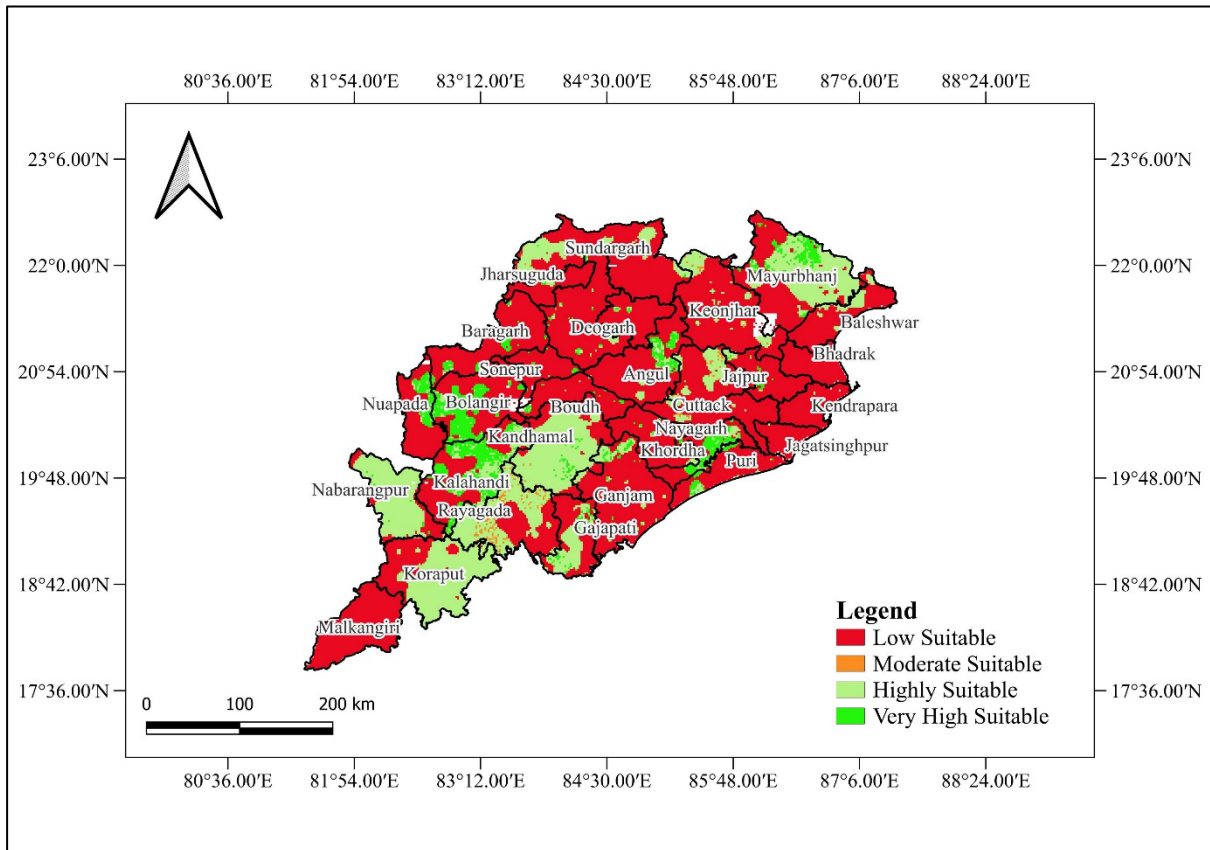


Figure 12. Managed Aquifer Recharge (MAR) Suitability Map for Odisha.

Overall, the map indicates that while the majority of Odisha remains in the low suitability category, however significant recharge potential exists in south-central and northern districts, where both natural and anthropogenic conditions favor MAR development. This spatial classification is useful for prioritizing districts for MAR interventions and groundwater sustainability planning to build resilience and adaptation to climate change.

The Managed Aquifer Recharge (MAR) appropriateness analysis at the district level (Table 3) shows notable regional variation throughout the state. The percentage values represent the share of each suitability class (Low, Moderate, High, Very High) with respect to the total geographical area of each district.

- **Districts dominated by Very High Suitability:** Several districts show a significant share of their area as very highly suitable for MAR. These include Bolangir (33.6%), Kalahandi (33.3%), Khordha (31.6%), Nuapada (17.0%), and Angul (10.4%). Such districts provide strong opportunities for large-scale MAR implementation owing to favourable aquifer conditions and groundwater response.

- **Districts with Predominantly High Suitability:** Some districts are dominated by high suitability zones, making them potential hotspots for recharge. Notable examples are Nabarangpur (80.5%), Koraput (68.5%), Kandhamal (71.9%), Rayagada (57.1%), Mayurbhanj (47.0%), and Gajapati (39.3%). These districts are particularly promising for medium- to large-scale MAR interventions.
- **Districts dominated by Moderate Suitability:** A few districts have a noticeable portion of their area classified under moderate suitability. Rayagada (7.8%), Dhenkanal (3.6%), and Cuttack (1.1%) are examples where moderate suitability zones exist, often interspersed with high or low suitability areas, indicating scope for localized recharge planning.
- **Districts with High Share of Low Suitability:** Many districts across Odisha are dominated by low suitability zones. These include Bhadrak (100%), Malkangiri (100%), Kendrapara (99.6%), Jagatsinghpur (99.5%), Cuttack (92.4%), Jajpur (88.3%), Keonjhar (87.9%), Puri (86.8%), Ganjam (89.3%), Sundargarh (80.0%), and Sambalpur (94.2%). In these regions, the scope for MAR development is relatively limited, and interventions would need to be carefully designed, localized, and small in scale.

Overall, the results indicate that while certain districts hold large tracts of highly and very highly suitable land for MAR development, others are constrained by geological and hydrogeological settings, showing predominance of low suitability areas. This district-level heterogeneity underscores the need for **region-specific recharge strategies** rather than a uniform approach across the state.

Table 3: District-wise distribution of area (%) under different MAR suitability classes in Odisha

District	Low suitable	Moderate suitable	Highly suitable	Very high suitable
Angul	82.01	0.00	7.64	10.36
Baleshwar	81.49	0.00	18.51	0.00
Baragarh	91.38	0.00	1.03	7.59
Bhadrak	100.00	0.00	0.00	0.00
Bolangir	62.98	0.00	3.38	33.64
Boudh	95.68	0.00	0.98	3.35
Cuttack	92.43	1.10	6.37	0.11
Deogarh	95.85	0.00	2.29	1.86
Dhenkanal	69.55	3.62	26.74	0.10
Gajapati	55.24	0.00	39.25	5.50
Ganjam	89.34	0.00	8.57	2.09
Jagatsinghpur	99.47	0.00	0.26	0.26
Jajpur	88.34	0.00	5.54	6.12
Jharsuguda	94.88	0.00	3.28	1.84
Kalahandi	44.26	0.11	22.37	33.26
Kandhamal	25.86	0.16	71.88	2.11
Kendrapara	99.64	0.00	0.36	0.00
Keonjhar	87.90	0.80	11.25	0.05
Khordha	58.63	0.00	9.80	31.58

Koraput	31.53	0.00	68.47	0.00
Malkangiri	100.00	0.00	0.00	0.00
Mayurbhanj	43.79	0.00	46.98	9.22
Nabarangpur	18.83	0.00	80.45	0.72
Nayagarh	93.80	0.00	4.78	1.41
Nuapada	79.30	0.00	3.73	16.97
Puri	86.75	0.00	4.29	8.96
Rayagada	34.55	7.84	57.14	0.46
Sambalpur	94.23	0.00	3.49	2.28
Sonepur	96.27	0.00	0.37	3.36
Sundargarh	80.03	0.18	19.61	0.18
Grand Total	69.67	0.57	23.23	6.53

Type of MAR Interventions

Based on the comprehensive evaluation of Odisha's hydrogeological, geological, land use, and topographical features, the following interventions for Managed Aquifer Recharge (MAR) are recommended (Table 4). These recommendations are tailored to the specific conditions of different regions within the state to ensure effective and sustainable groundwater management.

Table 4. Type of recommended MAR interventions for high, moderate and low suitability areas.

S. No	Suitability Category	Key Characteristics	Recommended MAR Interventions	Example Districts
1	High to Very High	Flat topography, alluvial soils, deep groundwater table.	Large check dams, recharge ponds, recharge wells/shafts, injection wells.	Baleshwar, Bhadrak, parts of Jajapur, Puri.
2	Moderate	Moderate slopes, fractured rock aquifers, climate-vulnerable.	Smaller check dams, percolation tanks, recharge trenches.	Koraput, Kandhamal, Mayurbhanj, and much of the central and western regions.

3	Low	Steep slopes, urban areas, impervious surfaces, shallow water table.	Rooftop rainwater harvesting, small recharge pits.	Urban centers and scattered pockets of the coastal plains.
---	-----	--	--	--

5. Conclusion and Way Forward

The MAR suitability assessment for Odisha highlights significant potential to enhance groundwater availability, reduce climate-induced water stress, and support expanded irrigation in vulnerable districts. By strategically prioritizing high-suitability zones, MAR investments can strengthen water security for smallholder farmers while reducing pressure on stressed aquifers. Going forward, integrating MAR into state irrigation planning, MGNREGS structures, and watershed programmes can accelerate large-scale implementation. Building a real-time monitoring system, coupled with community-led O&M, will be critical for ensuring long-term sustainability of groundwater resources. Finally, aligning MAR expansion with climate-resilient crop planning and renewable-energy-based irrigation offers a robust pathway for Odisha to build a resilient and productive agricultural future.

6. References

- Alam, M. F., Pavelic, P., Villholth, K. G., Sikka, A., & Pande, S. (2022). Impact of high-density managed aquifer recharge implementation on groundwater storage, food production and resilience: a case from Gujarat, India. *Journal of Hydrology: Regional Studies*, 44, 101224.
- Alam, M.F., Pavelic, P., 2020. Underground transfer of floods for irrigation (UTFI): exploring potential at the global scale (IWMI Research Report No. 176). Int. Water Manag. Inst. (IWMI), Colombo, Sri Lanka. <https://doi.org/10.5337/2020.204>.
- ASCE, 2001. Standard Guidelines for Artificial Recharge of Ground Water. ASCE, Reston.
- Baghel, S., Tripathi, M.P., Khalkho, D., Al-Ansari, N., Kumar, A., Elbeltagi, A., 2023. Delineation of suitable sites for groundwater recharge based on groundwater potential with RS, GIS, and AHP approach for Mand catchment of Mahanadi Basin. *Sci. Rep.* 13, 1–22. <https://doi.org/10.1038/s41598-023-36897-5>.
- CGWB, 2020. Master Plan for Artificial Recharge to Groundwater in India – 2020. Central Ground Water Board (CGWB), Department of Water Resources, RD & GR Ministry of Jal Shakti. Government of India,, Faridabad, India (Available at). <http://cgwb.gov.in/Master%20Plan%20to%20GW%20Recharge%202020.pdf> .
- Dillon, P., 2005. Future management of aquifer recharge. *Hydrogeol. J.* 13, 313–316.

Dillon, P., Pavelic, P., Page, D., Beringen, H., Ward, J., 2009. Managed Aquifer Recharge. In an Introduction Waterlines Report Series No. 13. National Water Commission, Canberra, Australia.

Dillon, P., Stuyfzand, P., Grischek, T., Lluria, M., Pyne, R.D.G., Jain, R.C., Bear, J., Schwarz, J., Wang, W., Fernandez, E., Stefan, C., Pettenati, M., van der Gun, J., Sprenger, C., Massmann, G., Scanlon, B.R., Xanke, J., Jokela, P., Zheng, Y., Rossetto, R., Shamrukh, M., Pavelic, P., Murray, E., Ross, A., Bonilla Valverde, J.P., Palma Nava, A., Ansems, N., Posavec, K., Ha, K., Martin, R., Sapiano, M., 2019. Sixty years of global progress in managed aquifer recharge. *Hydrogeol. J.* 27, 1–30. <https://doi.org/10.1007/s10040-018-1841-z>.

Gale, I. (2005). *Strategies for Managed Aquifer Recharge (MAR) in semi-arid areas*.

GoO (Government of Odisha). 2020a. Annual Report 2019-20. Bhubaneswar: Department of Water Resources, Government of Odisha.

GoO .2020b. Five Decades of Odisha Agriculture Statistics. Bhubaneswar: Directorate of Agriculture and Food Production, Odisha.

Hammouri, N., Al-Amoush, H., Al-Raggad, M., Harahsheh, S., 2014. Groundwater recharge zones mapping using GIS: a case study in Southern part of Jordan Valley, Jordan. *Arabian J. Geosci.* 7, 2815–2829.

Hani, H. M., El Din, M. M. N., Khalifa, A., & Elalfy, E. (2023). Development of suitability map for managed aquifer recharge: Case study, West Delta, Egypt. *AQUA—Water Infrastructure, Ecosystems and Society*, 72(6), 868-884. Ringleb, J., Sallwey, J., & Stefan, C. (2016). *Assessment of managed aquifer recharge through modeling—a review*. *Water* 8, 579.

Jain, R.C., 2012. Role of Decentralized Rainwater Harvesting and Artificial Recharge in Reversal of Groundwater Depletion in the Arid and Semi-arid Regions of Gujarat, India. IWMI-Tata Water Policy Research Highlight. International Water Management Institute. https://www.iwmi.cgiar.org/iwmi-tata/PDFs/2012_Highlight-49.pdf

Mahdavi, A., Tabatabaei, S.-H., Mahdavi, R., Nouri Emamzadei, M.R., 2013. Application of digital techniques to identify aquifer artificial recharge sites in GIS environment. *Int. J. Digit. Earth* 6, 589–609.

Mitra, A.; Alam, M. F.; Sikka, A.; Mahapatra, S. 2024. Facilitating agricultural growth in Odisha, India, through improved irrigation efficiency and access to water. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Initiative on National Policies and Strategies. 6p.

Pai, D.S., Latha, Sridhar, Rajeevan, M., Sreejith, O.P., Satbhai, N.S., Mukhopadhyay, B., 2014. Development of a new high spatial resolution (0.25° X 0.25°) Long period (1901-2010) daily gridded rainfall data set over India and its comparison with existing data sets over the region. *MAUSAM* 65, 1–18, 1(January 2014).

Palma Nava, A.; Parker, T.K.; Carmona Paredes, R.B. Challenges and Experiences of Managed Aquifer Recharge in the Mexico City Metropolitan Area. *Ground Water* 2022, 60, 675–684.

Patel, P.M., Saha, D., Shah, T., 2020. Sustainability of groundwater through community-driven distributed recharge: An analysis of arguments for water scarce regions of semi-arid India. *J. Hydrol.: Reg. Stud.* 29, 100680.

Rahman, M. A., Rusteberg, B., Uddin, M. S., Lutz, A., Saada, M. A., & Sauter, M. (2013). An integrated study of spatial multicriteria analysis and mathematical modelling for managed aquifer recharge site suitability mapping and site ranking at Northern Gaza coastal aquifer. *Journal of Environmental Management*, 124, 25-39.

Ringleb, J., Sallwey, J., & Stefan, C. (2016). *Assessment of managed aquifer recharge through modeling—a review. Water* 8, 579.

Sallwey, J., Bonilla Valverde, J.P., V´asquez L´opez, F., Junghanns, R., Stefan, C., 2019a. Suitability maps for managed aquifer recharge: a review of multi-criteria decision analysis studies. *Environ. Rev.* 27, 138–150.

Shah, T., Gulati, A., P, H., Shreedhar, G., & Jain, R. C. (2009). Secret of Gujarat's agrarian miracle after 2000. *Economic and Political Weekly*, 45-55.

Siddik, M.S., Tulip, S.S., Rahman, A., Islam, M.N., Haghghi, A.T., Mustafa, S.M.T., 2022. The impact of land use and land cover change on groundwater recharge in northwestern Bangladesh. *J. Environ. Manag.* 315, 115130.

Singh, A., Panda, S.N., Kumar, K.S., Sharma, C.S., 2013. Artificial groundwater recharge zones mapping using remote sensing and GIS: a case study in Indian Punjab. *Environ. Manag.* 52, 61–71.

Wang, W., Zhou, Y., Sun, X., Wang, W., 2014. Development of managed aquifer recharge in China. *Bol. Geol. Min.* 125, 227–233.

Zhang, H., Xu, Y., Kanyerere, T., 2020. A review of the managed aquifer recharge: historical development, current situation and perspectives. *Phys. Chem. Earth, Parts A/B/C.* 118–119, 102887.

Zheng, Y., Ross, A., Villholth, K.G., Dillon, P., 2021. Managing aquifer recharge: a showcase for resilience and sustainability. UNESCO/IAH/GRIPP 379. ISBN: 978-92-3-100488-9. <<https://unesdoc.unesco.org/ark:/48223/pf0000379962>> .



CGIAR is a global research partnership for a food-secure future. CGIAR science is dedicated to transforming food, land, and water systems in a climate crisis. Its research is carried out by 13 CGIAR Centres/Alliances in close collaboration with hundreds of partners, including national and regional research institutes, civil society organisations, academia, development organisations and the private sector. www.cgiar.org

To learn more about this program, please visit: <https://www.cgiar.org/cgiar-research-portfolio-2025-2030/climate-action/>

Contact

Giriraj Amarnath, Research Group Leader - Water Data for Climate Resilience (WDCR), and Principal Researcher – Disaster Risk Management and Climate Resilience, IWMI (a.giriraj@cgiar.org)



CGIAR

CLIMATE
ACTION

SUSTAINABLE
FARMING

DIGITAL
TRANSFORMATION

IWMI

International Water
Management Institute