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Groundwater Potential Zones in Goa: A GIS-Based Fuzzy Overlay Analysis

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Abstract:
This study utilizes Remote Sensing (RS), Geographic Information Systems (GIS), and Fuzzy Overlay Analysis to identify potential groundwater recharge sites in Goa, India. As population growth, rapid development, climate change, and inconsistent rainfall patterns continue to stress groundwater resources, efficient water resource management becomes essential. Groundwater serves as a critical resource for domestic, agricultural, and industrial needs. The study integrates RS and GIS technologies to assess groundwater potential zones (GWPZ), providing a spatial understanding of factors influencing groundwater recharge. Key parameters such as geomorphology, lithology, land use, rainfall, drainage density, and slope were analyzed using thematic layers within a GIS environment. The fuzzy overlay analysis allowed for a precise delineation of suitable groundwater recharge zones, with results indicating that northern Goa offers high recharge potential due to its favorable geomorphological and hydrogeological characteristics. This methodology presents a replicable approach for enhancing groundwater management and sustainability in regions facing similar water resource challenges.

Key Word: Remote Sensing, GIS, Groundwater Potential Zone, Fuzzy Overlay.

Introduction:

Groundwater is one of the most vital natural resources, serving as a key source of water for agriculture, domestic use, and industrial activities. In India, groundwater fulfills over 50% of urban water requirements and nearly 85% of rural demands, with irrigation consuming more than 90% of this precious resource. As a finite resource, the over-extraction of groundwater poses serious environmental challenges, including depletion of water tables, salinity intrusion, and degradation of water quality. Consequently, effective groundwater management and recharge strategies are essential to ensure long-term sustainability.

The state of Goa, located on the western coast of India, has experienced significant water stress due to rapid urbanization, population growth, and climatic variations. Goa's unique geomorphology, characterized by the Western Ghats in the east and coastal plains along the Arabian Sea, significantly influences groundwater availability. The diverse landscape presents both challenges and opportunities for identifying suitable groundwater recharge zones. Accurate delineation of these zones is crucial for improving groundwater management practices and ensuring sustainable water resources.

Remote Sensing (RS) and Geographic Information Systems (GIS) have emerged as powerful tools for groundwater exploration, providing spatial and temporal insights into the factors controlling groundwater recharge. By integrating RS and GIS, it is possible to identify and map groundwater potential zones (GWPZ) efficiently. Various thematic layers, such as geomorphology, lithology, land use/land cover, slope, drainage density, and rainfall, play critical roles in determining the suitability of an area for groundwater recharge. These spatial datasets, when analyzed within a GIS framework, offer a systematic approach to evaluating recharge potential, which is critical in regions where traditional field data may be limited.

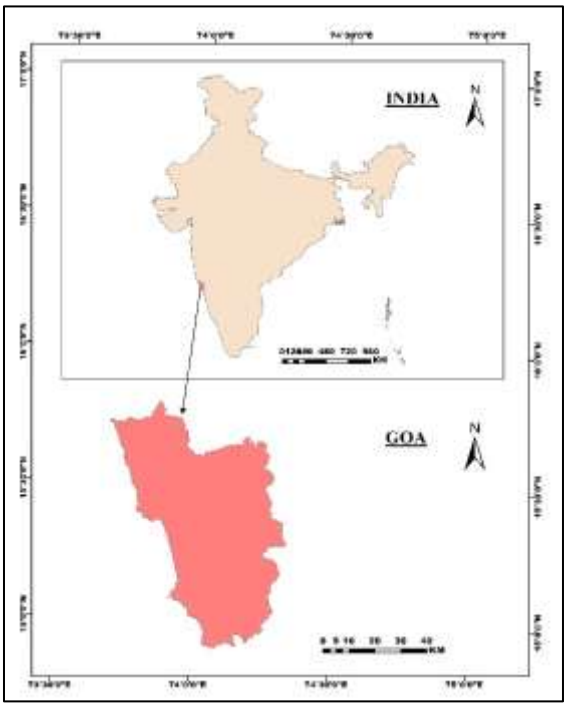
This study aims to delineate suitable sites for groundwater recharge in Goa using a combination of RS, GIS, and Fuzzy Overlay Analysis. The fuzzy overlay method provides a flexible approach to integrating multiple geospatial datasets, allowing for a more refined analysis of groundwater recharge potential. By focusing on critical hydrological and geological factors, the study identifies high and low groundwater potential zones across Goa, with the goal of informing water resource management strategies.

The significance of this study lies in its ability to provide decision-makers with spatially explicit information on groundwater recharge sites,

which is essential for planning sustainable groundwater use. Furthermore, the findings from this research can contribute to broader efforts in climate resilience and sustainable development, particularly in regions vulnerable to water scarcity. This research underscores the importance of using advanced geospatial technologies in natural resource management and presents a replicable methodology for regions facing similar groundwater challenges.

Study Area:

The study area is Goa state, which covers an area of 3,702 square kilometres. This is the smallest state of India by area and fourth in population. It is situated on the west cost of India, between the Arabian Sea and Western Ghat. It is near of Karnataka state to the east and south, Maharashtra to the north, and the Arabian Sea to the west. Goa extends between 140 degree 53minites 57second to 150 degree 47minites 59 second north latitudes, and 73 degree 40minites 35second to 74degree 20mitites 11second east longitudes. The Highest and lowest elevation is 1030 and 1 meter above MSL.



The state's geographical area is 3702 square kilometres and falls in the Survey of India toposheets Nos. 48E/13, 14, 15, and 16, 48I/2, 3,4,5, and 6, and 48J/1. Administratively, the state has divided into two district, north and south Goa with headquarters at Panaji and Madgaon respectly. The north geo district comprising six taluks has a total area of 1755.91sq.km mad south goa comprising six taluks covers an area of 1946.09aq.km. Total villages in the state is 272, out of which 213 are in north goa and remember in south Goa.

Data Acquisition:

Geology, Geomorphology, Lithology, soil, drainage density, land use land cover (LULC), lineament density, rainfall, elevation, topography wetness index were all analysis to established CPZs for the study area. The digital elevation model (DEM) was obtained from the United State geological Survey (USGS) of the Shuttle radar Topography mission (SRTM, 30m resolution) .The DEM was used to delineate the Goa state boundary, Elevation, slope drainage density using various spatial analysis tools in ArcGIS software.

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SN	Description	Source
1	Rainfall	Terraclimate,
2	SRTM-DEM	USGS Earth Explorer
3	LULC	ESRI Land Cover
4	Geology, lithology, geomorphology,	Bhukosh
5	Soil	Food and Agriculture Organization.

Methodology:

The current research demonstrated the use of different information sources for potential groundwater assessment in the Goa watershed. Groundwater recharge is the primary method by which water reaches an aquifer. The availability of groundwater from an aquifer at a specific location is based on the rates of withdrawal and recharge. Areas with high recharge rates indicate a high infiltration capacity of the soil and helping to

identify potentially good groundwater zones. estimated the annual groundwater storage based on fluctuations in water levels and specific yield approach. However, in the current study, the groundwater level data, the amount of groundwater data, and the groundwater quality data were limited due to the economic constraint and regional situation of the study area. Therefore, in this study, an estimation of the values in regions without incorporating the recharge and groundwater head data (i.e., pumping well tests) was carried out using an MCDM model based on hydrogeological factors.

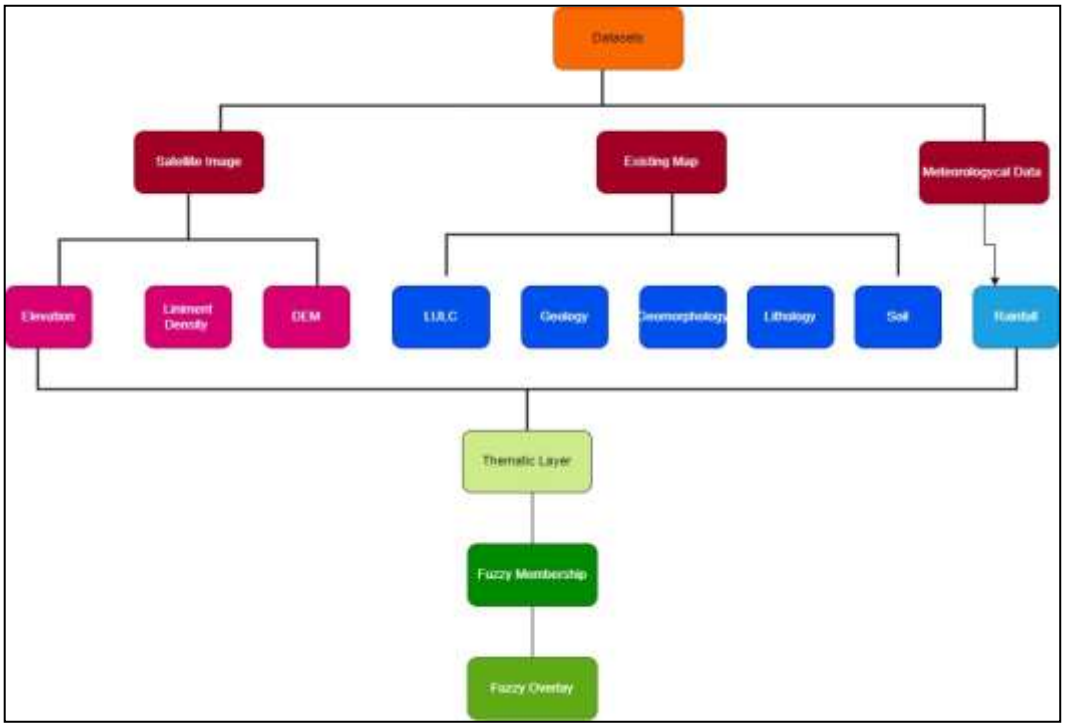

Figure 1 Flowchart of Research Methodology

Geology, Geomorphology, Lithology, Rainfall, Land use land cover, Soil type, Lineament Density, Dem, Topographic Wetness Index (TWI), Drainage density All these themes were generated using remote sensing (RS) and conventional data, with the help of ArcGIS (ESRI) software The dataset was geometrically rectified to a common projection (Universal Transverse Mercator and datum WGS84) based on the topographical base map and global positioning system points.

Result and Discussion:

Factors Influencing Groundwater Potential Zones:

The parameter mostly influencing the delineation of suitable sites for groundwater recharge based of potential zones are as discussed below.

1. Geomorphology

Geomorphology is the study of the physical features of the structure of earth and their relation to is its geological structures. It controls the subsurface movement of groundwater.

- In Goa State Western Ghats covered in 40 to 50% area. This region is Characterized by rugged terrain, steep slopes, and high elevations.
- Coastal plains and Beaches estimate in 30 to 40 % area. This part of Goa consist of costal plains along the Arabian Sea, flat terrain. Costal landforms include sandy beaches, estuaries, and mangrove ecosystems.
- River valley estimate 15-20% of Goa. This area interested by several rivers, including the Mandovi, Zuari, and Chapora, Contributing to river valleys, floodplains, and estuaries.
- ateritic Plateaus estimate 10-15% areas of Goa often feature lateritic plateaus formed by the weathering of underlying rocks, Laterite, a characteristics red or orange soil type, is associated with these plateaus.

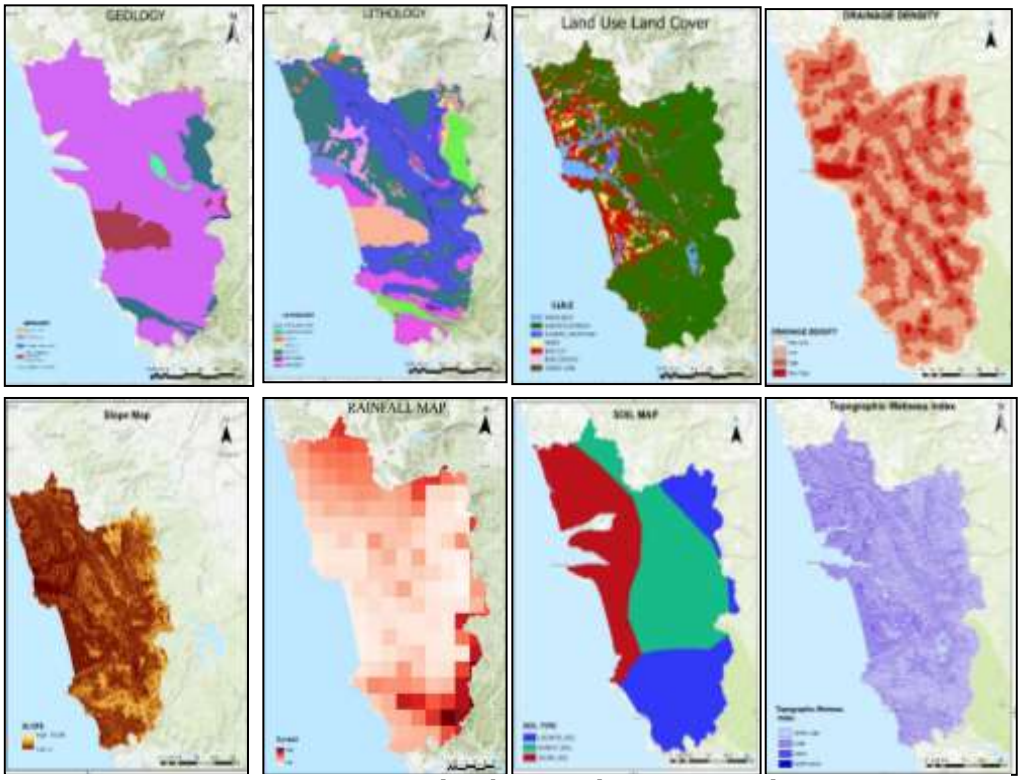

Figure 2 Parameters used in the ground water potential zones

2. Lineament Density

- A lineament is a linear feature in a landscape which is an expression of an underlying geological structure such as a fault, fracture, and joint. They provide pathways for groundwater movement and have water holding capacity. The presence of lineaments in an area result in increased secondary porosity and therefore serves as groundwater potential zone.

3. Land Use Land Cover:

Land use land cover plays a significant role in the development of groundwater resources. The nature of land surface and its pattern control infiltration and runoff. The regional relief setting along with land use land cover gives an idea about general direction of groundwater flow and its influence on groundwater recharge and discharge. The goa state has been blessed with favourable soil and climatic condition that favour growth of a variety of tropical crops. Agriculture is one of the important occupations that of the people of Goa.

The total geographical area of Goa state is 3,70,200 Ha according to Survey of India and the same according to Land survey Department is 3,61,113 Ha. The area under forest is 34.75 % while net sown area is 37.27 %. About 10.29 % of land is not available for cultivation. The area sown more than once is nearly 8.68 %.

4. Lithology:

The lithology of goa is characterized by a diverse range of rock formation, reflecting its geological history and the interplay of various geological processes. The state exhibits a variety of lithology unit, including ancient Precambrian rocks, sedimentary formations, and laterite soils.

- **Limestone and Dolomite:** Goa has considerable resources of limestone and dolomite. These sedimentary rocks are economically significant and find usage in industries such as cement manufacture.
- **Sediment Deposit:** Goa's coastal plains are underlain with sedimentary layers, including alluvium. These deposits were brought in by the state's rivers, such as the Mandovi and Zuari, and they help to fertilise the coastal soils.
- **Precambrian Rocks:** The Easern part of Goa, especially in the region influenced by the western ghat is dominated by Precambrian rocks. These rocks include granite, gneiss, and schist, and other metamorphic formation.
- **Iron Ore Formation:** One of the most economically significant lithological features in Goa is the presence of iron ore formations. The iron ore deposits mainly consist of certain types of vegetation.

5. Drainage density

Drainage density indicates the total length of all streams and rivers in a drainage basin divided by the total area of the drainage basin. It indicates the permeability and porosity of the terrain and therefore is an important factor in groundwater evaluation. More the drainage density, higher would be runoff. Thus, the drainage density characterized the runoff in the area or in other world, the quantum rainwater is the probability or recharge or potential groundwater zone.

6. Rainfall

The Goa state has a tropical-maritime monsoonal type climate with distinct aerographic influence. The months of January and February are dry with clear sky and generally pleasant. May is the hottest month with temperature around 30 °C and January is the coldest month with temperature 25 °C.

Rain occurred during the monsoon season from June to September. Over 90 percent of annual rainfall occurred during monsoon period. The analysis of rainfall is in the order from 12 stations over the Goa state indicates that the monsoon rainfall is in the order of 3460 mm, 218.1mmduring the post monsoon rainfall period of October to December and 102.5mm are from January to May months. The overall annual rainfall over the Goa state based on 30 years rainfall data is 3483.3 mm.

7. Slope:

The slope of a terrain refers to the incline or stepless of the land surface. In Goa the slope varies across the state due to its diverse topography, which ranges from costal plain to mountainous regions. The eastern part of Goa is characterized the Western ghats, a mountain range known for its steep slopes and ragged terrain. The Western Ghat influence the rainfall pattern and contribute to the states overall topographic diversity.

- The Western part of Goa consist of costal plains along the Arabian Sea. These plains often have gentler slopes than the hilly regions in the east.
- In Goa the highest point is the Sorsogon peak, also known as the Sonsohodd, which stands at an elevation of approximately 1163 meter (3829 feet) above sea level. This peak is situated in the Sattari taluka of Goa.

8. Geology

Geology determines the soil and exposed rocks infiltration capabilities and govern the flow and storage of water. Lithology characterized by massive rock along with topography influences the groundwater availability.

- **Archean and Precambrian Rocks:** The Eastern part of goa**,** particularly in the region influenced by the Western ghat is characterized by ancient Archan and Precambrian rocks. These rocks include granite gneiss, schist and other metamorphic formation.
- **Banded Iron formation:** Goa is renowned for its iron ore deposits Which are primarily founded in the form of banded Iron Formations.
- **Quaternary Deposits:** In Goa some coastal areas, there are Quaternary Deposits, including sand and shell formations.

9. Soil Type

The transmission of surface water into an aquifer system is a function of soil type, texture, permeability, and structure. The infiltration capacity of soil helps the rainwater to enter soil. Soil with high rate of infiltration act as a good groundwater recharge medium. Sand and gravel allow maximum infiltration whereas in clay or fine-grained soils infiltration is less which causes surface runoff.

- Soil of the Goa state can be grouped into 5 classes- Lateritic Soils, Saline Soils, Alluvial Soils, Marshy Soils and Sandy Soils.

10. Topographic Wetness Index

The Topographic Wetness Index is a terrain analysis tool to access the potential wetness or moisture content of a landscape based on its topography. It is calculated by considering the upslope contributing area and 6the slope of the terrain.

Fuzzy Overlay Analysis

Fuzzy Overlay Analysis was used to integrate the thematic layers and assess the groundwater potential. Each thematic layer was assigned a membership function using fuzzy logic based on its relative importance in contributing to groundwater recharge. This method allows for better handling of uncertainty and the spatial variability inherent in geospatial datasets.

Fuzzy Membership Functions: Each parameter was assigned a fuzzy membership score ranging from 0 to 1, indicating its potential contribution to groundwater recharge. For instance, high slope areas received lower scores, while areas with high rainfall and lower drainage density received higher scores.

Weight Assignment: The relative weights of the thematic layers were determined using expert judgment and literature review. For example, geomorphology and lithology were given higher weights due to their significant impact on groundwater recharge.

Overlay Process: The fuzzy layers were overlaid using the fuzzy gamma operator, which balances the trade-off between increasing certainty and handling variation in the datasets. This process results in a continuous groundwater potential map, highlighting areas with varying degrees of recharge potential.

Delineation of suitable sites for groundwater potential zones.

The suitable sites of groundwater potential zones for the Goa state ware delineated by using Fuzzy overlay analysis of various thematic maps using remote sensing and GIS methods. According to the fuzz overlay Analysis, groundwater potential zones of this state are classified into two zones. The areas with low potential zones are mainly concentrated in to the east And northwestern of the area. Due to their high elevation slope, there are don’t have water holding capacities. North side is high potential area for groundwater recharge.

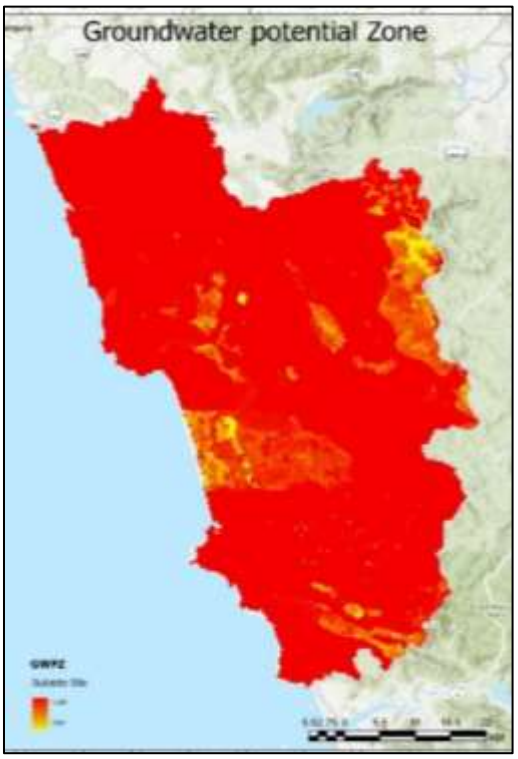

Figure 3 Groundwater Potential Zones of Goa

Development of management plan for high and low delineation of suitable sites for groundwater potential zones:

The high groundwater potential zone implies that the availability or bearing capacity of groundwater high in the area. And the management plan is needed for the low and low to medium potential zone for the development or recharging of groundwater. The type of structures to be constructed for groundwater management was selected based on the GPZs map, depth to water level map, and topography of the study area.

Appropriate locations for artificial recharge structures:

The artificial recharge structures ware suggested based on the topography, land use land cover class, slope, aspect, and soil type. In the present study, the artificial recharge structures have been proposed based on the reformations of the Indian national Committee on Hydrology (INCOH).

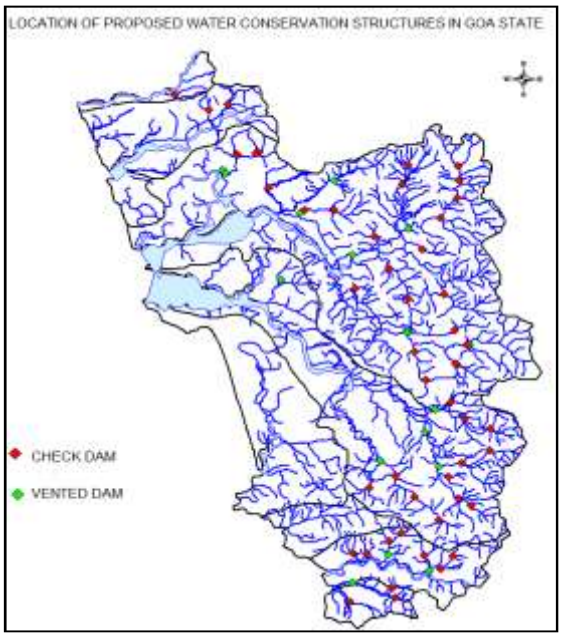

Figure 4 Appropriate locations for artificial recharge structures:

Conclusion:

This study successfully delineated suitable sites for groundwater recharge in the state of Goa by integrating Remote Sensing (RS), Geographic Information Systems (GIS), and Fuzzy Overlay Analysis. The research highlights the importance of considering various geospatial factors, such as geomorphology, lithology, slope, land use/land cover, rainfall, and drainage density, to accurately assess groundwater potential zones (GWPZ). By employing fuzzy logic, the study allowed for the handling of uncertainties and provided a more nuanced assessment of groundwater recharge potential across diverse landscapes.

The findings identified that northern and southeastern regions of Goa, with their favorable geomorphological conditions and moderate slope gradients, have the highest potential for groundwater recharge. Conversely, areas with steep slopes in the Western Ghats exhibit lower recharge potential due to higher runoff. This comprehensive spatial analysis provides valuable insights for water resource management in Goa, particularly in mitigating groundwater depletion and ensuring sustainable water supply for agricultural, domestic, and industrial purposes.

The research underscores the critical role of GIS and RS technologies in natural resource management, offering a replicable methodology for other regions facing similar groundwater challenges. The study's recommendations for artificial recharge structures, such as check dams and farm ponds, provide practical solutions for enhancing groundwater storage. Overall, this work contributes to the broader efforts of climate resilience and sustainable water resource management, with implications for both policy-making and on-the-ground applications in regions prone to water stress.

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