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Original Research Paper

Identification of Suitable Sites for Artificial Groundwater Recharge Structures in Semi-arid region of Anantapur District: AHP Approach

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Abstract

The conservation and sustainable advancement of soil and water assets is one of the fundamental standards for improvement of arid and semi-arid regions of India. The present study is underway to evaluate the Artificial Groundwater Recharge Zones (AGRZ) in the semi-arid region of Anantapur district, Andhra Pradesh, India using Remote Sensing (RS), Geographical Information System (GIS) and Analytical Hierarchy Process (AHP) technique. The comparative weights were assigned to different thematic layers with the help of the decision making tool of AHP. A set of eight thematic layers influence groundwater potential (GWP) is determined based on their corresponding weights, which depend on a Saaty's 9 points scale. These weights are normalized using AHP technique to identify the AGRZs. Five AGRZs were recognized as very low, low, moderate, good and very good, depending on its suitability to identify the sites for groundwater recharge. About 4.29 % (8.96km^2) and 17.70 % (36.95km^2) area in the region show very good and good potentials of artificial groundwater recharge, respectively. On the other hand 61.59% (128.60km^2), 11.94% (24.94km^2) and 4.48 % (9.35km^2) area showed moderate, poor and very poor potentials. Overall accuracy of AGRZ map is 82.05%. 92 check dams, 19 percolation tanks and 7 check walls were found suitable in the region. The effectiveness and prediction ability of the method depends on integrity of the criterion used. AHP based methodology can be useful for precise and reliable analysis and predictions of groundwater in semi-arid regions of India.

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1 INTRODUCTION

Significant contrasts in the capacity, occurrence and length of precipitation in distinct zones of India make watershed management as the defined need in the nation, which enriches the water supply and pulls back a comparable potential floods, thus gives twofold benefits. The financial improvement and the rural areas (India) is a standout amongst the most basic effects for the advancement of economy (Kumbhar *et al*., 2013). The water source is a released hydrological unit, from which the run-off, after the precipitation, crosses a single point in an enormous stream, river, lake or pond. Watershed is a multidisciplinary technique for conservation of regular assets (Chowdary *et al*., 2009). It includes an evaluation of different thematic layers about prospects, problems and the collection of educational activities in combination with financial auditory influences that can be connected to the field without endangering the environment (Kumar *et al*., 2008; Jahan *et al*., 2019). Therefore, it basically refers to the management of resources that guarantees the adequate use of land,

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shelter of the land against erosion, improvement and conservation of soil fertility, protection of water, protection against floods, reduction of sediments and improvement of productivity (Kadam *et al.*, 2012). Several strategies have been used to procure immediate or conventional data on soil-water conservation (SWC) and their possible existence, internally that hydrogeological and geospatial research is used regularly and appears to be common (Nsiah *et al.*, 2008; Kadam *et al.*, 2017). The geo-hydrological studies include some spatial layers of geology, geomorphology, drainage density, rainfall and run-off affecting the structures of the SWC. To investigate the suitability of SWC sites, Kothacheruvu Mandal has been selected as characteristic of semi-arid areas in Southern India with moderate rainfall. Accessible groundwater in the regfion probably misused especially during domestic, irrigation and industrial purposes (Rajasekhar *et al.*, 2018a, 2018b). This allows for the potential degradation of soils in reasonable areas and demanding soil and water conservation. With this expectation, Kothacheruvu mandal is chosen with the objectives to (1) comprehend the groundwater revive capability of a region, (2) distinguish potential SWC sites for water conservation and decrease of soil degradation, and (3) determine AGRZs with accuracy assessments. The methodology outlined and techniques used in the study will be useful for groundwater enrichment in the semi-arid and arid regions in India.

2 STUDY AREA

The Kothacheruvu Mandal (205 sq.km) is extended between 14º 07′ 30" N to 14º 16′ 0" N and 77º 41′ E 30" E to 77º 50′ 0" E (Figure 1). This region is formed by hard-rock terrain of semi-arid climatic conditions with potentials of high run-off and high evapotranspiration. The northern region is occupied by some hilly terrain having a slope of >45º. Some areas in the central area flat and some parts has hilly complex having higher slope about 26-45º. The area is drained by streams which are tributaries of lower Thungabadra River. The streams are mostly ephemeral in nature. The drainage pattern is dendritic, rectangular to sub-rectangular due to the influence of geological structures. The average rainfall in the Mandal is 622 mm. The normal temperature ranges from 15ºC in December-January to 40ºC in May-June. People in this area mostly involved in agriculture and dairy farming.

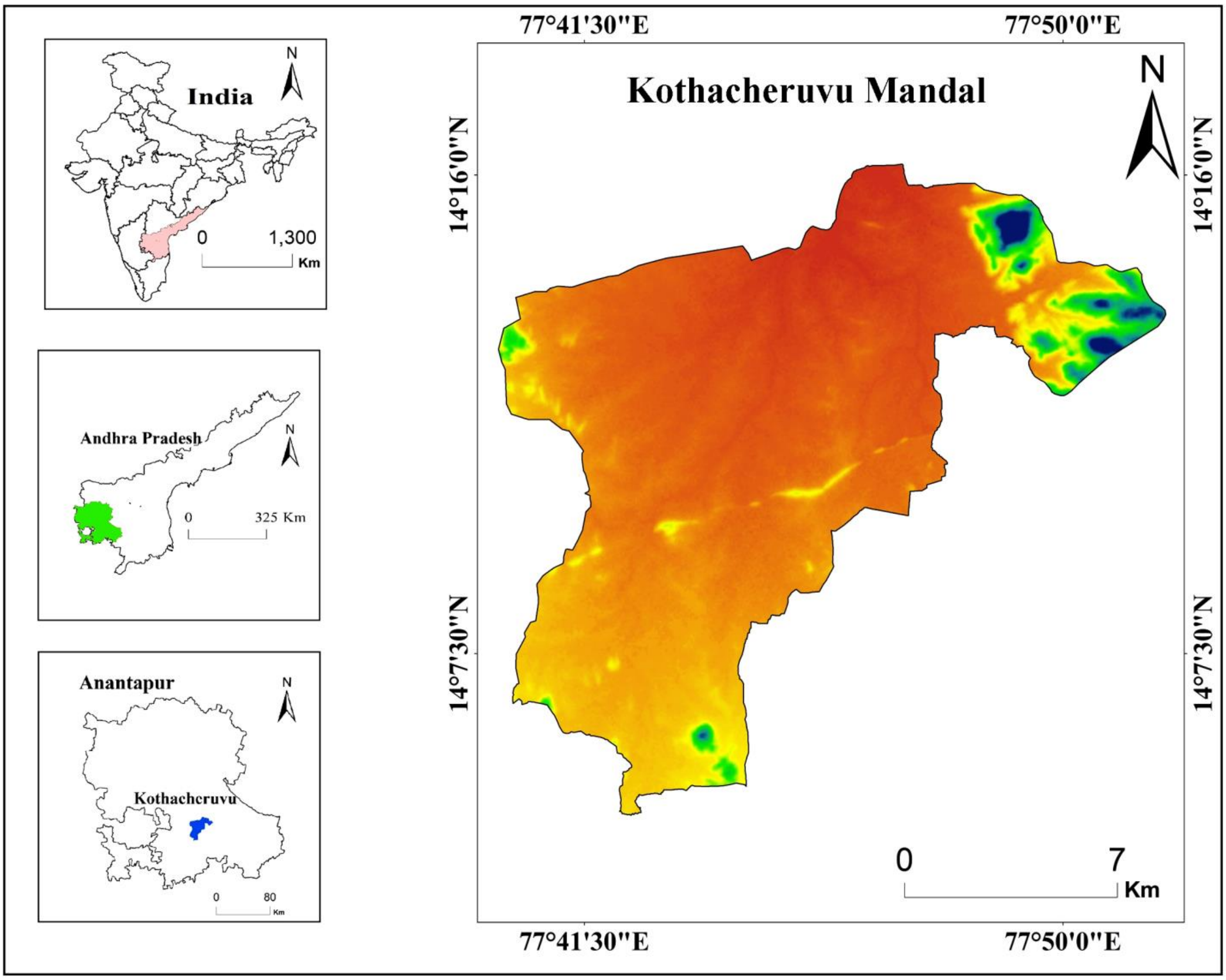

Figure 1. Study area: Kothacheruvu Mandal of Anantapur District, A. P. (India)

3 MATERIALS AND METHODS

The thematic maps such as geology, geomorphology, drainage density (DD), land use / land cover (LULC), lineament density (LD), slope, soils, and rainfall were prepared using ArcGIS environment. LULC layer was prepared using Landsat-8 satellite dataset using supervised classification in ERDAS Imagine software (Kumar *et al.*, 2014). The drainage map was prepared using topographical maps from Survey of India (SOI) and soil map using district soil resource map by Groundwater Department, Anantapur. The slope map was derived from the CARTOSAT DEM data from NRSC Bhuvan website. The rainfall data obtained from Groundwater Department, Anantapur for the period from 1998 to 2018. The various layers such as geology, geomorphology and lineaments were digitized from satellite imageries in ArcGIS environment (Chowdhury *et al.*, 2010; Ghayoumian *et al.*, 2007). An aggregate of eight thematic layers such as geology, geomorphology, slope, DD, LD, soil, rainfall and LULC with their inter-relationship, which is inferred to incite AGRZ methodology (Figure 2) for Anantapur District.

3.1 Criterion

A detailed procedure for groundwater resource evaluation of particular area needs the exhaustive investigation of various thematic layers like geology, geomorphology, LULC, LD, DD, soils, slope and rainfall so as to identify AGRZs in the present study, typical thematic maps were prepared from RS data, SOI maps and land maps associated to the collateral maps and field outline. The specifics of the thematic layers prepared from RS information and field overview, composed with the groundwater potential outcomes (Mundalik *et al.*, 2018; Rahman *et al.*, 2012; Rahmati *et al.*, 2015). The AHP weights are increased by the percentage of total weight to obtain the final weight. The average weight given to the rainfall varies from 293.89 to 945.29mm for very low to very high potential of recharge, respectively (Table 1) (Kadam *et al.*, 2017).

3.1.1 Geology

Geological formation of this region incorporates hornblende-biotite-gneiss, granites, and metadacite. The study area is commonly composed by gneiss and weathered crystalline granites in Northern and small patches in Southern part of the region. The metadacite formations show a low degree of infiltration, while the hornblende-biotite-gneiss deposits show a higher degree of infiltration due to their permeable nature (GSI 2002). The gneissic formations show 'high fractured zones and lineaments' and good potentials for groundwater recharge (Figure 3).

3.1.2 Geomorphology

Geomorphology is a study of land forms, which includes its description, types and physical processes that have helpful to assess possible areas of groundwater. The main geomorphological units (Figure 4) are classified into five types: structural low-dissected hills and valleys, denudational origin having low and moderate dissected hills and valleys, pediment pediplain complex and water bodies. Depending on total groundwater level, about 70% of the area has a moderate GWPZ (Rajasekhar *et al.*, 2018c). They are described by very permeable and porous material and have a good GWPZ. The pediplain areas spread a larger part of the present study and the groundwater hold in these areas is exceptionally restricted because of less recharge. The pediment-pediplain complex include the run-off zone and are available in the maximum of the present study and are reasonable for groundwater conservation.

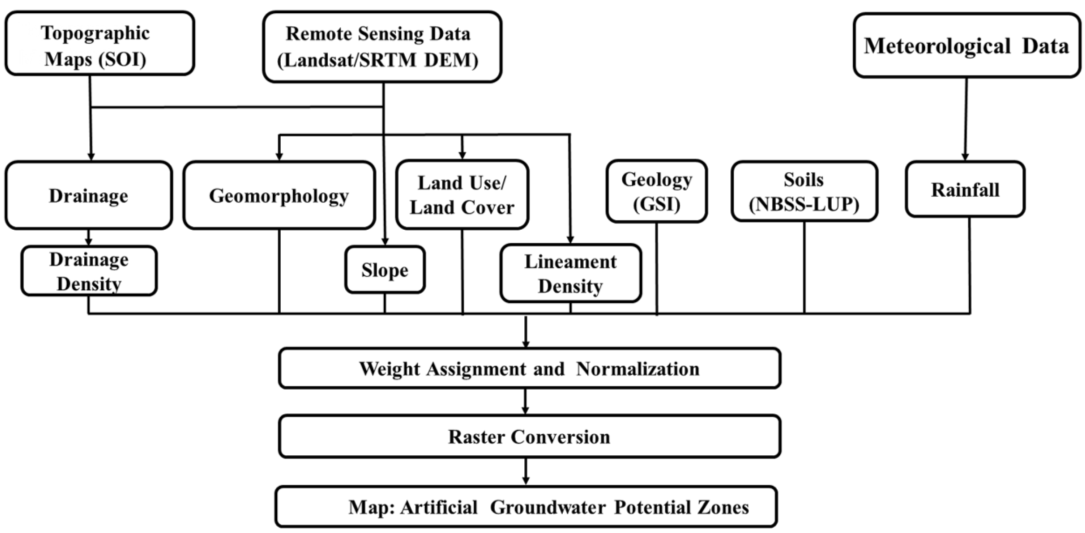

Figure 2. Methodology

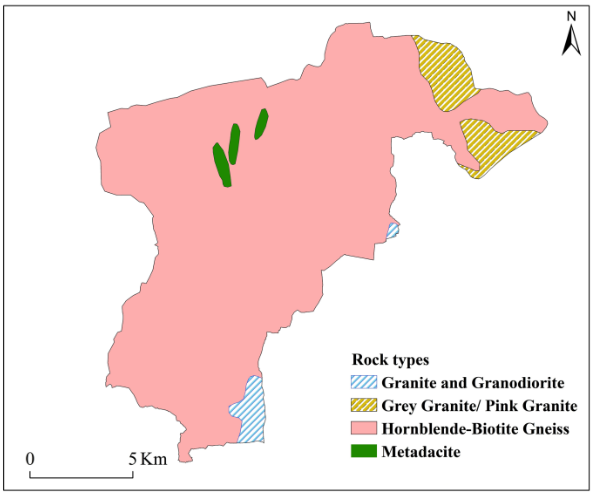

Figure 3. Rocks

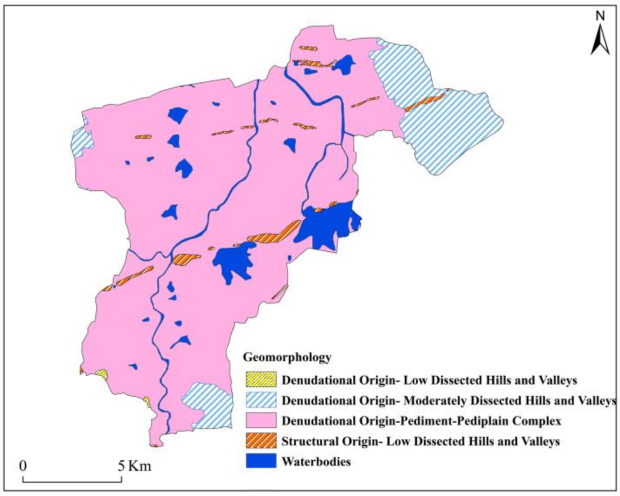

Figure 4. Geomorphology

3.1.3 Lineament Density (LD)

LD can be calculated as the total 'length of lineaments per unit degree'. It manages many esteemed land actualities about the structural distortion, fracturing, shearing and groundwater conceivable outcomes. The control of LD is a noteworthy and helpful strategy to catch many connected geological aspects and reasonable datasets and cautious perception offer more accuracy if there should be an occurrence of lineament convergence of a zone (Rajasekhar *et al.*, 2018b). LD in the area indirectly finds the groundwater capacity of the region, and then proximity of lineaments generally means a GWPZs. LD in the study area varies from 0 to 0.0141 km/km^2 (Figure 5). The higher LD values show good potential of groundwater recharge and effective sites can be selected for construction of groundwater structures from the region.

3.1.4 Drainage Density (DD)

DD is a converse capacity of porousness and thus, it is a significant parameter in assessing the GWPZs. DD is defined as closeness of spacing of stream channels per unit area. The drainage density of the area has a direct relation with topography, geomorphology, subsurface geology and LULC. DD values are classified into five categories (Horton, 1932; 1945) as: low (0-1.34 km/km^2), moderate (1.34-3.12km/km^2), moderately high (3.12-5.11 km/km^2), high (5.11-7.91 km/km^2) and very high (7.91-13.73km/km^2), respectively (Figure 6). These classes show relationship with surface runoff and rock permeability and helpful for delineation of groundwater potential zones in the region.

3.1.5 Slope

The slope factor implies a significant character in determining the rate of water flow. It controls the infiltration water into subsurface layers. Therefore, slope is an indicator of groundwater reasonableness. The surface run-off is moderate enabling good opportunity for water to infiltrate into subsurface in gentle slopping area while high slopping zone enable high surface run-off permitting less infiltration. Slope map of the region (Figure 7) is extracted from the CARTOSAT DEM image in ArcGIS environment and classified into five categories: 0º-6º, 6º-16º, 16º-26º, 26º-45º and > 45º. The study shows that the region with low to moderate surface run-off and infiltration is suitable for SWC structures (Kadam *et al.*, 2018).

3.1.6 Soils

Soil map was prepared based on information procured from office of Groundwater Department, Anantapur District (Figure 8). The soil in the region includes five principal classes: clay, coarse, fine and mixed loamy calcareous soils. Sandy soil shows higher infiltration rate, thus given higher score in AHP and the clayey soil show least infiltration subsequently allocated lower score.

3.1.7 Rainfall

The disparity in rainfall is a main cause of variation in recharge (Musa *et al.*, 2000; Magesh *et al.*, 2012; Shekhar and Pandey, 2014). It significantly affects the groundwater potentials and the proficiency of AHP (Kadam *et al.*, 2017). Monthly information of rainfall regularly collected at meteorological stations for 20 years (i.e., 1998-2018) was obtain from the District Irrigation Administration Office, Anantapur. The rainfall map was reclassified into five categories: 293.89-472.71, 472.71-582.55, 582.55-669.40, 669.40-774.14, and 774.14-945.29mm/year (Figure 9). The normal yearly rainfall in elevated regions is significantly more than the low lands (Siddi Raju *et al.*, 2018). Run-off potential map was prepared using information about LULC, HSGs and rainfall intensity (Figure 11). The formation of surface water is a standout amongst the most critical parameters of RWH. The run-off potential of the present study area is classified into four types: low run-off, moderate run-off, high run-off and very high run-off potentials. Extreme run-off potentials are observed in the Eastern part because of more thickness of water bodies.

3.1.8 Land use / Land cover (LULC)

Land use depicts how a piece of land is utilized, for example, for irrigation, built up (houses, industries, roads, etc.) identifies with human activities or financial capacities. LULC is interpretable by using satellite imageries (Rajasekhar *et al.*, 2018d). LULC in the region incorporates forest, cropland, fallow land, barren land and water bodies. Cropland and water bodies are very good categories for groundwater recharge and subsequently given maximum score (Figure 10). Sandy regions show good potentials of groundwater recharge while urban areas show poor potentials.

3.2 Analytical Hierarchy Process

AHP is multi-criteria decision making tool which combining various themes, amassing them in a different leveled structure, choices making on the general consequence of sets of segments and mixing the results (Saaty, 1999, 2004). Each thematic layer has been classified into five categories, which shows the connections between the consistent classes. The method for determining the weights to the thematic layer and their comparing features using AHP separately includes the accompanying advances (Saaty, 1980; 2008). A pairwise correlation framework is gathered based on Saaty's 9 point scale to assess the groundwater potentials in the region (Table 1).

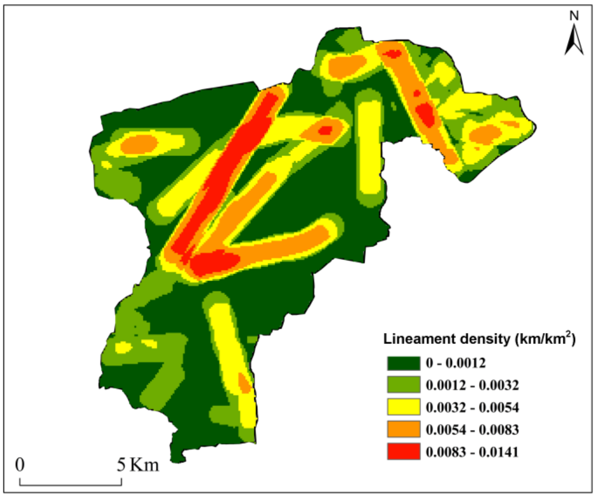

Figure 5. Lineament density

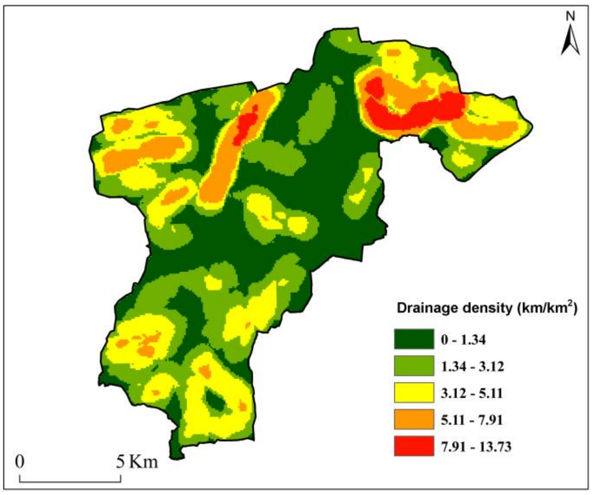

Figure 6. Drainage density

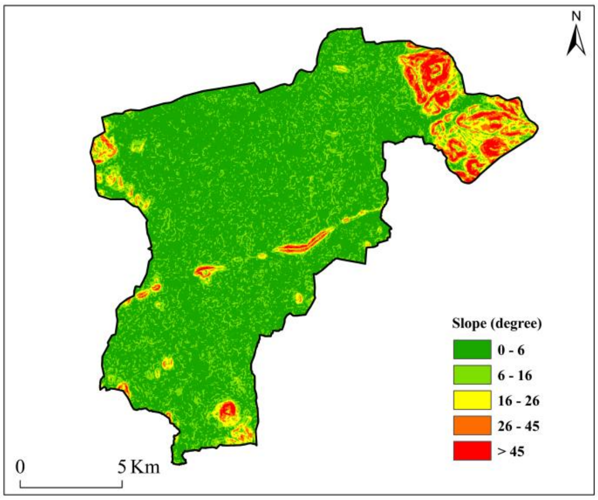

Figure 7. Slope

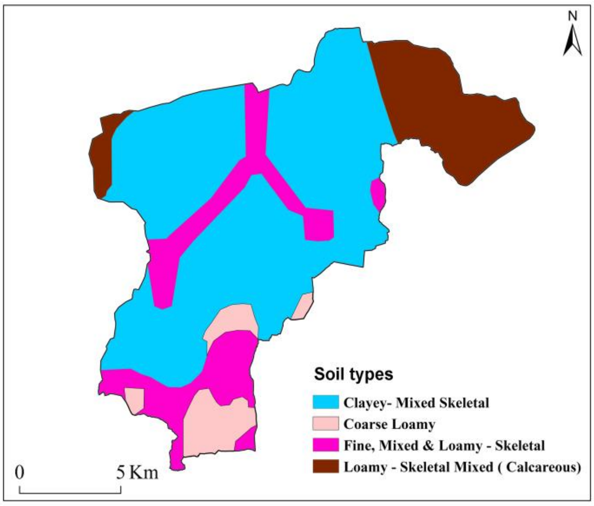

Figure 8. Soils

Table 1. Criterions: weights, influences and scores

Criterion	Weights	Influences (%)	Sub-criterion	Scores
Geology	0.15	15	Granite and Granodiorite	7
			Grey Granite/Pink Granite	6
			Hornblende-Biotite Gneiss	8
			Metadacite	3
Geomorphology	0.11	11	Water bodies	8
			Denudational Origin-Low Dissected Hills and Valleys	4
			Denudational Origin-Pediment-Pediplain Complex	7
			Denudational Origin-Moderately Dissected Hills and Valleys	6
			Structural Origin-Low Dissected Hills and Valleys	3
Land use/Land cover	0.12	12	Deciduous Broadleaf Forest	4
			Crop Land	7
			Mixed Forest	6
			Shrub Forest	6
			Barren Land	3
			Fallow Land	4
			Water bodies	8
Drainage Density	0.15	15	0 - 1.34	8
			1.34 - 3.12	6
			3.12 - 5.11	5
			5.11 - 7.91	4
			7.91 - 13.73	3
Soils	0.10	10	Clayey- Mixed Skeletal	3
			Coarse Loamy	6
			Fine, Mixed & Loamy-Skeletal	8
			Loamy-Skeletal, Mixed (Calcareous)	4
Slope	0.12	12	0 - 6	8
			6 - 16	6
			16 - 26	5
			26 - 45	4
			> 45	3
Lineament Density	0.10	10	0 - 0012	3
			0.0012 - 0.0032	5
			0.0032 - 0.0054	6
			0.0054 - 0.0083	7
			0.0083 - 0.0141	8
Rainfall	0.15	15	293.89 - 472.71	3
			472.71 - 582.55	4
			582.55 - 669.40	5
			669.40 - 774.14	7
			774.14 - 945.29	8

Table 2. Pair-wise comparison matrix

Criterion	Geomorphology	Geology	LULC	DD	LD	Soil	Slope	Rainfall	Normalized Weight
Geomorphology	1.000	0.500	0.333	5.000	5.000	0.500	1.000	0.143	0.11
Geology	2.000	1.000	0.250	4.000	1.000	0.500	0.500	3.000	0.15
LULC	3.000	4.000	1.000	5.000	2.000	0.333	3.000	0.250	0.12
DD	0.200	0.250	0.200	1.000	0.333	0.250	0.200	0.333	0.15
LD	0.200	1.000	0.500	3.000	1.000	0.333	2.000	1.000	0.10
Soil	2.000	0.500	3.000	4.000	3.000	1.000	3.000	2.000	0.10
Slope	1.000	2.000	0.333	5.000	0.500	0.333	1.000	0.200	0.12
Rainfall	7.000	0.330	4.000	3.000	1.000	0.500	5.000	1.000	0.15

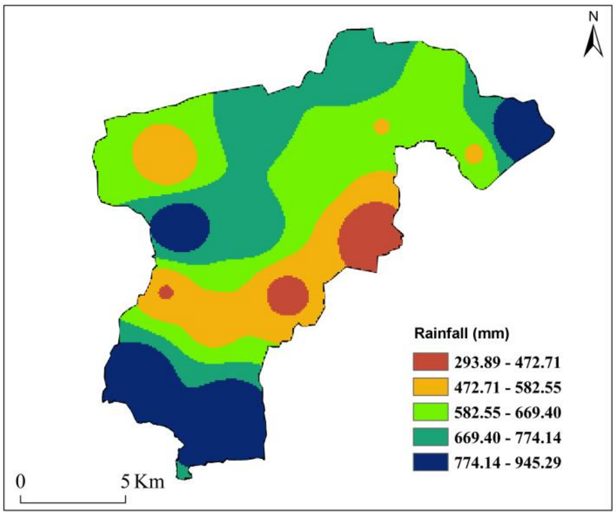

Figure 9. Rainfall

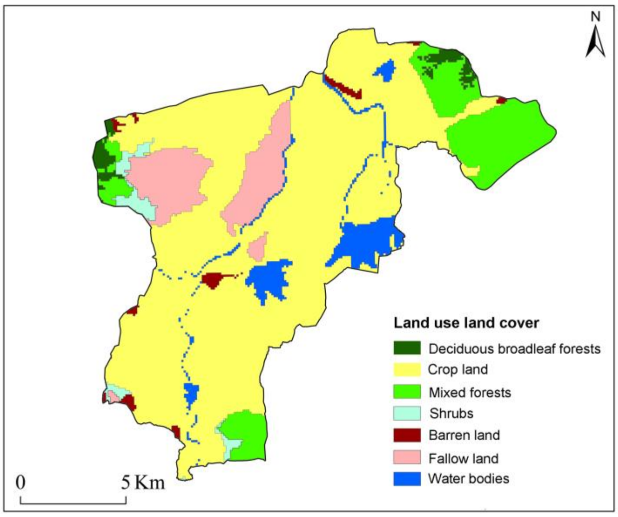

Figure10. Land use/Land cover

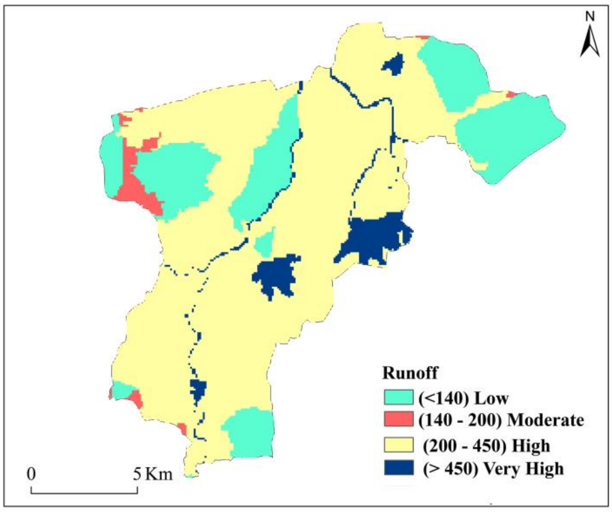

Figure 11. Runoff

4 RESULTS AND DISCUSSIONS

4.1 Artificial Groundwater Recharge Zones (AGRZ)

AGRZs of the present study were identified through weighted overlay of thematic maps: geology, geomorphology, LULC, LD, DD, soils, slope and rainfall in ArcGIS software. The weights were assigned for these eight thematic layers (Shailaja *et al*., 2018; Shankar *et al*., 2005) (Table 2) and the normalized weights for various features were calculated (Table 2). The AGRZ map was prepared using GIS-based AHP approach (Figure 12). As per the quintile process, the AGRZ values were reclassified into five categories: very low, low, moderate, good, and very good categories (CGWB 2006; 2007; 2013a; 2013b). The outcomes additionally demonstrated that 4.48%, 11.94%, 61.59%, 17.70%, and 4.29% area of the region shows very low, low, moderate, good, and very good potential of groundwater recharge (Table 3). In view of figure 12, the very good GWP are observed at the north-eastern piece of the region. As a result of a high slope, high DD and lithology with low porousness, the Eastern part falls into low AGRZ. It is obvious from the AGRZ map that Northwestern and Southwestern region of the present study is most reasonable for AGRZ (Kumar, *et al.* 2016; Singh *et al*., 2017). The accuracy assesment carried out through the existing ARS in the study area and matched with AGRZ map. ARS data according to AGRZs was collected from the field observations. The accuracy of the results is as:

Total number of artificial recharge structures	= 78
Number of structures: agreement with AGRZ map	= 64
Number of structures disagreement with AGRZ map	= 14
Over all accuracy	= 82%

The overall accuracy of the prediction shows that the methods and techniques used in the study are significantly reliable and precise.

4.2 Types and Feasible Numbers of Recharge Structures

Distinctive SWC sites have recommended in this study by various topographical and hydrogeological constraints and plausibility of structures in the present study AGRZ map prepared using AHP technique was used here to propose different artificial recharge structures (ARS) (Kumar *et al.*, 2016). The proposed and existing ARS in the study region are Check Dam (92), Check Wall (7) and Percolation Tank (19) (Figure 13).

Table 3. Potentials of artificial groundwater recharge

Classes	Area	
	%	km^2
Very Low	4.48	9.35
Low	11.94	24.94
Moderate	61.59	128.60
Good	17.70	36.95
Very Good	4.29	8.96

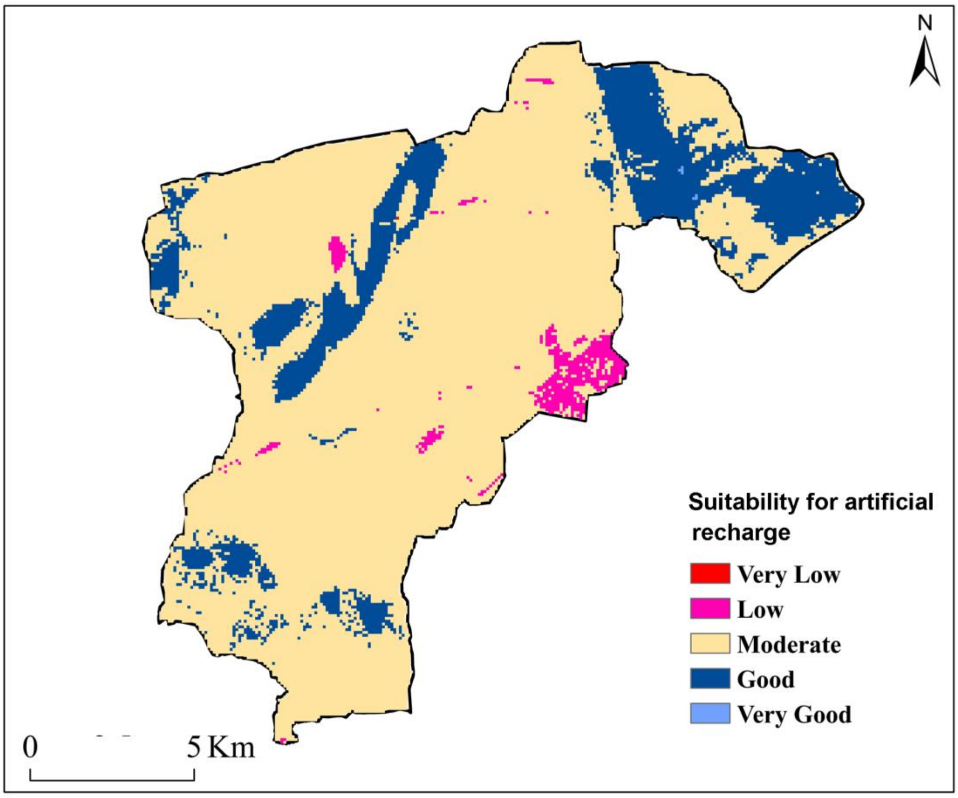

Figure 12. Suitability of artificial groundwater recharge

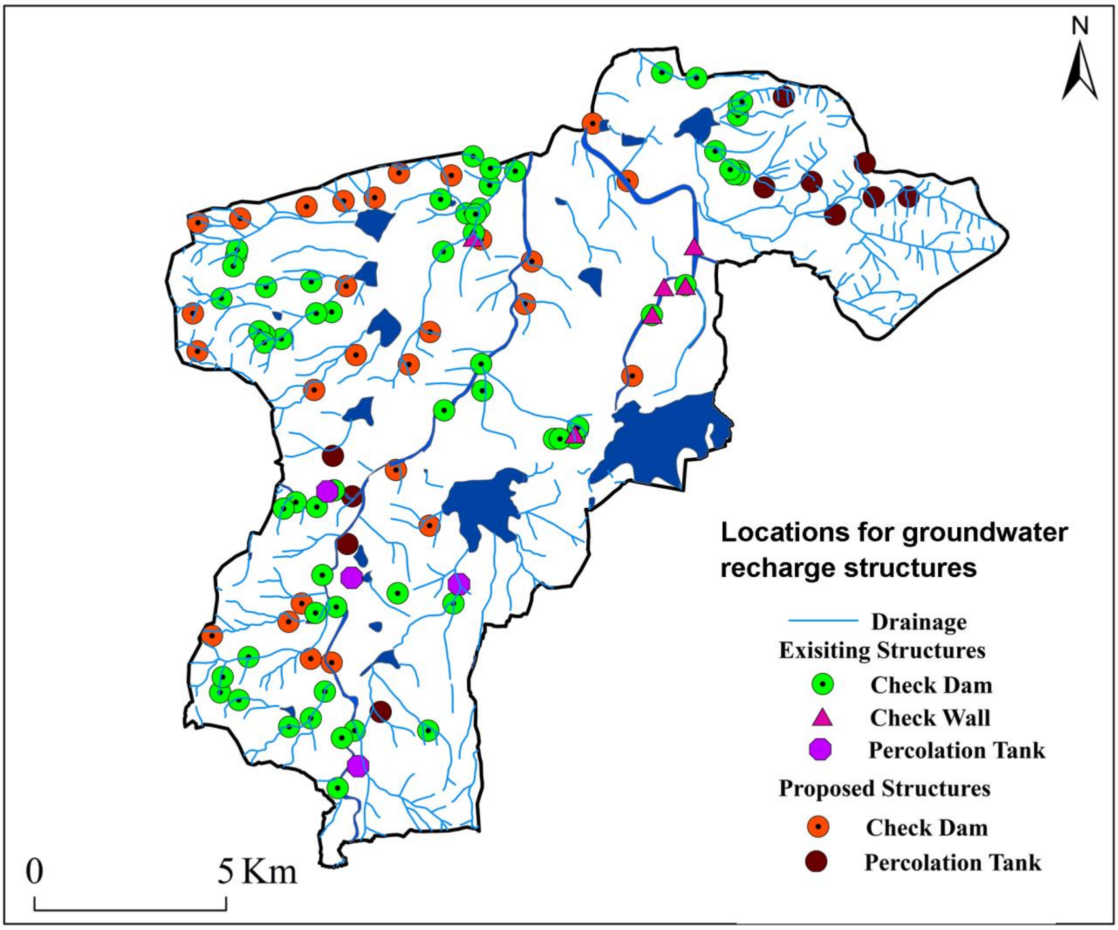

Figure 13. Identified locations for groundwater recharge structures

5 CONCLUSIONS

AHP based procedure has been embraced to identify AGRZs and suitable sites for ARS to improve groundwater status of the Anantapur district. AHP strategy underpins the overall significance of various thematic maps and their subclasses which influences groundwater recharge potentials. About 4.29 % of area in the region was found as very good and 17.70 % area show good groundwater potentials. On the other hand, 61.59, 11.94 and 4.48 % area shows moderate, poor and very poor groundwater recharge potentials. RS, GIS and AHP based integrated approaches were proved gainful to distinguish reasonable ARS for groundwater.

The suitability of the CD, PT and CW for areas near the villages was determined. Each of the structures was identified based on the specific need for the construction and environmental sustainability. 92 CDs, 19 PTs and 7 CWs were found suitable in the region. The Eastern part of the region has proven inadequate groundwater recharge potentials. This analysis shows precise site suitability for artificial recharge in the region.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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ABBREVIATIONS

AGRZ: Artificial Groundwater Recharge Zone; **AHP:** Analytical Hierarchy Process; **ARS**: Artificial Recharge Structure; **CD:** Check Dam; **CW**: Check Wall; **DD**: Draiange Density; **DEM**: Digital Elevation Model; **GIS**: Geographical Information System; **GWPZ:** Groundwater Potential Zone; **LD**: Lineament Density; **LULC**: Land use / Land cover; **PT**: Percolation Tank; **RS**: Remote Sensing; **SOI**: Survey of India; **SWC**: Soil Water Conservation.

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