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Project Name: Ground Water Potential Zone Mapping

Study Area: Kakinada District

Abstract:

This study aims to identify and map the groundwater potential zones in Kakinada District, Andhra Pradesh, India, using GIS and remote sensing techniques. The district is situated in the Eastern Ghats with the Bay of Bengal to the east. Various thematic parameters and layers such as geology, soil type, land use, drainage density, slope, rainfall, and lineament density were utilized. High-resolution satellite imagery and topographic sheets were adopted for enhanced accuracy and spatial resolution.

Water is a crucial resource that can significantly impact socio-economic conditions. A country with a robust economy but scarce water resources can face more complications than a country with an average economy and sufficient water availability. Several thematic maps and parameters were assigned weights based on their influence on groundwater potential. The Weighted Overlay Analysis technique was used to normalize the ranks for these thematic maps. The Analytical Hierarchical Process (AHP) was employed to determine the areas with high groundwater potential.

The district was classified into five classes of groundwater potential zones: poor, fair, moderate, good, and extreme. The narrow belt along the periphery of Kakinada District (excluding the coastline) was identified as having high groundwater potential. The entire district is predominantly blessed with moderate groundwater potential, with fair zones in some eastern and western areas. The process was validated with a consistency ratio of 10%, which is acceptable as it is greater than the required threshold (0.1 for large matrices). These results can aid in sustainable groundwater management and planning by implementing necessary arrangements and strategies for the future.

1. Introduction

1.1. Background

Groundwater is a crucial resource for drinking, irrigation, industrial purposes, and many other applications. The increasing demand and over-extraction of groundwater necessitate the identification of potential zones for sustainable management and development.

1.2. Importance of Groundwater Potential Zone Mapping

Mapping groundwater potential zones helps in effective water resource management, preventing over-extraction, allocating water for various applications, and ensuring the availability of groundwater for future use and development.

1.3. Objectives of the Study

- To identify and map the groundwater potential zones in the Kakinada District region.
- To use GIS and remote sensing techniques for integrating various thematic layers.
- To validate the identified groundwater potential zones with ground truth data.
- To identify areas with low groundwater potential and take necessary actions to replenish them.
- To support water-based projects aimed at maintaining sustainable development.

2. Study Area

2.1. Location and Extent

The study area is located in Kakinada District, Andhra Pradesh, covering an area of approximately 3,019.8 sq km. It is situated between latitudes 16.8265083°N to 16.8291531°N and longitudes 81.7680493°E to 82.6077878°E.

2.2. Climate and Hydrology

The region experiences a tropical climate with an average annual rainfall of 110–115 centimeters (43–45 inches). The main rivers in the area are the Godavari and Pushkara. Additionally, the Yeleru, Thandava, and Pampa river channels supply water to a limited area in the district, significantly influencing the hydrology.

2.2. *Geology and Soil Characteristics*

Geology:

- **Quaternary Sediment**: Comprising unconsolidated materials such as sand, gravel, and silt, these sediments are highly permeable and contribute significantly to groundwater recharge.
- **Water Regions (Aquifers)**: These areas consist of highly permeable geological formations that store and transmit groundwater, making them crucial for water supply.
- **Undivided Quaternary Sedimentary Rock**: These formations include a mix of sediments deposited during the Quaternary period, exhibiting moderate permeability and contributing to groundwater potential.
- **Neogene Sedimentary Rock**: Formed during the Neogene period, these rocks have moderate permeability and porosity, influencing groundwater recharge in the region.

The northern part of the district is dominated by undivided Precambrian rock, the southern part by Quaternary sediments, the west side by Neogene sedimentary rock, and the east side by aquifers.

Soil: In Kakinada District, predominant soil types include sandy clay loam, clay loam, sandy loam, and clay. The majority of the region is dominated by sandy clay soils, which provide moderate infiltration and water retention. The eastern part of the district is dominated by clay loams and sandy loam, which have varying degrees of permeability and influence on groundwater recharge.

2.4. Land Use and Land Cover

The majority of the district is dominated by vegetation and agricultural fields, which play a crucial role in groundwater recharge due to their high infiltration capacity. The northern part of the district is mostly covered by mountains and hills, contributing to the diverse topography and influencing water flow patterns. The rest of the district is dominated by barren lands, with some agricultural fields being replaced by barren lands and open areas. Additionally, the southernmost part of the district features aquaculture activities, which can impact local groundwater dynamics.

3. Data and Methodology

3.1. Data Collection

3.1.1. Satellite Imagery

Sentinel-2 imagery with a spatial resolution of 10m dated April 24, 2024, was used to derive land use/land cover, drainage density, slope maps, and lineament maps.

3.1.2. Digital Elevation Model (DEM)

A Digital Elevation Model from SRTM with a spatial resolution of 30m was utilized to derive slope, flow direction, flow accumulation, and drainage network.

3.1.3. Topographic Maps

Topographic maps (Toposheets) from the Survey of India at a scale of 1:50,000 were used to generate the drainage and slope maps. The Toposheet numbers used include 65K3, 65K4, 65K6, 65K8, 65K10, 65K11, 65L1, 65L2, 65G15, and 65G16.

3.1.3. Geological, Soil, and Hydrological Data

The rainfall data was collected from the CHRS Data Portal, providing a weighted average of the rainfall over the past 18 years. The geological data was sourced from the USGS (United States Geological Survey), ensuring accurate geological mapping and analysis. Soil data was obtained from the FAO website, providing detailed information on soil types and characteristics across the study area.

3.2. Data Processing

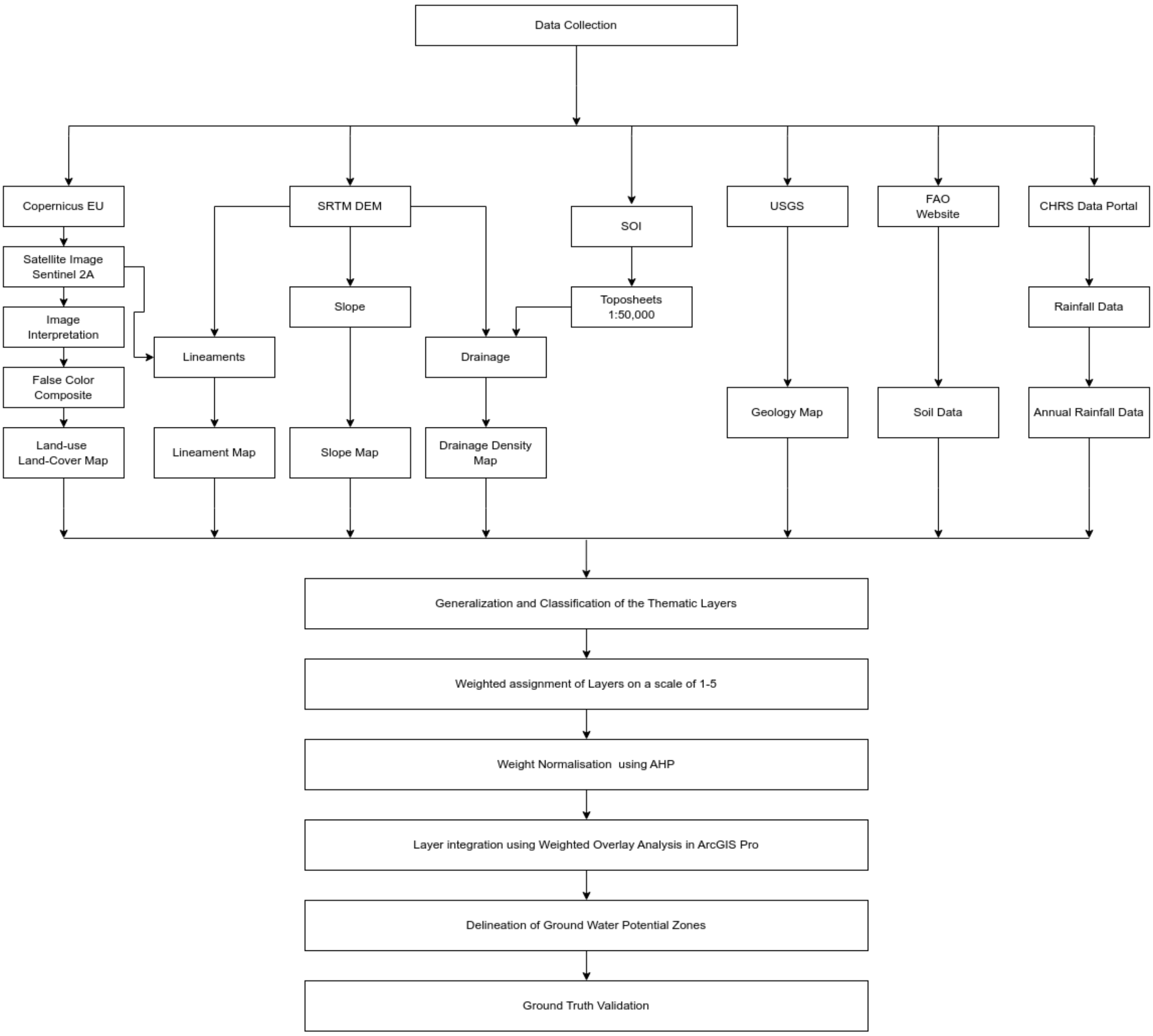
3.2.1. Image Preprocessing

Satellite images were pre-processed using atmospheric correction and radiometric normalization techniques sourced from the official Copernicus website. False-color composite imagery was prepared for T44QNE, T44QND, T44QPD, T44QPE, and clipped to align with the shapefile of Kakinada District.

3.2.2. Thematic Layer Generation

Various thematic maps, such as drainage density, lineament density, and slope maps, were generated from SRTM DEM with a resolution of 30m using ArcGIS Pro software. The soil and geology data collected from FAO and USGS were processed in ArcGIS Pro. The land use/land cover thematic map was generated from a mosaic of four Sentinel-2A images.

3.3. Methodology

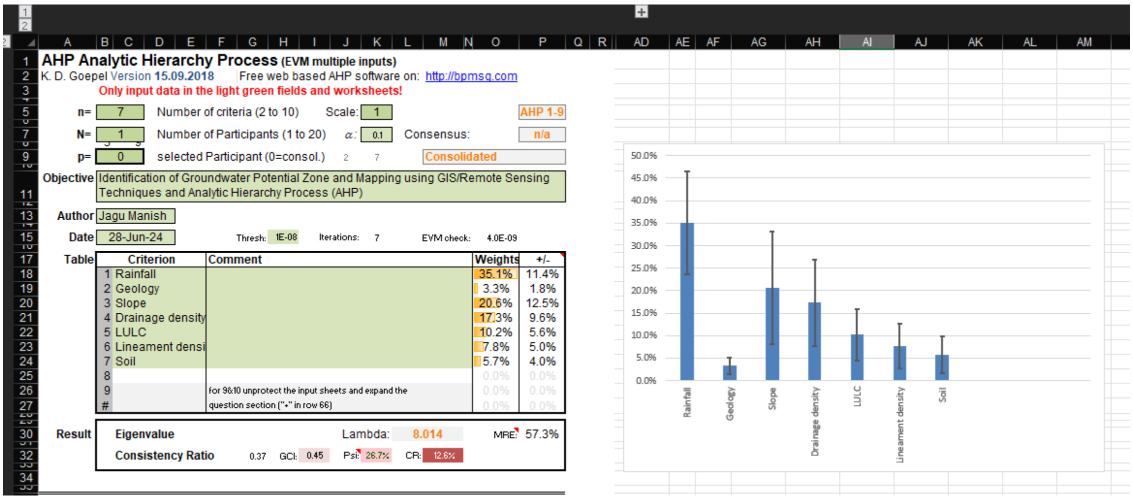


3.3.1. GIS and Remote Sensing Techniques

Multiple datasets from Copernicus, USGS and FAO were collected and integrated into GIS to generate new maps such as lineament, drainage density, and slope maps derived from DEM. Remote sensing imagery provides a wide range of spatial data, enabling high-quality research. Sentinel-2A satellite images are among the most commonly used remote sensing data due to their high resolution and extensive coverage.

3.3.2. Weightage Assignment for Different Parameters

The Analytical Hierarchical Process (AHP) was used to compare and assign various rankings to different parameters. AHP is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. It involves decomposing a decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. The elements of the hierarchy are then systematically evaluated using pairwise comparisons to assign weights. These weights reflect the relative importance of each parameter in influencing groundwater potential. The consistency of the comparisons is checked through a consistency ratio, ensuring the reliability of the assigned weights.



n	Criteria	Comment	RGMM	+/-
1	Rainfall		35.0%	11.1%
2	Geology		3.5%	2.1%
3	Slope		20.6%	10.4%
4	Drainage density		17.4%	8.8%
5	LULC		10.1%	4.8%
6	Lineament density		7.8%	4.4%
7	Soil		5.7%	3.0%
8				
9		for 9&10 unprotect the input sheets and expand the		
10		question section ("+" in row 66)		

Participant 1	1		α:	0.1	CR:	10%
Name	Weight	Date			Consistency Ratio	

i	j	Criteria A	B	more important? A or B	Scale (1-9)
1	2	Rainfall	Geology	A	7
1	3		Slope	A	3
1	4		Drainage density	A	3
1	5		LULC	A	3
1	6		Lineament density	A	5
1	7		Soil	A	7
1	8				
2	3	Geology	Slope	B	3
2	4		Drainage density	B	5
2	5		LULC	B	2
2	6		Lineament density	B	5
2	7		Soil	B	5
2	8				
3	4	Slope	Drainage density	A	3
3	5		LULC	A	3
3	6		Lineament density	A	3
3	7		Soil	A	3
3	8				
4	5	Drainage density	LULC	A	3
4	6		Lineament density	A	5
4	7		Soil	A	3
4	8				
5	6	LULC	Lineament density	A	3
5	7		Soil	A	3
5	8				
6	7	Lineament density	Soil	A	3
6	8				
7	8				

3.3.3. Integration of Thematic Layers

The integration of different thematic layers involves combining datasets such as geological formations, soil types, land use/land cover, rainfall patterns, and topographical features into a unified spatial framework. This process allows for the synthesis of complex environmental variables that collectively influence groundwater potential. By overlaying and analyzing these layers in GIS, spatial relationships and interactions are identified, providing insights into the distribution and variability of groundwater recharge zones. The resultant groundwater potential zone map delineates areas with varying levels of recharge capacity, guiding sustainable management practices and resource allocation strategies.

3.3.4. Ground Truth Verification

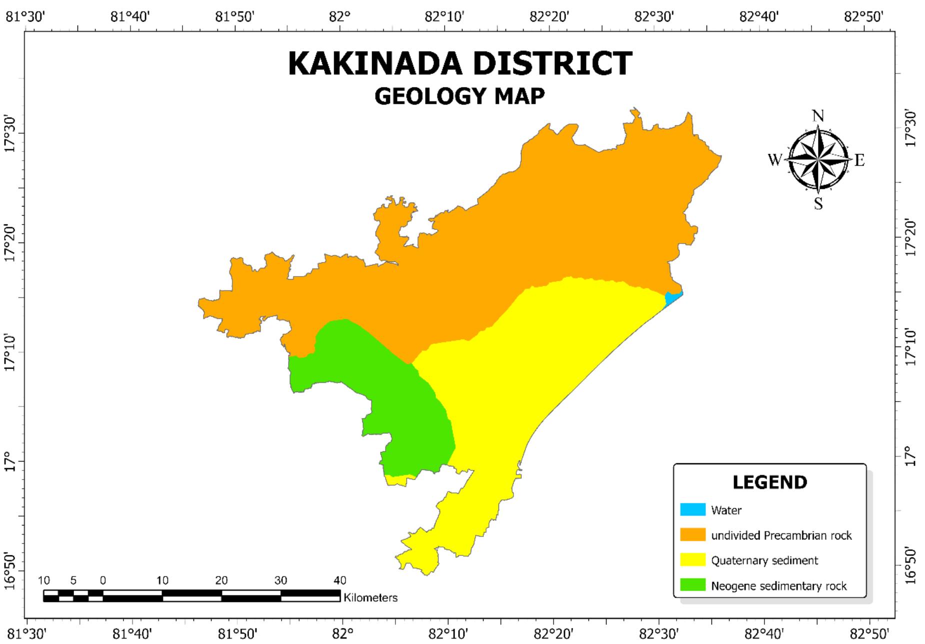
To validate the accuracy of the groundwater potential zone map, ground truth verification was conducted. Soil and geological samples were collected at selected stations across the study area. These samples were analyzed to verify the characteristics and properties identified through remote sensing and GIS analysis. By comparing field observations with mapped data, the reliability and consistency of the thematic layers and their integration were assessed. This verification process ensures the robustness of the spatial analysis and enhances confidence in the identified groundwater potential zones for effective resource management and planning

4. Thematic Layers and Their Influence on Groundwater Potential

4.1. Geology

The geological composition plays a crucial role in groundwater potential. Quaternary sediment and aquifer regions in the study area exhibit higher groundwater potential due to their permeability and water-holding capacities influenced by fractures and weathering. Therefore, Quaternary sediment regions are rated 4 out of 5. Neogene sedimentary rocks, with moderate permeability and porosity, are rated 3 out of 5. Undivided Precambrian rocks, characterized by poor permeability and porosity, receive a rating of 1 out of 5 due to their limited ability to store and transmit water.

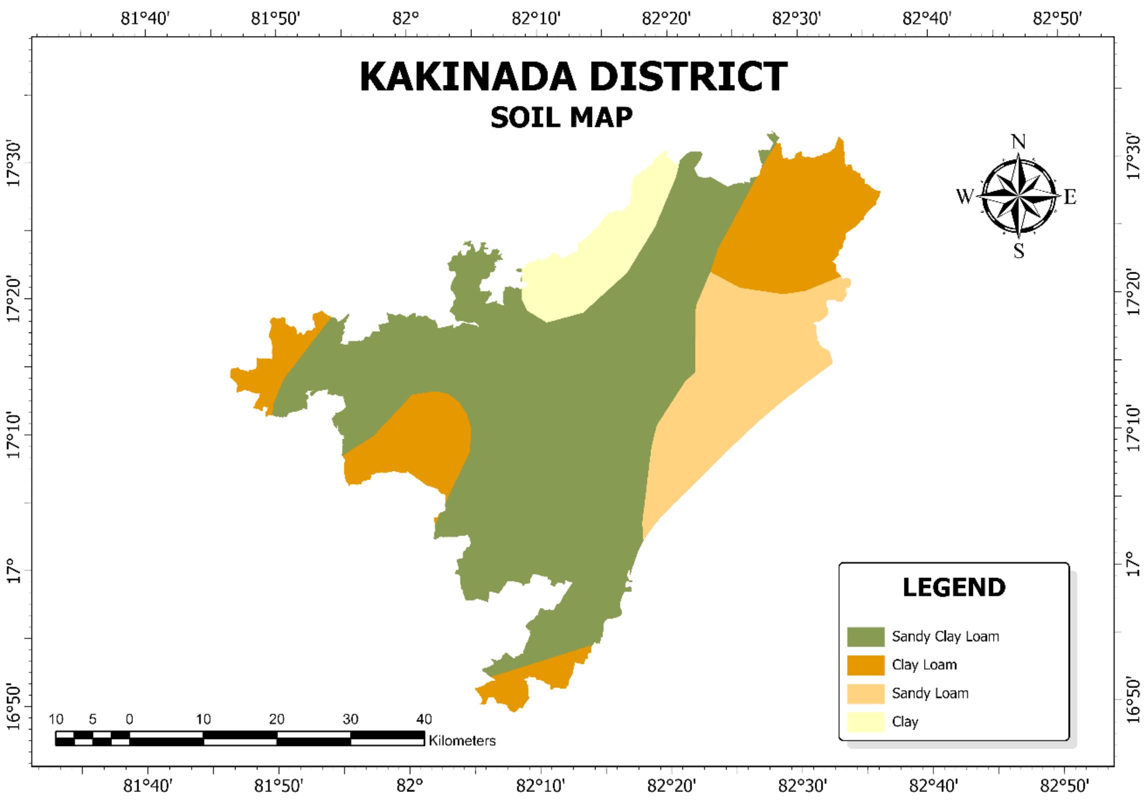
- **Quaternary Sediment (4/5)**: Quaternary sedimentary formations, consisting of unconsolidated materials like sand, gravel, and silt, exhibit good permeability and porosity, facilitating significant groundwater storage and recharge.
- **Water (Aquifers) (5/5)**: Aquifers represent the most favorable geological formations for groundwater storage and extraction. These formations, characterized by high permeability and considerable water retention capacity, are critical for sustainable groundwater supply.
- **Neogene Sedimentary Rock (3/5)**: These sedimentary rocks formed during the Neogene period generally exhibit moderate permeability and porosity. While they contribute to groundwater recharge, their effectiveness varies based on lithological variations and structure.
- **Undivided Precambrian Rock (1/5)**: Precambrian rocks, typically comprising igneous and metamorphic formations, have very low permeability and porosity. They are generally unsuitable for significant groundwater storage or recharge.



4.2. Soil

Soil composition significantly affects groundwater potential by influencing infiltration rates and water retention capacities. In Kakinada District, predominant soil types include sandy clay loam, clay loam, sandy loam, and clay. Sandy loam, characterized by its high permeability and good water-holding capacity, receives a rating of 4 out of 5 for its positive impact on groundwater recharge. Sandy clay loam, with moderate permeability and water retention, is rated 3 out of 5. Clay loam, having lower permeability but some water retention capability, is rated 2 out of 5. Clay soil, with its poor permeability and low water-holding capacity, receives a rating of 1 out of 5 for its limited contribution to groundwater recharge.

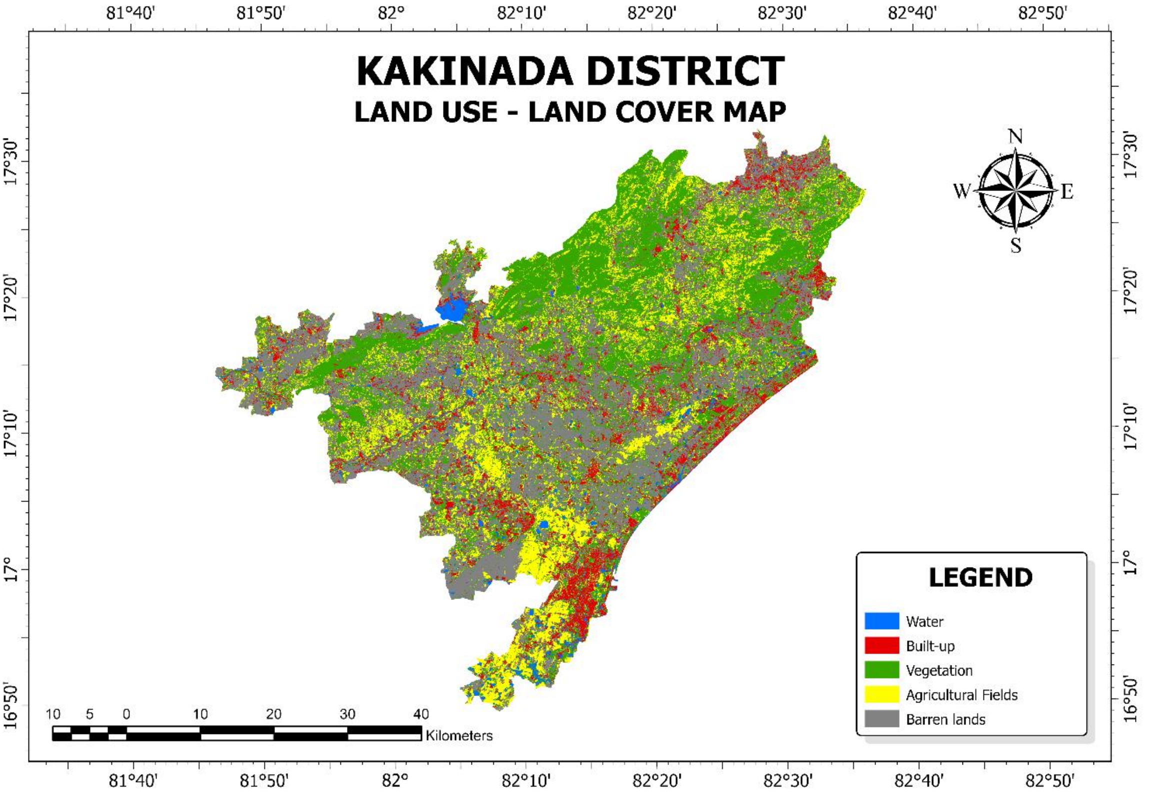
- **Sandy Loam (4/5)**: Sandy loam soils allow for effective water infiltration and moderate water retention, making them conducive to groundwater recharge.
- **Sandy Clay Loam (3/5)**: This soil type combines sand, clay, and silt, offering moderate permeability and reasonable water-holding capacity, supporting groundwater recharge to a lesser extent than sandy loam.
- **Clay Loam (2/5)**: Clay loam soils have lower permeability than sandy soils but retain some water, contributing modestly to groundwater recharge.
- **Clay (1/5)**: Clay soils have very low permeability, restricting water infiltration and making them least effective for groundwater recharge.



4.3. Land Use/Land Cover

Land use/land cover (LULC) describes the physical and biological cover of the Earth's surface and plays a crucial role in groundwater potential by influencing surface infiltration rates, runoff generation, and groundwater recharge. Using Sentinel-2A data with a resolution of 10m, the study area was classified into five main classes: vegetation, built-up areas, agricultural fields, water bodies, and barren lands.

- **Agricultural Fields (5/5)**: These areas are characterized by regular cultivation practices and relatively permeable soils, facilitating significant infiltration and groundwater recharge.
- **Water Bodies (5/5)**: Water bodies such as rivers, ponds, and lakes provide direct recharge to groundwater through seepage and infiltration, making them critical for groundwater replenishment.
- **Vegetation (5/5)**: Vegetated areas, including forests and grasslands, enhance groundwater recharge by intercepting rainfall, reducing runoff, and promoting infiltration through root systems.
- **Built-Up Areas (1/5)**: Urban and built-up areas have extensive impervious surfaces like concrete and asphalt, which drastically reduce infiltration rates and increase surface runoff, limiting groundwater recharge.
- **Barren Lands (1/5)**: Barren or sparsely vegetated lands have minimal vegetation cover and often poor soil permeability, resulting in limited groundwater recharge potential.



4.4. Drainage Density

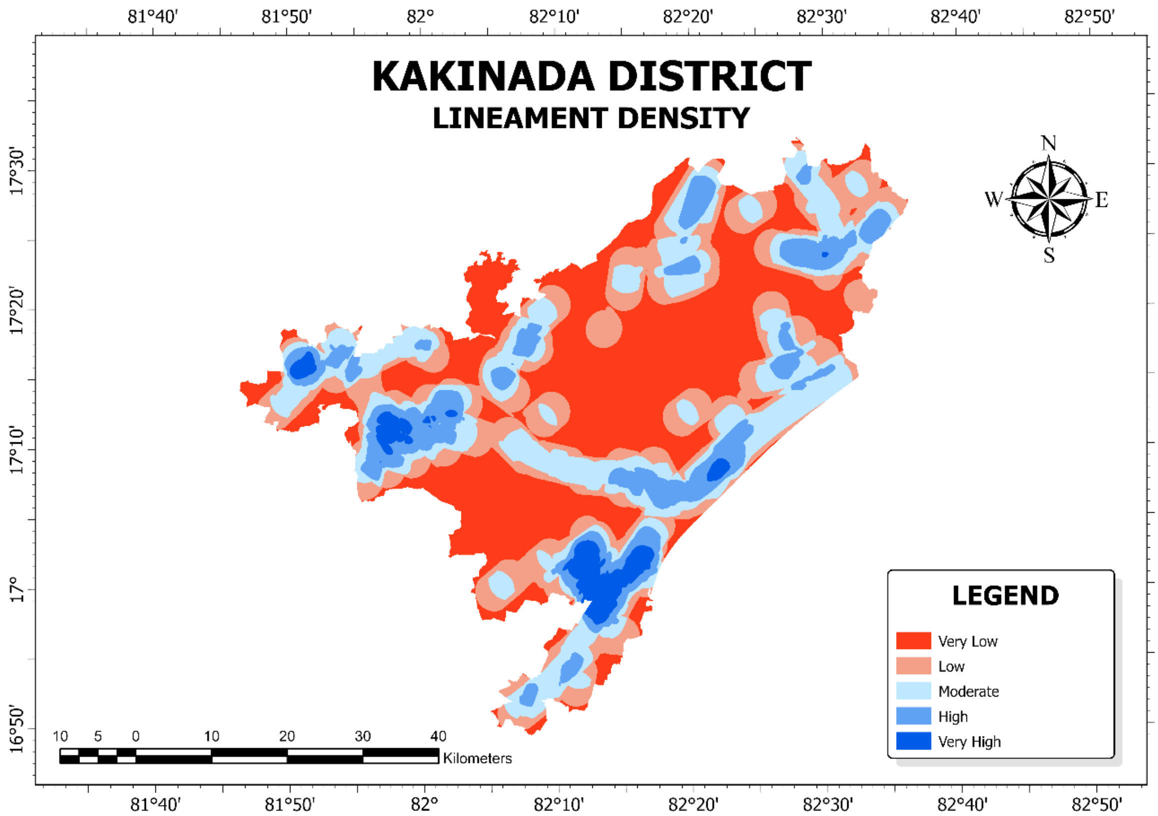
Drainage density refers to the total length of streams and rivers per unit area in a watershed, indicating how well water is drained from the land surface. It is a critical factor in geomorphology influencing groundwater potential through its impact on surface runoff and infiltration.

- **Very Low Density (5/5)**: Areas with very low drainage density have sparse stream networks, resulting in minimal surface runoff and enhanced groundwater recharge due to increased infiltration into the soil.
- **Low Density (4/5)**: Regions with low drainage density exhibit a relatively sparse but interconnected stream network, allowing moderate surface runoff and reasonable groundwater recharge capabilities.
- **Moderate Density (3/5)**: Moderate drainage density indicates a balanced stream network with average connectivity, resulting in moderate surface runoff and groundwater recharge potential.
- **Good Density (2/5)**: Areas with good drainage density have a well-developed and interconnected stream network, leading to significant surface runoff and reduced groundwater recharge compared to lower density areas.
- **Very Good Density (1/5)**: Regions with very good drainage density have an extensive and well-connected stream network, resulting in high surface runoff and minimal groundwater recharge potential.

4.5. Lineament Density

Lineaments are significant linear features on the Earth's surface, often representing underlying structural formations such as faults, fractures, and joints. In geomorphology, lineament density refers to the frequency and distribution of these linear features within a given area. High lineament density often indicates regions with enhanced groundwater recharge potential due to increased permeability and secondary porosity.

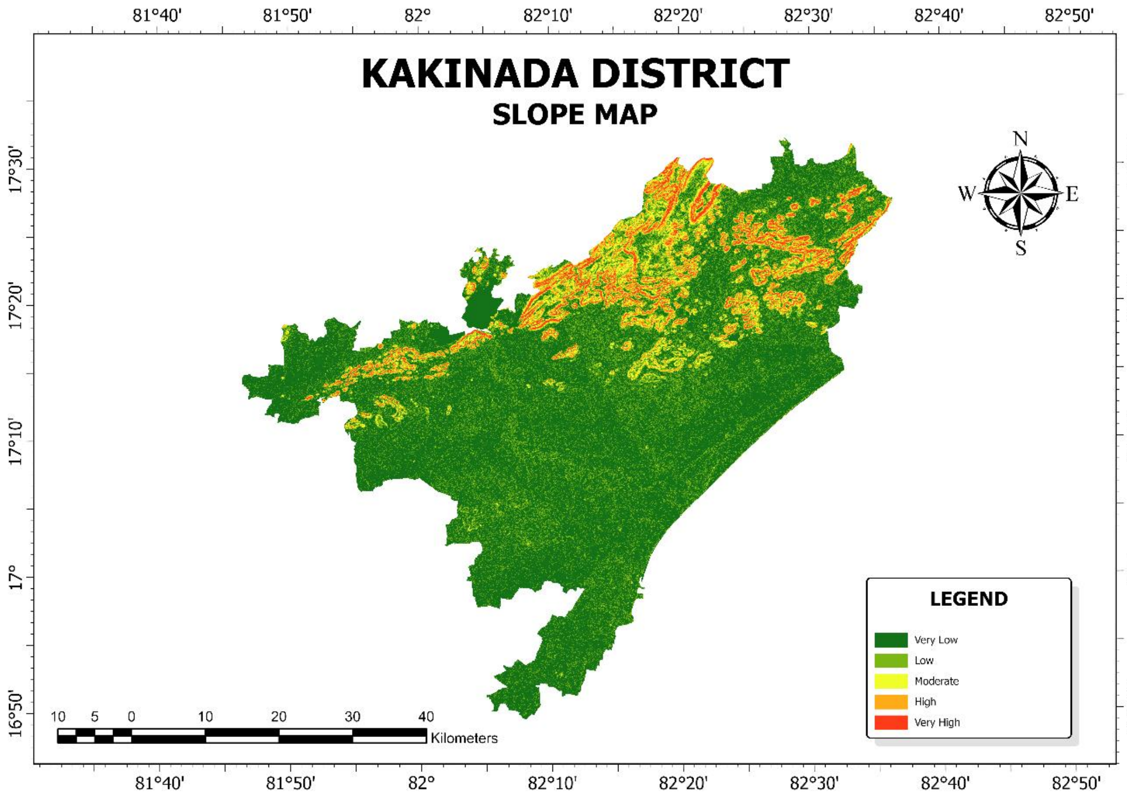
- **Very Low Density (1/5)**: Areas with very low lineament density have few linear features, resulting in limited groundwater recharge due to minimal structural pathways for water infiltration.
- **Low Density (2/5)**: Regions with low lineament density exhibit slightly more linear features than very low density areas but still have restricted groundwater recharge potential due to insufficient structural permeability.
- **Moderate Density (3/5)**: Moderate lineament density indicates a balanced presence of linear features, providing a fair amount of pathways for groundwater infiltration and recharge.
- **Good Density (4/5)**: Areas with good lineament density have a well-distributed network of linear features, significantly enhancing groundwater recharge potential by increasing the permeability and connectivity of aquifers.
- **Very Good Density (5/5)**: Regions with very good lineament density are characterized by an extensive and highly interconnected network of linear features, leading to excellent groundwater recharge potential due to optimal structural pathways for water movement and storage.



4.6. Slope

In geomorphology, slope refers to the steepness or incline of the land surface, which significantly affects water movement, erosion, and infiltration rates. The slope influences how quickly water flows over the surface and the likelihood of water infiltrating the ground to recharge aquifers.

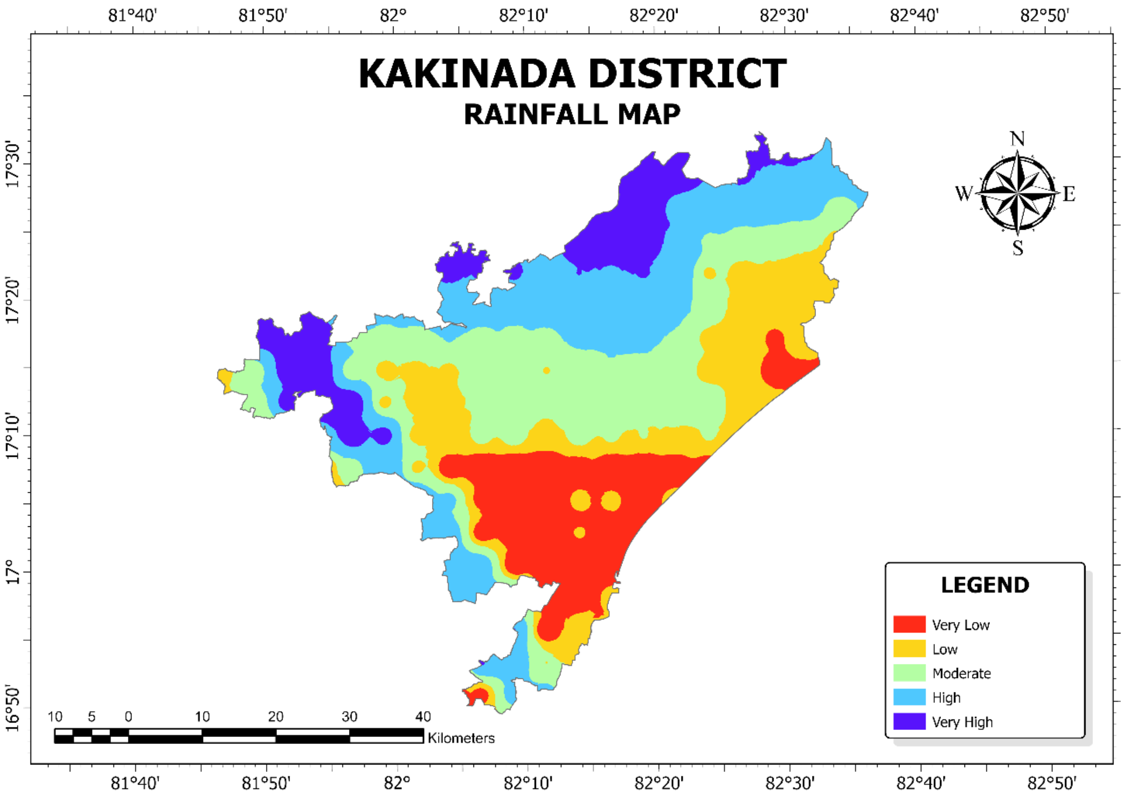
- **Very Low Slope (5/5)**: Areas with a very low slope have almost flat terrain, which promotes maximum water infiltration and minimal surface runoff, resulting in high groundwater recharge potential.
- **Low Slope (4/5)**: Regions with a low slope exhibit gentle inclines, facilitating good water infiltration while producing moderate surface runoff, thereby offering considerable groundwater recharge potential.
- **Moderate Slope (3/5)**: Moderate slope areas have a balanced inclination, resulting in a fair amount of water infiltration and surface runoff. These areas provide average groundwater recharge potential.
- **Good Slope (2/5)**: Areas with a good slope are more inclined, leading to increased surface runoff and reduced water infiltration. As a result, these regions have limited groundwater recharge potential.
- **Very Good Slope (1/5)**: Regions with a very good slope are characterized by steep inclines, causing significant surface runoff and minimal water infiltration, thus offering the least groundwater recharge potential.



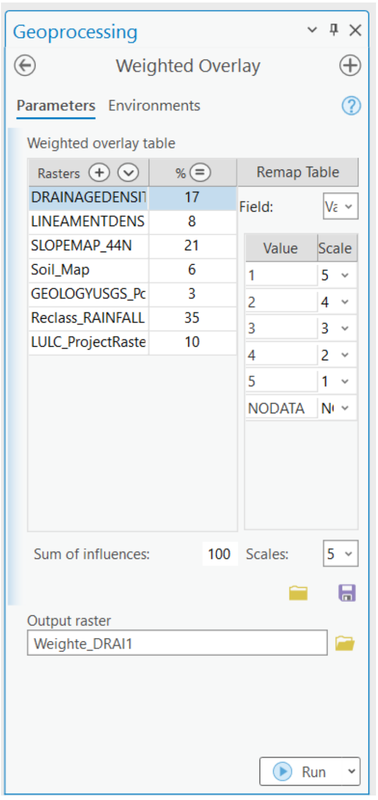
4.7. Rainfall

Rainfall is a critical factor in groundwater recharge as it provides the primary source of water that infiltrates the ground. In the context of GIS, rainfall data can be spatially analyzed to assess its distribution, intensity, and impact on groundwater potential. Variations in rainfall patterns influence the amount of water available for infiltration and subsequent groundwater recharge.

- **Very Low Rainfall (1/5)**: Areas with very low rainfall receive minimal precipitation, resulting in limited water availability for infiltration and significantly low groundwater recharge potential.
- **Low Rainfall (2/5)**: Regions with low rainfall experience slightly more precipitation than very low rainfall areas, but still have restricted groundwater recharge potential due to insufficient water availability.
- **Moderate Rainfall (3/5)**: Moderate rainfall areas receive a balanced amount of precipitation, leading to a fair amount of water infiltration and average groundwater recharge potential.
- **Good Rainfall (4/5)**: Areas with good rainfall experience substantial precipitation, facilitating increased water infiltration and enhancing groundwater recharge potential.
- **Very Good Rainfall (5/5)**: Regions with very good rainfall receive abundant precipitation, maximizing water infiltration and offering excellent groundwater recharge potential.



5. Analysis and Results



5.1. Integration of Thematic Layers

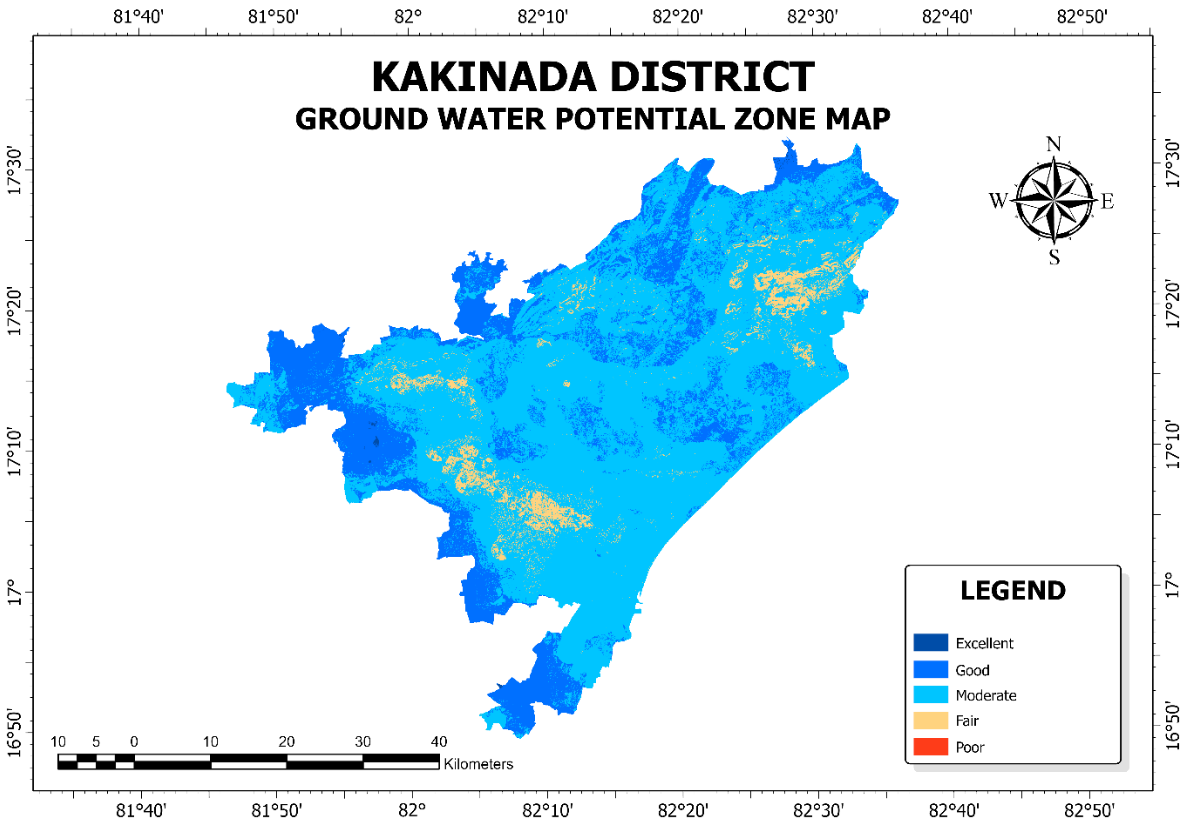
Thematic layers including geological formations, soil types, land use/land cover, rainfall patterns, and topographical features were integrated using GIS techniques. Each layer was weighted based on its influence on groundwater potential, determined through the Analytical Hierarchy Process (AHP). By overlaying these layers, spatial relationships and interactions were analyzed to produce a comprehensive groundwater potential zone map. This integrated approach provided insights into the distribution and variability of groundwater recharge zones across the study area, supporting informed decision-making for sustainable water resource management and planning.

5.2. Weighted Overlay Analysis

In the Weighted Overlay Analysis, each thematic parameter was assigned values totaling 100 based on its influence on groundwater recharge. Parameters such as geological formations, soil types, land use/land cover, rainfall patterns, and topographical features were categorized into classes reflecting their varying impacts on groundwater potential. The weighted values for each parameter were integrated spatially using GIS to derive a composite index representing groundwater recharge potential across the study area. This approach facilitated the identification and delineation of distinct groundwater potential zones, providing a quantitative basis for decision-making in water resource management and planning.

5.3. Delineation of Groundwater Potential Zones

The various thematic layers were overlaid and integrated using GIS techniques to delineate groundwater potential zones. This integration provided a spatial representation of areas with varying groundwater recharge capacities, enabling effective resource management.



5.4. Validation of Groundwater Potential Zones

Soil and geological samples were collected from selected stations for ground truth validation. These samples were analysed to verify the accuracy of the mapped groundwater potential zones, ensuring the reliability of the spatial analysis and the thematic layer integration.

6. Discussion

6.1. Interpretation of Results

Most parts of the district exhibit moderate groundwater potential, indicating a balanced capacity for recharge across these areas. The peripheral belt of the district is characterized by good groundwater potential, suggesting favorable conditions for recharge. Some zones with poor groundwater potential are identified in the eastern and western regions. The area with extreme groundwater recharge potential is located on the west side of Kakinada District, highlighting its significant capacity for groundwater replenishment.

6.3. Limitations of the Study

Given the extensive area of the district, covering over 3,020 sq km, it is challenging to validate the results comprehensively using ground truth techniques. Consequently, the accuracy of this project is not 100%, and there may be errors induced during the analysis and integration of the data. These limitations highlight the need for further field validation and refinement to enhance the reliability of the findings.

7. Conclusion

This study, covering an area of over 3,020 sq km, identified and mapped the groundwater potential zones in the Kakinada District using GIS and remote sensing techniques. The soil in the study area is predominantly loam and clay, which are conducive to moderate groundwater recharge. The geology is characterized by sedimentary rocks of different ages, influencing the groundwater potential. The results indicate that the region is blessed with moderate to high groundwater potential zones, with peripheral areas showing particularly good recharge capacities. These findings provide a valuable basis for effective groundwater management and planning, supporting sustainable water resource utilization in the district.

8. References

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