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Mapping of Groundwater Recharge Zones and Potential Recharge Sites Using Geospatial Techniques in Suryapet District of Telangana in India

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ABSTRACT

Suryapet district in Telangana state of India is a semi-arid region facing frequent droughts and depleting groundwater levels despite receiving an average annual rainfall is 820 mm. Dependance on deep bore wells causes severe water shortages during summer, making groundwater recharge essential for sustainable water management. in this region. This study uses geospatial techniques—integrating GIS and remote sensing—to identify groundwater recharge zones and potential artificial recharge sites. Thematic layers comprising of rainfall, geomorphology, drainage density, slope, and Land Use Land Cover were prepared and used. The study introduces a comprehensive methodology categorizing the zones into five classes namely, very poor, poor, moderate, high, and best. The findings indicated that the best groundwater recharge area spans 488.54 km^2 (13.54%), followed by high potential zones covering 2077.97 km^2 (57.61%), and moderate zones spanning 754.6 km^2 (20.92%). Conversely, poor potential zones account for 285.79 km^2 (7.92%). The study identified additional recharge sites characterized by low drainage density, optimal water storage capacity, flat terrain, and agricultural utility. By intersecting lineament and drainage maps, an artificial recharge site map was generated, identifying 1102 potential sites. Among these, 502 sites fall under the moderate potential zone, while 49 sites lie in the best zone. The results were verified against field data, demonstrating strong concurrence. The research underscores the efficacy of GIS innovation coupled with RS and weighted overlay analysis in identifying groundwater recharge zones and artificial recharge sites. This method not only enhances accuracy but also optimizes resource utilization, reduces time, and curtails costs.

Keywords: *Artificial recharge sites, drainage density, GIS, groundwater recharge, remote sensing (RS), recharge zones, weighted overlay.*

1. Introduction

Groundwater, a vital component of the natural water cycle, plays an important role in meeting the water demands of growing populations, industries, and agriculture [13;16;18]. Water scarcity issues are becoming increasingly apparent worldwide due to factors like inadequate soil and water conservation, inefficient water usage, etc. [13]. Human activities rather than natural causes are the root of groundwater crises [11]. Rapid extraction has led to declining water levels in various regions, notably in India where per capita water availability has drastically reduced. In India, the per capita availability of water has reduced to 1486 m^3 in 2020 from 5177 m^3 in 1951 and is predicted to decrease to 1140 m^3 by 2050s, resulting in a water-scarce condition of less than 1000 m^3 per year [17]. Rising population, changing lifestyles, and industrial growth have escalated water demand, driving aquifer depletion and resulted in reduction in stream flow, drying of wetlands, and reduction in vegetation and well yield. Similarly, the number of over-exploited blocks in India is growing at a rate of 5.5% per year [24].

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Factors such as geological attributes, slope, land use, and climatic conditions significantly influence groundwater formation and movement [6;21]. Quantification of runoff potential and groundwater recharge is crucial for designing recharge structures [22;29;12;24]. Previous research demonstrated the effectiveness of RS and GIS techniques in sustainable groundwater management by integrating various thematic layers [15;3;6;27;25]. Researchers reported the application of RS, GIS, and analytic hierarchy process (AHP) to find the groundwater recharge zones across different parts of the globe and it will help the stakeholders in planning [4;7;2;14;30]. In previous studies, researchers delineated the groundwater potential zones using geospatial techniques and multi-criteria decision-making [5].

Suryapet district, a semi-arid region in Telangana state is facing frequent failures in monsoon, prolonged dry spells, unreliable surface water, and rapid urbanization with over-exploitation of groundwater. The district's dependency on deep bore wells for water supply results in severe shortages during summer months due to inadequate understanding of geomorphology and drainage. The district's water scarcity issues are exacerbated by unreliable surface water, climate vulnerabilities, rapid urbanization, and industrialization. The study aligns with the Ground Water Year Book (2020-2021) [8] Telangana, revealing the district's varying groundwater status across its mandals. Groundwater recharge is a pre-requisite for sustainable water management and can be achieved through the desilting of existing water harvesting structures and the construction of new ones. In this context, the present study focuses on Suryapet district, a semi-arid area facing groundwater depletion amidst climatic vulnerabilities and rapid urbanization. Identifying the available groundwater and stressed areas in relation to the potential for water beneath the surface earth is made easier by the perspective zoning of the area. Water is mainly found in the faults and joints of the rocks and in the valleys. Understanding the extent of faults and geomorphology of these areas is essential to explore the groundwater in these areas effectively and economically. For demarcating groundwater recharge zones, GIS combined with RS can be used efficiently. To address the issue in Suryapet district, this study employs an integrated approach involving GIS and remote sensing techniques to identify the groundwater recharge zones and potential recharge sites. By leveraging GIS and RS tools, the study aims to guide sustainable groundwater management strategies for the selected area.

2. Materials and Methods

Study area

The study focuses on Suryapet district in Telangana state of India, situated between latitudes 16º 37' 29" to 17º 30' 29" N and longitudes 79º 21' 2.5" to 80º 04' 7.1" E, spanning an elevation range of 0 to 522 m above MSL (Fig.1). Encompassing an area of 3,374.41 km^2, the district benefits from the Krishna River and its tributary, Musi. Predominantly agricultural, the area cultivates crops like paddy, sugarcane, cotton, chili, turmeric, oil palm, and green gram. The soil profile consists of moderately shallow to moderately deep gravelly red loam, underlain by 15 to 25 cm thick dark greyish loamy soils (*Central Ground Water Board* (*CGWB*)). Suryapet district, chosen due to its water table depletion, water scarcity, and susceptibility to soil erosion, is classified under the Koppen climate as Tropical Wet and Dry. Annual rainfall averages 820 mm, with 90% occurring during the South-West monsoon and the majority in July, August, and September. May registers the highest temperature (39ºC), while January and December mark the coolest months (16ºC). The district's relevance stems from its degraded status, water table issues, and undulating terrain, emphasizing its significant runoff generation capacity. The district's groundwater scenario, as detailed in the Ground Water Year Book 2020-2021 [8] Telangana, reveals varying mandal-wise conditions, with one over-exploited, four critical, four semi-critical, and twelve safe.

Data used for evaluating groundwater potential and pinpointing recharge sites was sourced from diverse sources. Daily rainfall data of 70 years, geomorphology and lineament maps (1:50,000), Land Use Land Cover maps (1:50,000) and soil maps (1:50,000) was used. Digital elevation models (DEMs) of ASTER were processed to derive slope, aspect, and flow accumulation maps. This study undertakes a comprehensive analysis of the hydrological and geographical factors impacting Suryapet district's water resources, aiming to contribute to effective soil and water management strategies in the region. This holistic approach ensures robust insights for sustainable soil and water management strategies in the region.

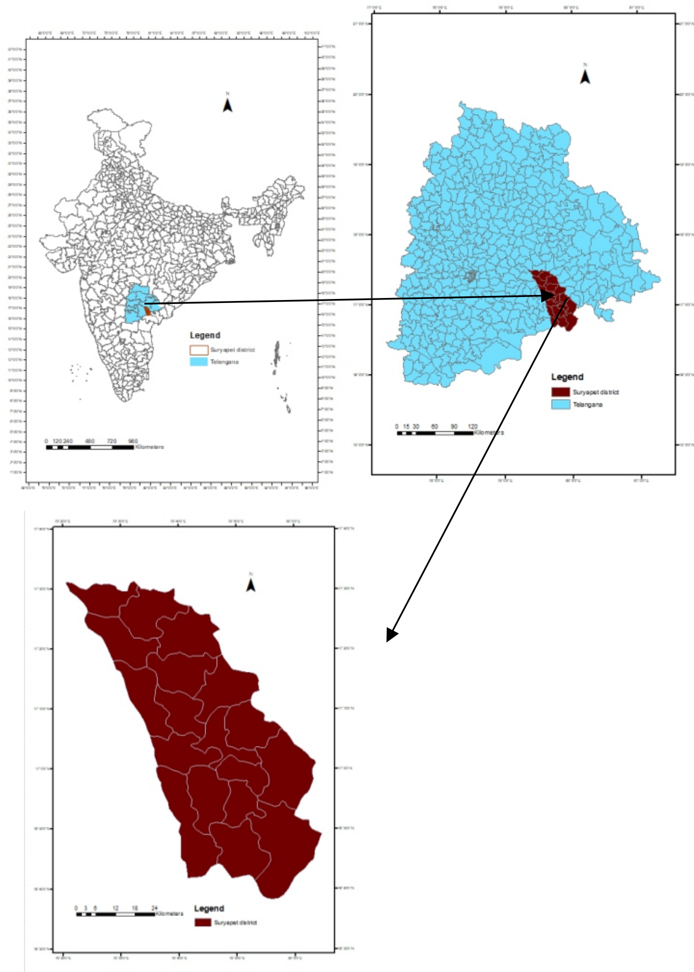

Fig. 1. Location of the study area

Preparation of Thematic Maps

To evaluate the groundwater recharge zones and artificial recharge zones, thematic layers of rainfall, geomorphology, drainage network, drainage density, slope, land use/land cover, and lineament were used.

Rainfall

Rainfall significantly governs groundwater recharge in the selected area, particularly during the southwest monsoon. The hydrological and hydrogeological processes are intricately tied to precipitation's spatial and temporal distribution. For this study, 1951-2020 Indian Meteorological Data (IMD) on a 0.25° x 0.25° grid was utilized and classified the area into: very low (700–750 mm), low (750–800 mm), moderate (800–850 mm), high (850–900 mm), and very high (>900 mm) rainfall regions. Results indicated predominant coverage of moderate to high rainfall classes (75%), consistent with prior research linking high rainfall to enhanced groundwater potential due to substantial percolation (Fig. 2).

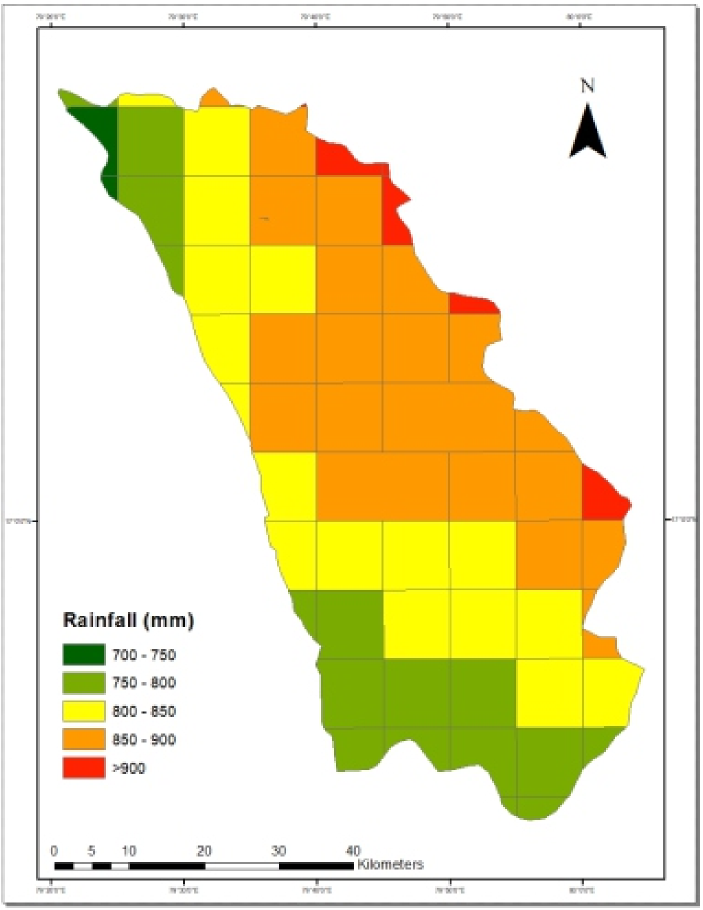

Fig. 2. Rainfall distribution in the study area

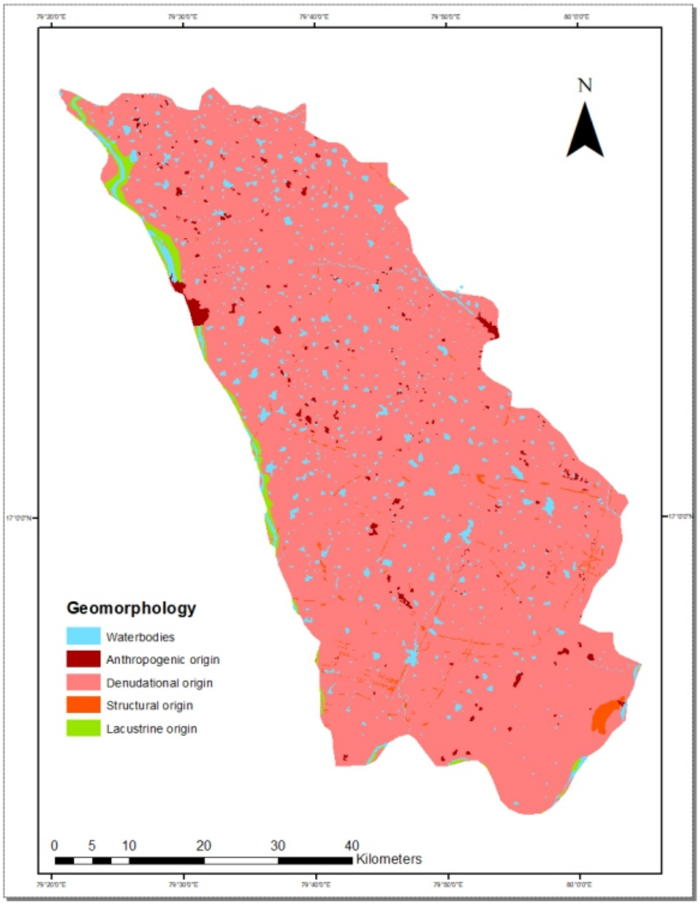

Fig 6. Geomorphology map of Suryapet district

Geology and Geomorphology

The geomorphology of a specific region is managed by the soil type, rock type, and drainage pattern and hence subsequently, geomorphic units and related features indirectly control the groundwater prospect of an area [23]. In the present study, prior referenced information acquired from bhuvan.nrsc.gov.in has been digitized and reclassified in GIS software. The reclassification was done to make the obtained data viable and clear for additional examination. With data from various source classes like waterbodies, anthropogenic origin, denudational origin, structural origin, and lacustrine origin great to excellent conceivable groundwater potential and recharge zones [6]. The study region features Banded Gneissic Granite, Quartzite, Limestone, and Shales, with Banded Gneissic Granite being dominant. Geomorphological analysis categorized landforms into denudational, waterbodies, lacustrine, anthropogenic and structural origins, aiding groundwater recharge potential assessment (Fig. 3). Denudational origin prevails in 76.5% of the area with promising groundwater recharge. Waterbodies encompass 20%, indicating excellent groundwater potential. Lacustrine origin covers 1.5%, beneficial for recharge. Anthropogenic and structural origins represent around 1%, possibly with moderate to poor recharge potential.

Drainage line and Drainage density

ASTER DEM was used to generate the drainage network map of the study region. The drainage network is completely reliant upon the slope, nature, and features of bedrock, and on the patterns of local fractures (Fig.7a). Drainage which is effectively apparent on remote sensing imagery hence reflects differing degrees of the lithology and design of a specific region. Thus, it is critical for groundwater resource assessment. Drainage density, the ratio of total stream length to drainage area, gauges the extent of area drained by stream channels. It reflects land infiltration capacity and vegetation cover. Influenced by climate and basin characteristics, drainage thickness is determined by drainage pattern (substratum nature) and drainage texture (rock/soil type). Soil permeability and underlying rock impact drainage; impermeable substrates yield higher runoff and more streams. Rugged terrain and sparse vegetation correlate with high drainage density. Groundwater potential and recharge zones hinge on drainage density and high density leads to diminished surface water infiltration and, subsequently, poor recharge. However, groundwater perception varies; low drainage density may yield low groundwater potential, while high drainage density could elevate it. Drainage density gauges stream length relative to area, reflecting drainage quality.

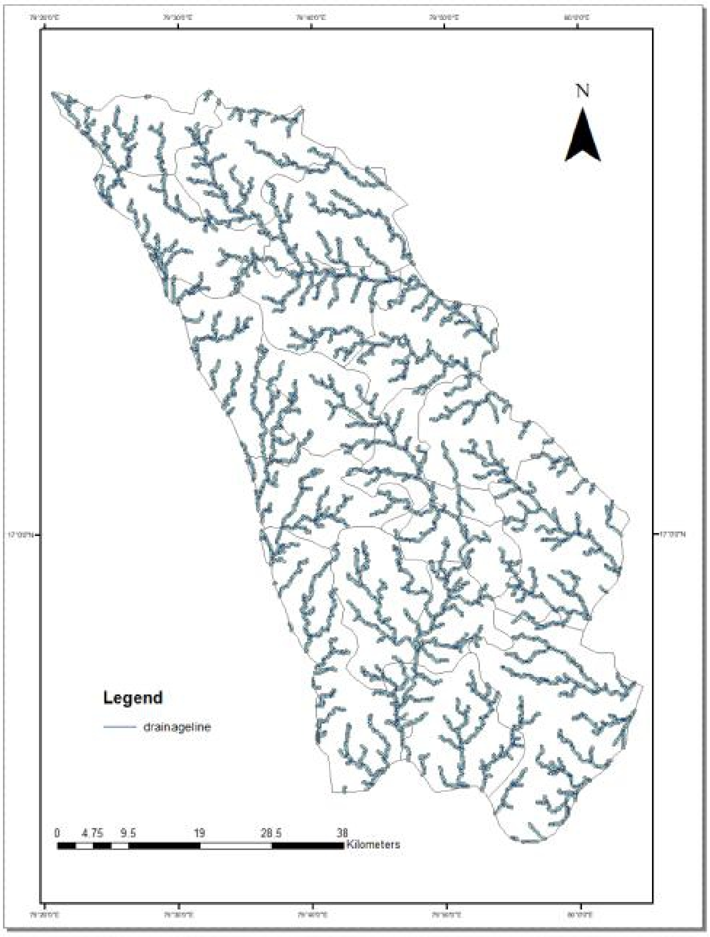

Fig. 4a. Drainage map of Suryapet district

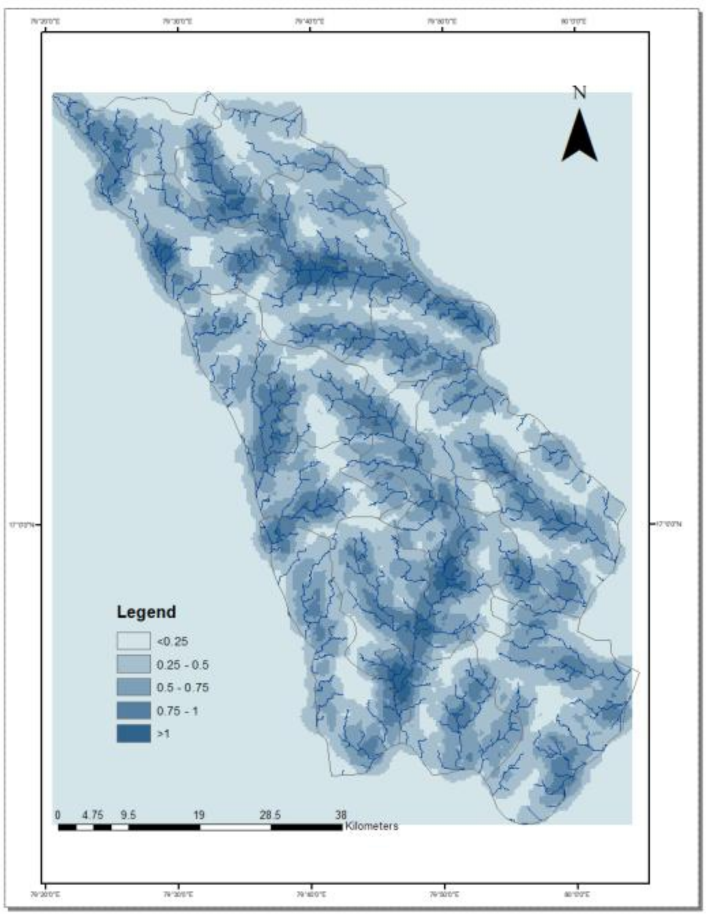

Fig. 4b. Drainage density of Suryapet district

The study region's drainage pattern is rectangular to sub-dendritic. The drainage density was categorized into five groups- very low (<=0.25 km/km^2), low (0.25-0.5 km/km^2), moderate (0.5-0.75 km/km^2), high (0.75-1.0 km/km^2), and very high (>1.0 km/km^2) and the drainage densities depicts the groundwater potential and recharge zoning. Around 14.14% (510.14 km^2) exhibits very low drainage density, promising high groundwater recharge. Low drainage density covers 44.18% (1593.54 km^2), enhancing recharge and dampening runoff potential. Moderately dense drainage characterizes 30.51% (1100.44 km^2). Conversely, 5.7% (205.65 km^2) and 5.47% (197.12 km^2) indicate good and very good drainage density, translating to poor recharge and high runoff potential. Analysis highlights predominant poor to moderate drainage density zones in the study area, suggesting significant surface water retention (Fig.4).

Slope

The slope of a specific territory is a significant factor in groundwater studies since it regulates the time expected for the water to infiltrate a given area. The percentage of the slope directly impacts the percolation of rainfall. The lesser the slope, the lesser the runoff, and consequently infiltration and recharge will be more subsequently making flat land better for groundwater accessibility [10]. The slope map was generated from ASTER DEM. The study region exhibits varying topography spanning from 0 to 522 m above sea level. Slope, determined from DEM data, significantly influences the surface water flow, impacting water retention and infiltration. Infiltration capacity directly affects groundwater recharge, evident in Fig. 8. Areas with 0 to 1% slope, cover 95.07% of the region, exhibit 'very good' groundwater storage due to high infiltration in flat terrain. A slightly undulating topography with 1 to 2% slope is 'good' for storage covers 3.16% area. Regions with 2-3% moderate slope have limited infiltration and higher runoff, leading to 'moderate' recharge potential in 0.57% area. Elevated slopes of 3-4% in 0.3% area result in poor recharge and high runoff. An extremely steep slope (>4%) in 0.9% area covering 32.35 km^2 indicates 'very poor' groundwater potential and recharge (Fig.5). Elevated areas have lower groundwater potential, inversely correlating with elevation.

Land Use Land Cover

Land use/Land cover is one of the primary thematic layers to the study which gives the current status of land pattern and its utilization. The land use/Land cover map (1:50,000) of the National Remote Sensing Centre (NRSC) was used. The study area encompasses six land classes: built-up land, agricultural land, fallow land, forest, degraded forest, wasteland, and water bodies. Agricultural land, spanning 2685.457 km^2 (76%), dominates, primarily featuring crops like paddy, sugarcane, cotton, and others (Fig.6). Private and irregularly used cultivated land leads to poor groundwater potential and recharge. Wasteland covers 502.538 km^2 (14% area) followed by current fallow in 8.2% area and water bodies encompass 69.021 km^2, indicating excellent potential for groundwater recharge. Forest and degraded forest, totaling 20.602 km^2 show promise for groundwater potential and recharge. Settlement areas, covering 39.73 km^2, show poor groundwater potential, likely due to built-up land.

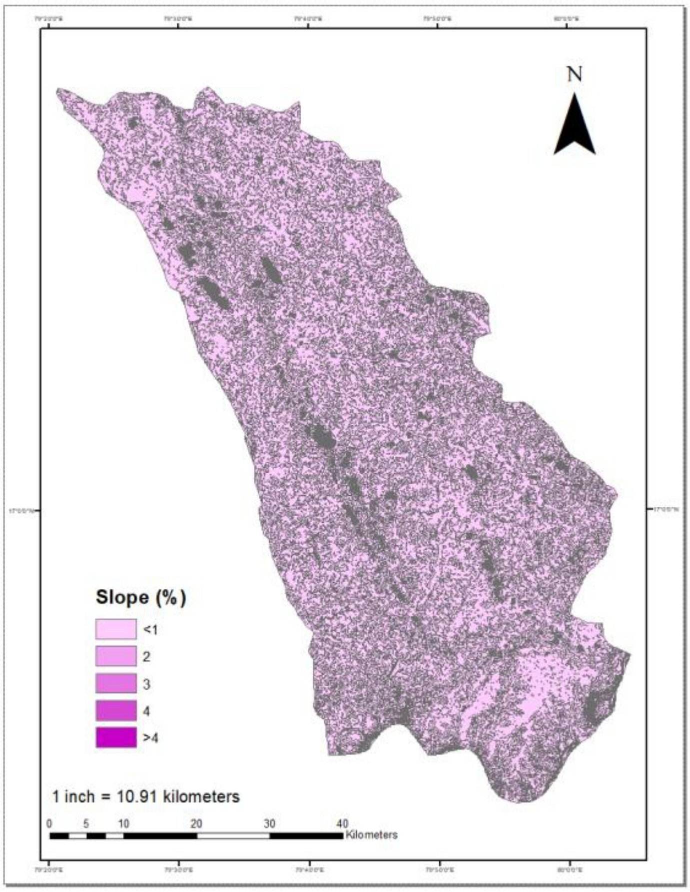

Fig 5. Slope map of the study area

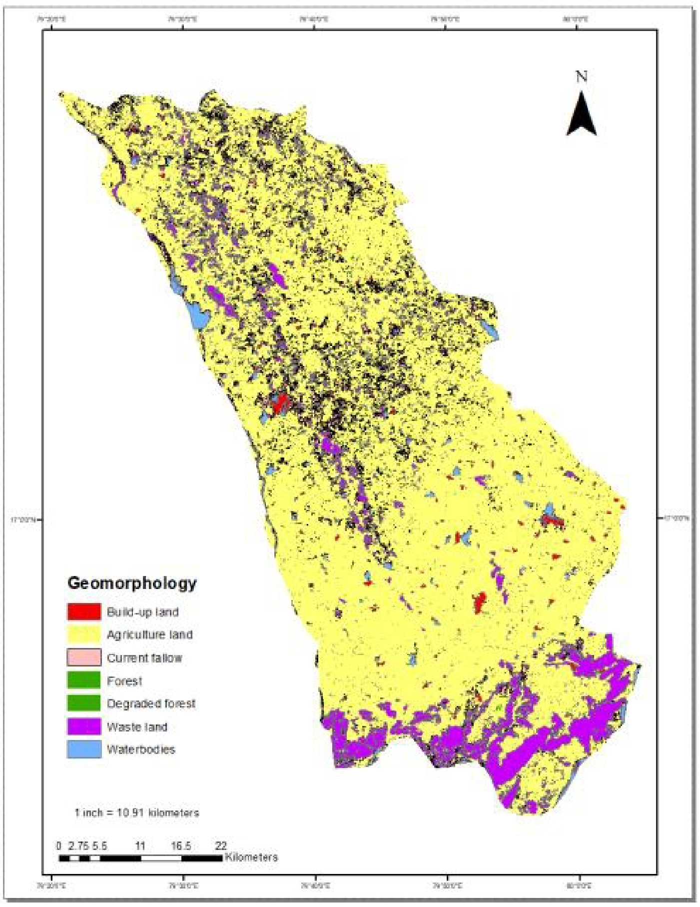

Fig 6. Land use/Land cover map of Suryapet district

Lineament map

Lineaments are normally referred in the analysis of structures or fractures. Lineaments are structures on the earth's surface and it delineates the weaker zone of bedrocks and the region considered as the second aquifer in hard rock areas could be identified by remote sensing [19]. The intersection of lineaments is important to find groundwater potential zones. For the current study, lineament maps (1:50,000) were obtained from ISRO's bhuvan.nrsc.gov.in and was digitized (Fig. 7).

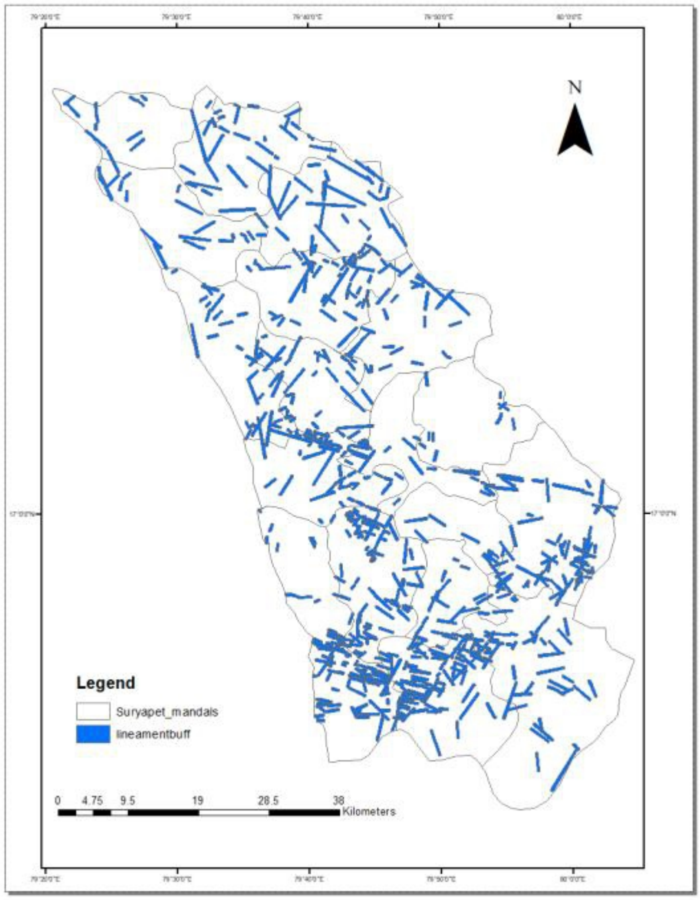

Fig 7. Lineament map of the study area

Recharge Potential Analysis

The different parameters like rainfall, geomorphology, drainage line, lineament, drainage density, slope, land use/land cover, and soil were assigned weight for the process of identification of groundwater recharge and potential sites [28]. From these, the five parameters mentioned above were used because they play a significant role in finding groundwater recharge sites and artificial recharge sites. In the result part, a relative comparison between various factors and their effects on groundwater availability in the area is discussed.

Weighted overlay analysis

This study employs weighted overlay analysis to assess groundwater recharge potential by integrating multiple factors using raster analysis (Fig. 8). Each factor was pre-assigned with a weight based on its suitability for recharge. This technique efficiently combines various layers' characteristics into one, making it ideal for such multi-layer analyses [9]. For each pixel, an output layer is generated with new values assigned using numerical weights derived from the thematic layer's pixels. These weights, ranging from 1 to 5, signify potential magnitude, with higher values indicating higher potential.

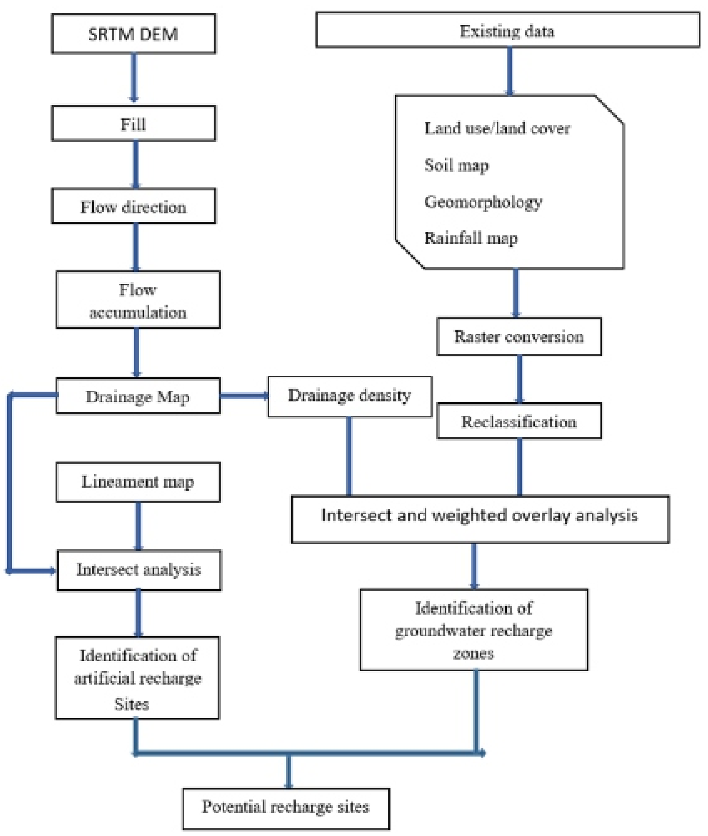

Fig 8. Flow chart for determination of groundwater recharge zones and potential recharge sites for the study area

The sum of influence weights should equal 100%, and these weights are assigned to both feature classes within layers and to layers with similar influence. Calculating the total weight index involves multiplying the scale weight by the percentage influence weight for each parameter, considering direct and indirect influences on groundwater recharge. This method effectively integrates diverse factors to create a weighted raster layer, contributing to an overall cell rank [6; 14]. A feature class with more influence within a layer will be assigned a higher scale weight value. Likewise, the more influential class of a layer is represented by a higher scale weight value. Consequently, the layer with the highest percentage of influencing weight is assigned a higher weight value. In order to accomplish the objective, the multiple thematic layers are analyzed to find the recharge potential zone using equation (1),

$$S = [(R_c * R_f) + (G_c * G_f) + (DD_c * DD_f) + (S_c * S_f) + (LU_c * LU_f)] \text{ ...... (1)}$$

Where,
R = annual average rainfall
G = geomorphology
DD = drainage density
S = slope or topography
LU = land use/land cover
c = scale weight assigned to a feature class of a particular layer
f = percentage of influence weight assigned to thematic layer
Analysis of groundwater recharge potential zones in a particular region results in a dimensionless map with weighted index values.

Potential Recharge Site Identification

Globally, successful artificial recharge methods encompass rainwater harvesting structures, injection recharge, on-stream interventions, and groundwater dams [7]. Techniques like bunds, terraces, and rain pits enhance infiltration by reducing runoff. On-stream interventions such as check dams and gabion dams increase dry season stream capacity, encouraging infiltration. Injection techniques introduce artificial flow to established or confined aquifers through wells and shafts. This can be integrated with interventions and gully plugs for less porous beds. Groundwater dams impede lateral flow and store water in sloping areas. In this study, an artificial recharge zone map was generated using five layers (rainfall, geomorphology, drainage density, slope, and land use/land cover). Subsequently, potential recharge sites were identified by overlaying drainage and lineament maps on artificial recharge zones within 100 m buffer around stream order streams. This approach targeted feasible recharge areas where drainage lines intersect with lineament features in the study region.

3. Results and Discussion

Identification of groundwater recharge zones

Weighted Overlay analysis

The study employs weighted overlay analysis, integrating diverse criteria through GIS to identify suitable groundwater recharge sites. Thematic maps, transformed into raster format, were superimposed based on rank assignment and weightage. Geomorphology, rainfall, drainage density, slope, and land use/land cover were evaluated. Geomorphology, given the highest weight (30%), favors denudational origin and water bodies, both with lower ranks indicating high recharge potential (Table 1). Rainfall (>900 mm) received the second-highest weight (25%), benefiting from higher recharge. Drainage density, with 10% weight, favored low drainage regions. Slope (15%) prioritized gentle slopes (0-1%) for high recharge. Land use/land cover (20%) highlighted water bodies and forest/degraded forests as recharge-friendly, while agriculture and other land types had lower potential. The overlay analysis generated a map showing four recharge potential zones: best, high, moderate, and very poor (Fig.9). The best potential zone covered 13.5% of the area, mainly near water bodies, low drainage, and high rainfall areas. The high potential zone (57.61%) included agricultural and forest lands with gentle slopes and moderately low drainage. The moderate zone (20.9%) covered regions with moderate drainage. The study lacked poor recharge zones, while very poor areas (7.92%) were attributed to low rainfall, steep topography, and specific geomorphology.

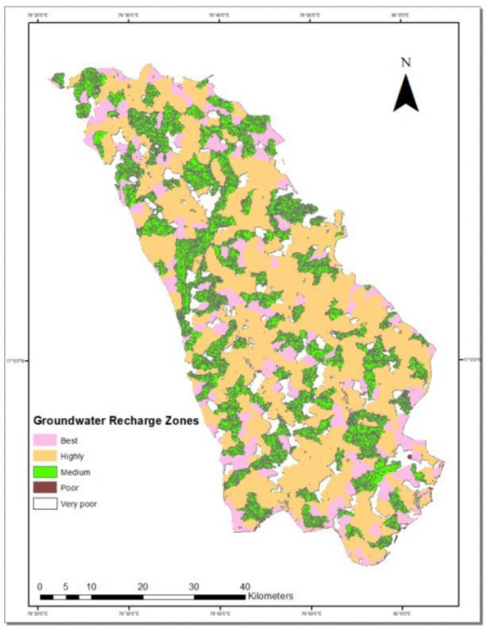

Fig 9. Groundwater recharge zones of the study area

Table 1. Ranks and weightages of parameters for groundwater recharge potential zones

Sr. No.	Groundwater recharge potential factor	Classes/feature	Rank	Assigned Weight	Weightage (%)
1	Rainfall (mm)	700 - 750	5	1	25
		750 - 800	4	3	
		800 - 850	3	4	
		850 - 900	2	5	
		>900	1	6	
2	Geomorphology	Waterbodies	1	6	30
		Anthropogenic origin	5	1	
		Denudational origin	2	4.5	
		Structural origin	4	1.5	
		Lacustrine origin	3	2.5	
3	Drainage density (km/km^2)	<=0.25	1	6	10
		0.25 - 0.5	2	5	
		0.5 - 0.75	3	4	
		0.75 - 1	4	2	
		>1	5	1	
4	Slope (%)	0 - 1	1	6	15
		1 – 2	2	5	
		2 – 3	3	4	
		3 – 4	4	2	
		> 4	5	1	
5	Land use/land cover	Build-up	4	2	20
		Agriculture	3	4	
		Current fallow	3	3.5	
		Wasteland	5	1	
		Water bodies	1	6	
		Forest/Degraded forest	2	5	

Identification of potential artificial recharge sites

The artificial recharge site map was generated by intersecting drainage lines and lineament maps along with a 100-meter buffer to identify promising locations for recharge (Fig 10). Landform features reflect subsurface geology and structures, influencing drainage patterns and infiltration. Lineaments were compared with major faults in the area, potentially indicating surface manifestations of faults. After overlying the artificial recharge sites with a groundwater potential zone map, potential recharge sites were obtained (Fig. 11). The map displays 1102 recharge sites, with 32.30% in high-suitability and 45.55% in moderate-suitability zones (Table 2). Mainly permanent and semi-permanent check dams were recommended, enhancing infiltration into aquifers through permeable stream beds and lineaments. Check dams can divert water from higher-order streams to recharge aquifers, bolstering groundwater replenishment [9].

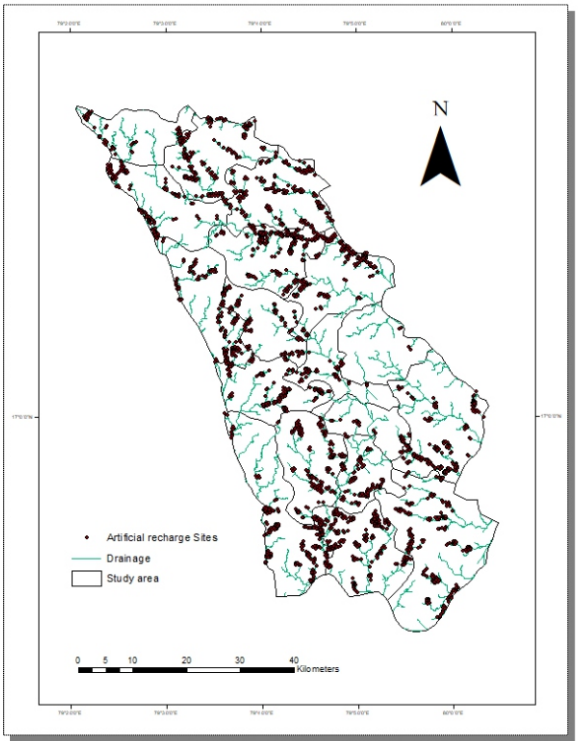

Fig 10. Artificial recharge sites map of study area

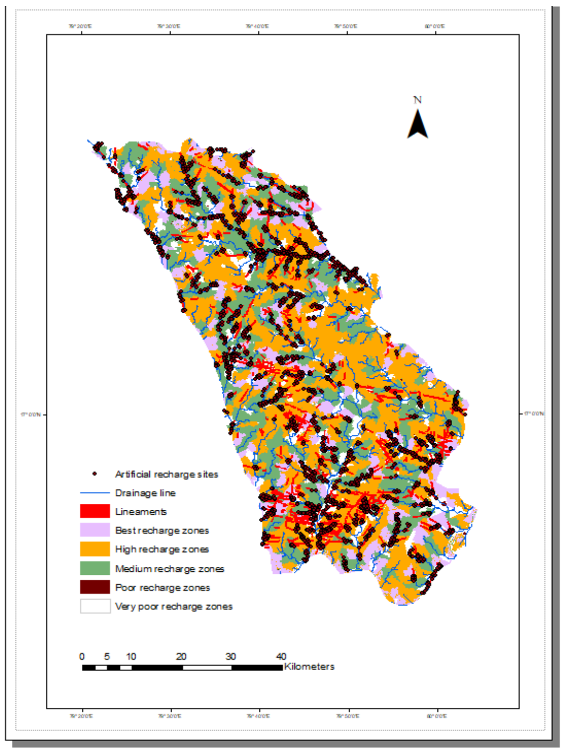

Fig 11. Potential groundwater recharge sites map of study area

Table 2. Groundwater recharge zones area distribution table

S.No.	Groundwater recharge zones	No. of artificial recharge sites	% of artificial recharge sites in different recharge zones
1	Best	49	4.44
2	High	356	32.30
3	Moderate	502	45.55
4	Very poor	195	17.69
	Total	1102	100

DISCUSSION

Integrated mapping using RS and GIS identified groundwater recharge zones based on multiple factors. The study area was categorized into best (excellent), high, moderate, poor, and very poor recharge zones. Artificial recharge sites were identified by overlaying lineament and drainage maps, resulting in 1102 sites mainly recommended for permanent and semi-permanent check dams. These sites are in line with successful implementations reported in previous studies. Implementing these findings can enhance water availability and inform sustainable groundwater management strategies. For instance, percolation tanks and groundwater recharge structures have proven effective in improving groundwater levels and crop yields. Local authorities can utilize the recharge zone map to formulate effective groundwater management strategies, such as regulating groundwater extraction in high-recharge zones. Identified potential recharge sites can be used for implementing artificial recharge methods, such as rainwater harvesting and injection wells, to enhance groundwater levels. The recharge zone map can guide land use planning, promoting sustainable practices in high-recharge areas while minimizing activities that may degrade recharge potential. The present study delves into the pressing issue of water scarcity in Suryapet district, Telangana, a semi-arid region plagued by recurrent droughts and depleting groundwater reserves. In response, we propose an integrated methodology utilizing Geographic Information System (GIS) and remote sensing (RS) techniques to delineate groundwater recharge zones and suitable artificial recharge sites.

The present study used various thematic layers including rainfall patterns, geomorphology, drainage density, slope, and Land Use Land Cover (LULC). A significant portion of the study area exhibits moderate to high potential for groundwater recharge, with the best recharge zones covering approximately 13.54% of the region. This aligns with the work [1] who observed similar trends in neighboring regions. Furthermore, our identification of 1102 potential recharge sites, particularly through the intersection of lineament and drainage maps, mirrors successful implementations reported in [10] analogous settings. This comprehensive analysis not only confirms the relevance of previous studies but also contributes novel insights into groundwater recharge dynamics in semi-arid regions. This research offers a pragmatic solution rooted in technological innovation, as advocated in [20], for addressing water scarcity challenges. By optimizing resources and reducing costs, this approach holds promise for enhancing groundwater resources and fostering resilience in water-stressed environments. This study contributes to sustainable water management strategies, emphasizing the critical role of advanced GIS and RS techniques in addressing pressing environmental concerns.

4. Conclusion

This study employed a geospatial approach to assess groundwater recharge potential and zoning. Thematic layers were prepared, and weighted overlay analysis was applied to determine the impact of various parameters on recharge potential. Groundwater recharge zones were categorized as best (excellent), high, moderate, poor, and very poor. By intersecting lineaments with drainage lines, artificial recharge sites were identified. After overlying the artificial recharge sites with a groundwater potential zone map, potential recharge sites were obtained. The study area's characteristics, such as rainfall, drainage density, slope, and land use, were assessed. A substantial portion of the area exhibited high and moderate recharge potential, emphasizing the significance of these zones for water management. The findings underscore the effectiveness of geospatial techniques coupled with weighted overlay analysis, for identifying groundwater potential and recharge sites.

Future scope of the study

This approach offers accuracy, cost-effectiveness, and applicability for planning groundwater recharge structures. This methodology could be adopted for finding groundwater recharge sites in similar regions facing groundwater depletion. Identified potential recharge sites can be used for implementing artificial recharge structures like injection wells, to enhance groundwater levels. The recharge zone map can guide land use planning, promoting sustainable practices in high-recharge areas.

Conflict of interest

The authors have no conflict of interests.

Acknowledgments

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