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Artificial Groundwater Recharge Zones Mapping using Remote Sensing and GIS for Sub-Watersheds of Krishna Basin

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ABSTRACT

The exacerbated exploitation of groundwater resources has led to alarming decrease in groundwater levels. It is necessary to identify areas that allow for efficient recharge so that implementation of artificial groundwater recharge can be conducted in such areas with better efficiency. This study maps zones with their varying degrees of affinity for groundwater recharge in two of the sub-watersheds of the Krishna Basin.

The factors affecting potential of groundwater recharge were determined and then thematic maps for each factor were generated in ArcGIS 10.8. Remote sensing data from sources like 'Bhuvan' and 'Bhukosh' were used for the generation of the thematic layers. The Analytic Hierarchy Process (AHP) was used while deciding the relative and subsequently overall importance of each layer. The weights derived from the AHP were applied to the thematic layers and the mapping of zones for artificial groundwater recharge was done.

Keywords-- Artificial Groundwater Recharge, ArcGIS 10.8, Saaty's AHP, AGR Zones Mapping, Remote Sensing, GIS

I. INTRODUCTION

Groundwater is one of the most exploited resources, withdrawal rates around 100 km^3 per year globally (Jean Margat, 2013). India alone draws an estimated 249 billion cubic meters of water from the ground on an annual average (Kaur, 2019). A large percentage of the water used for irrigation and drinking purposes is provided by groundwater resources (Smith, 2016). This unchecked exploitation has led to a multitude of problems stemming from lowered groundwater levels aggravated by insufficient groundwater recharge. It is predicted that by 2050, almost 1.8 billion of the population could be living in areas of near complete groundwater depletion, leading to food, water and economic shortages (AGU Fall Meeting, 2016).

There is thus an immediate necessity to switch to using sustainable sources of water and encourage the wide-spread implementation of practices like artificial groundwater recharge (AGR) to avoid all of the aforementioned problems. While the significance of AGR has been recognized and its implementation has increased globally since the early 1900s (Babcock HM, 1942) ((ed), 1985), there is a need for better planning to yield results with higher efficiency.

The success of AGR highly depends on the suitability of area chosen and its affinity for recharge (Meysam Gavahi, 2018). This affinity is affected by geology, geomorphology, LULC, soil texture, etc. There are various socio-economical, hydrological, economical and administrative aspects that determine site selection. To scientifically find locations that can adequately support the construction of artificial recharge structures, each hydro-geomorphic unit is evaluated for its recharge potential, and a map showing zones with the varying degrees of potential are prepared (Patil, 2014).

Mapping these sites via conventional methods is time consuming and might not result in the most accurate results (Alesheikh, 2008). Though the use of RS and GIS techniques to map AGR zones has emerged relatively recently, the results are promising (Alivia Chowdhury, 2010). GIS methods used to map AGR zones are able to take into consideration the multiple factors that affect groundwater recharge and thus yield better results (Ismail Chenini, 2010).

When dealing with a a large number of factors affecting the decision, it would make sense to adopt multiple criteria decision-making (MCDM) such as Multi-Attribute Utility Theory, Analytic Hierarchy Process (AHP) (Saaty, 1980), Fuzzy Set Theory, Goal Programming, etc. This study uses the AHP technique for demarcating zones with varying potential for AGR. The methodology discussed in this study could be useful to concerned decision-makers and governing bodies in the efficient planning and management of vital groundwater resources, especially on a large scale (Alivia Chowdhury, 2010).

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II. STUDY AREA

The Krishna River is the second largest eastward draining interstate river in Peninsular India. It rises in the Mahadev range of the Western Ghats at an altitude of 1,337 meters near Mahabaleshwar in Maharashtra State, about 64 km from the Arabian Sea. It flows for a distance of 305 km in Maharashtra, 483 km in Karnataka and 612 km in Andhra Pradesh and Telangana before finally flowing into the Bay of Bengal. The total length of the river is about 1,400 km.

The Krishna basin or watershed lies between the latitudes 13° 07' N and 19° 20' N and longitudes 73° 22' E and 81° 10' E. On the north, the basin is bound by the range separating it from the Godavari basin, on the south and east by the Eastern Ghats and on the west by the Western Ghats. The total drainage area of the basin is around 258,948 km^2.

The study area comprises of the last two sub-watersheds of the Krishna basin. They each occupy an area of 11013.16 and 36592.24 square kilometers and lie in the lower riparian region. Let us call them 'sub-watershed 1' and 'sub-watershed 2'.

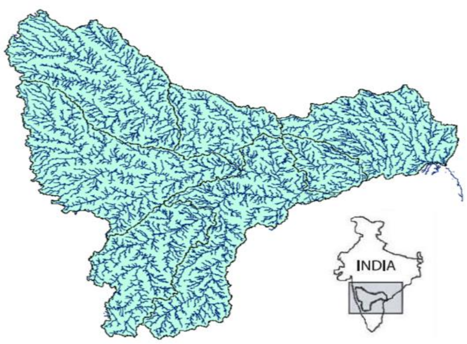

Figure 1: Krishna Watershed

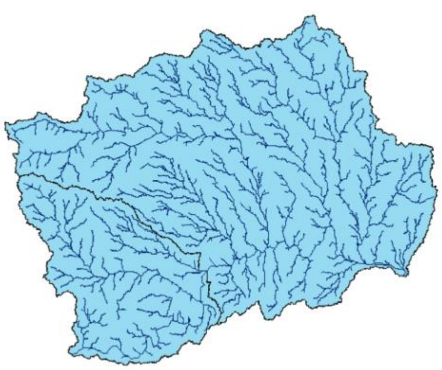

Figure 2: Sub-watershed 1 on the right and sub-watershed 2 on the left

III. DATA

The data for creating the thematic layers was procured from various sources. The shapefiles for geology and geomorphology for India were readily available in the 'Bhukosh' portal offered by the Geological Survey of India.

Table 1: Data and their source

FACTOR	SOURCE
Geo-morphology	Geological Survey of India (Bhukosh)
Geology	Geological Survey of India (Bhukosh)
LULC	Decadal LULC maps for India in NASA's ORNL DAAC Portal
Drain density	Earthdata - NASA
Slope	Earthdata - NASA
Specific yield	Indian Water Resources System
Aquifer Transmissivity	Indian Water Resources System
Soil texture	Data download from Bhuvan portal

The LULC shapefiles were downloaded from the ORNL DAAC portal which is made available by NASA. The shapefiles for slope and line density of the catchment were developed in ArcGIS 10.2 from ASTERGDEM downloaded from NASA's 'Earthdata' website. The separate shapefiles for each soil texture were downloaded from the 'Bhuvan' portal and merged in ArcGIS 10.8 interface. The shapefiles for specific yield and aquifer transmissivity were manually generated with reference to maps available in the Indian Water Resources System website.

IV. METHODOLOGY

Each sub-section briefly discusses the methodology used to delineate the sub-watersheds, generate the shapefiles for each thematic layer and then application of the final weights to derive a map with the Artificial Groundwater Recharge potential zones. This section will also shed some light on the AHP process that is used to decide the weights for each level of the decision-making process.

4.1 Generation of LULC Map

Readily available decadal LULC maps for India in NASA's ORNL DAAC portal were used. The map is available as a raster with each LULC class being assigned a different value. The raster was first clipped to the extent of the study area. The existing 19 classes were reclassified into four classes- vegetation, developed land, water bodies and barren land.

4.2 Generation of Geology and Geomorphology Maps

Shapefiles for both Geology and Geomorphology were readily available for the administrative boundaries of India in the Geological survey of India (Bhukosh) website. The Krishna Basin lies in the states of Karnataka, Maharashtra, Andhra Pradesh and Telangana. The shapefiles corresponding to these states were downloaded, merged using the 'Union' tool in ArcGIS 10.8 and clipped to the extent of the study area.

4.3 Generation Of Soil Texture Map

The Bhuvan Portal offers separate maps for each type of soil texture- sandy, loamy, clayey, skeletal- clayey. The individual maps were downloaded and merged in the GIS interface to get the soil map. The shapefile was then clipped to the study extent.

4.4 Generation Aquifer Transmissivty and Specific Yeild Maps

The Indian Water Resources System (WRIS) website has downloadable raster data concerning the aquifer types of India. As there was no defined attribute table, the polygon for each shapefile was manually traced and the values of aquifer transmissivity and specific yield were manually entered in the Attribute Table.

4.5 Generation of Drainage Density and Slope Maps

The data had been downloaded from Earth data - NASA. The data had been reclassified using a reclassified data management tool and converted to shape file using raster to polygon tool.

4.6 Analyttic Heirarchy Process (AHP)

The Analytical Hierarchy Process is a decision-making process that decomposes a complex multi-criteria decision problem into a hierarchy, prioritizes the hierarchy, and finally makes a decision. The evaluations of AHP are also included without needing to involve all decision-makers in the final choice to elicit the utility functions of their subjective and objective utility functions criterion, based on pair wise comparisons of the options (Saaty, 1980). As a result, AHP has been applied to a wide range of situations. The process of AHP is briefly discussed in the following paragraphs.

Let C1, C2, ..., Cn denote the "n" separate and independent options, and a_{ij} denotes a quantified alternative. On two choices, C_i and C_j, make a decision. The result is an n*n matrix A. After building the matrix, weights are assigned to each choice according to personal preference. This is done by using Saaty's preference scale which is shown in Table.2.

After building a pair wise comparison matrix, consistency is checked, this can be done by Consistency index (CI) and Consistency ratio (CR) proposed by Saaty to verify the consistency of the comparison matrix. CI and CR are defined as follows:

$$CI=\frac{\lambda \max * n}{n-1}$$

Where 'λ_{max}' is the maximum Eigen Value of the Normalized Pair wise matrix

And 'n' is the dimension of comparison matrix

$$CR=\frac{CI}{RI}$$

Where CI is Consistency Index

Table 2: Saaty's scale of reference

Numerical rating	Importance
1	i is equal importance to j
3	i is slightly more important than j
5	i is strongly more important than j
7	i is very strongly more important than j
	i is extremely important than j
9	Intermediate values
2, 4, 6, 8	

And 'RI' is Random Index

The Random Index takes on the values as shown in Table.3 depending on the number of elements being compared. If the CR is less than 0.1, the estimate is accepted; otherwise, a new comparison matrix is requested until the CR is less than 0.1.

Table 3: RI Values as given by Saaty

Matrix Size	Random Consistency Index (RI)
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

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The subject layers with weight assignments have been merged (Overlay) in ArcGIS 10.8 normalized weights of different polygons in the integrated layer resulting from the following equation to calculate the Groundwater Recharge index (GWRI).

$$GWRI = (GM_wGM_{wi} + GG_wGG_{wi} + LULC_w\ LULC_{wi} + DD_wDD_{wi} + SLwSL_{wi} + AT_wAT_{wi} + SY_wSY_{wi} + ST_wST_{wi})$$

Where GG = Geology; GM = geomorphology; LULC = Land Use / Land Cover; DD = Drainage Density; SL = Gradient; AT = Aquifer Penetration; SY = Specific Yield; ST = soil texture; `` w`` = normalized weight of the topic; `` wi`` = normalized weight of each feature of the theme.

The range of GWRI values was divided into three classes (called a zone) and the GWRI of different polygons was grouped into one class in different disciplines. The entire study area was qualitatively divided into three different Charging zones. Finally, a map showing different types of groundwater recharge zones in the study area were created in ArcGIS 10.8.

V. RESULTS AND DISCUSSIONS

The results can be broadly categorized as the AHP results comprising of all the matrices built and weights obtained, and the GIS results which show the thematic layer and final zones of recharge potential. Each section of this chapter is dedicated to one of the two types of results obtained.

5.1 AHP Results

Table.4 shows the weights assigned to each factor at the very first level and the normalized weights that were derived by building AHP matrices.

Table 4:1 Assigned and normalized weights

Theme	Assigned weight	Normalized Weight
Geomorphology	8	0.17
Geology	7	0.2
LULC	6	0.15
Slope	5	0.13
Drainage density	4	0.05
Aquifer transmissivity	3	0.09
Specific yield	3	0.09
Soil texture	2	0.12

Table.5 shows the weights assigned at the second level of the decision making process and the final weights for each class.

5.2 Thematic Layers

The thematic maps for all the 8 factors were generated and are shown in Table.6 and Table.7.

Table 5: Final Weights for Sub-Classes

Theme	Class	Recharge prospect	Assigned weight	Normalized Weight	Final weight
Geomorphology	Sand	Very Good	9	0.2	0.034
	Alluvial	Very good	8	0.18	0.030222
	Pediment plain	Good	7	0.16	0.026444
	Sandstone	Good	7	0.16	0.018328
	Silty loam, clay	Moderate	5	0.11	0.0151111
	Sea-stack/saltpan	Moderate	4	0.09	0.015111
	Water body	Moderate	4	0.09	0.003777
	Concrete	Poor	1	0.02	0.169439
Geology	Alluvium	Very Good	5	0.29	0.058826
	Quartz	Good	3	0.18	0.035294
	Shale	Good	2	0.12	0.053529
	Black soil	Good	2	0.12	0.026529
	Clay	Moderate	1.5	0.09	0.017145
	Intrusive Igneous	Moderate	1.3	0.08	0.015294
	Metamorphic	Moderate	1.2	0.07	0.014117
	Rock soil	Poor	1	0.06	0.011764

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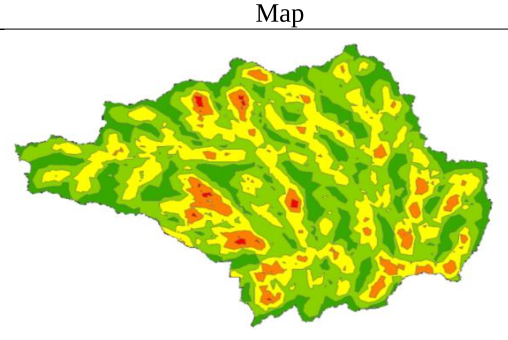
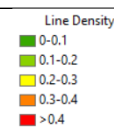
LULC	Vegetation	Very good	8	0.372	0.055
	Barren land	Good	7.5	0.3488	0.0523
	Water Body	Moderate	5	0.23255	0.03488
	Urban Area	Poor	1	0.0465	0.0069
Slope	0-1	Very good	5	0.2333	0.016666
	1-3	Good	4	0.2666	0.013333
	3-5	Good	3	0.2	0.01
	5-10	Moderate	2	0.1333	0.00666
	>10	Poor	1	0.0666	0.03333
Drainage density	0-0.1	Very Good	5	0.3333	0.01666
	0.1 -0.2	Good	4	0.2666	0.0133
	0.2 - 0.3	Good	3	0.2	0.01
	d 0.3 -0.4	Moderate	2	0.1333	0.00666
	>0.4	Poor	1	0.0666	0.00333
Aquifer Transmissivity	>300	Very good	8	0.33	0.048
	151-300	Good	4	0.566	0.024
	51-150	Moderate	2	0.1666	0.012
	0-50	Poor	1	0.0666	0.006
Special Yield	>3	Very good	6	0.4615	0.0415
	2-3	Good	4	0.6076	0.02769
	1-2	Moderate	2	0.15384	0.0138
	0-1	Poor	1	0.0769	0.006923
Soil Texture	Sandy	Very good	9	0.5294	0.063529
	Loamy	Good	5	0.2941	0.03529
	Skeletal Clay	Moderate	2	0.1176	0.014117
	Clay	Poor	1	0.0588	0.00705

Table 6: Thematic Layers for Sub-Watershed 1

Theme	Map	Legend
Line Density		

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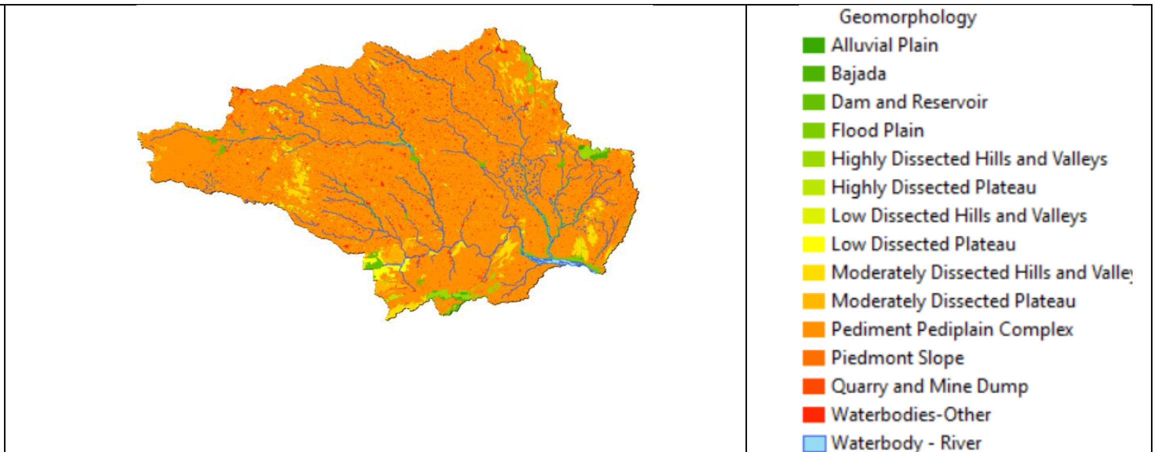
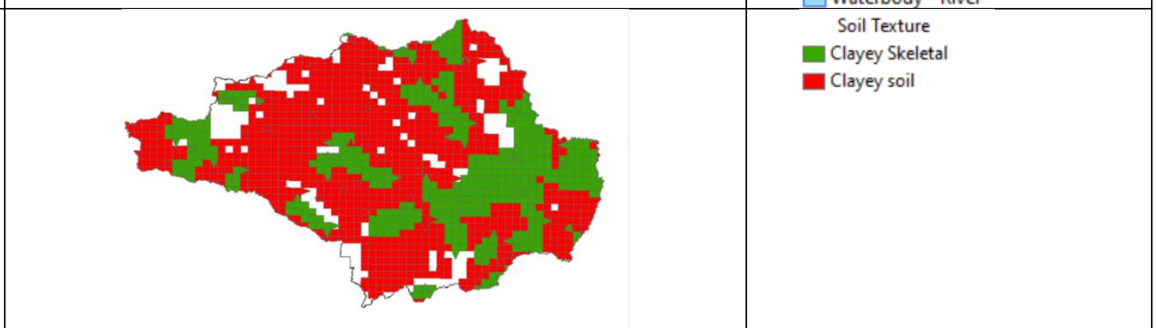
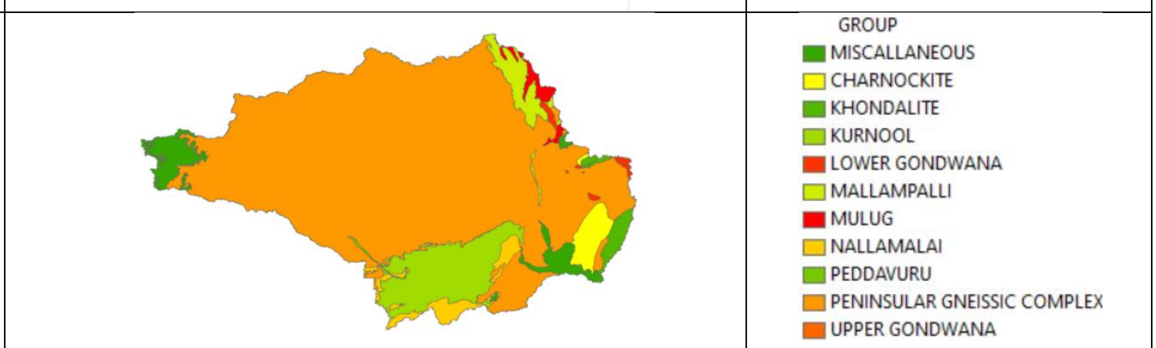
Geo-morphology



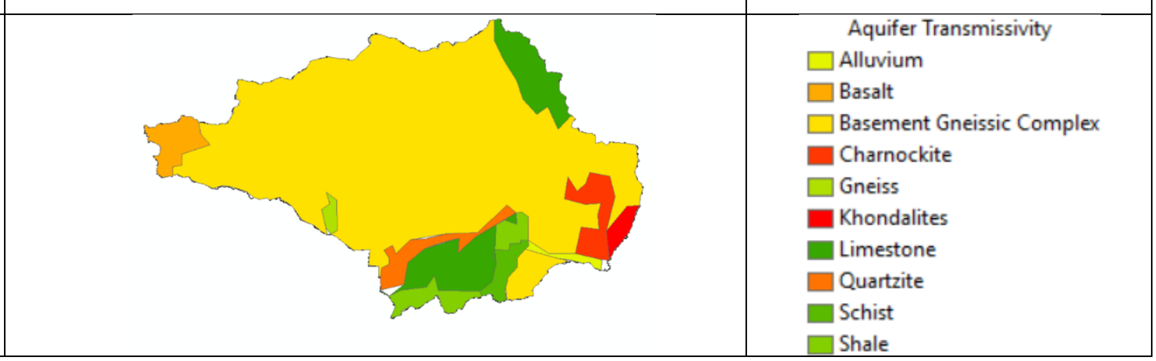
Soil Texture



Geology



Aquifer Transmissivity



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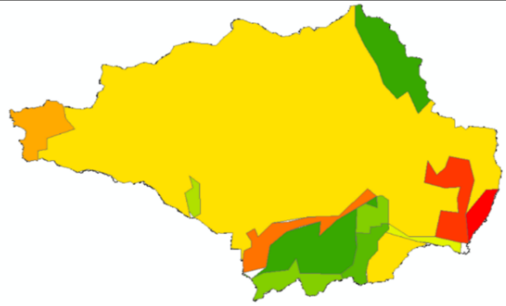
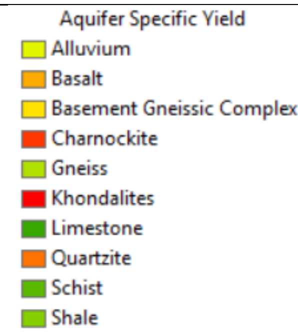
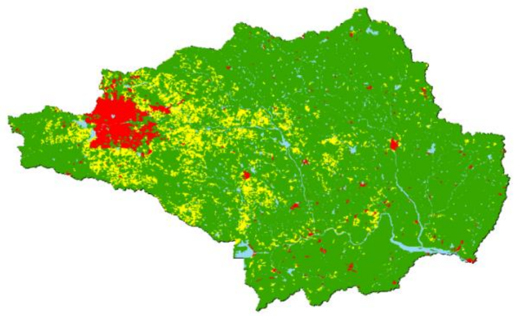
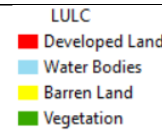
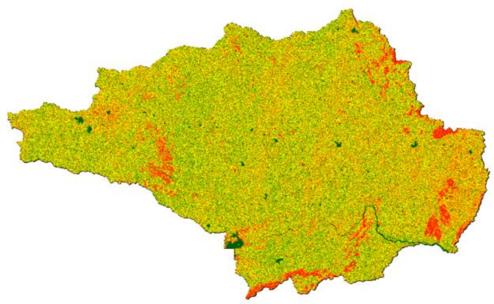
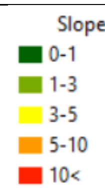
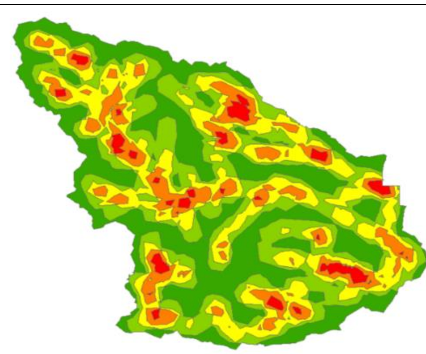
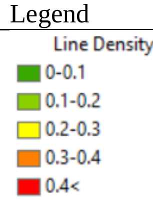
Aquifer Specific Yield		
LULC		
Slope		

Table 7: Thematic Layers for Sub-Watershed 2

Theme	Map	Legend
Line Density		

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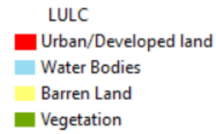
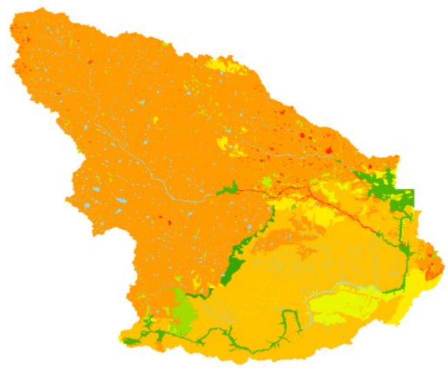
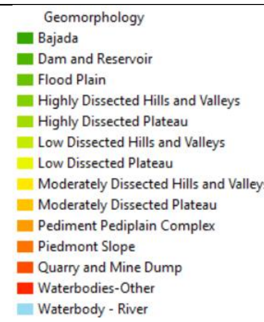
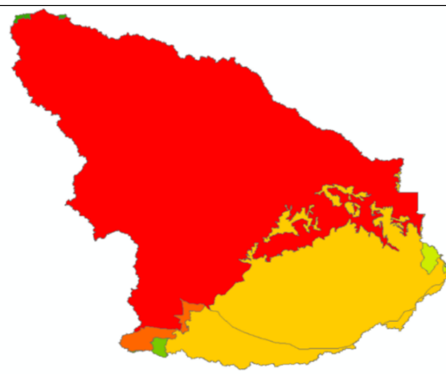
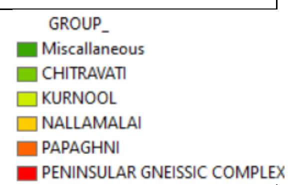
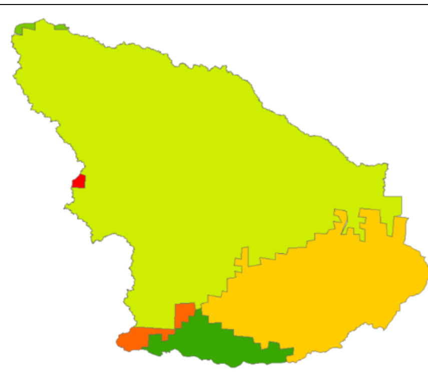
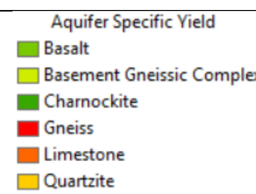
LULC		
Geo-morphology		
Geology		
Aquifer Specific Yield		

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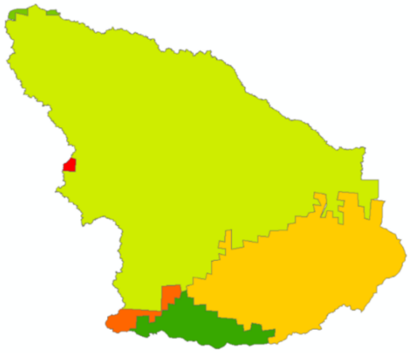
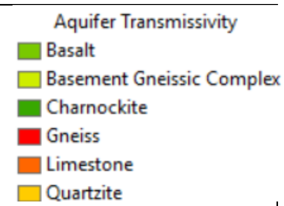
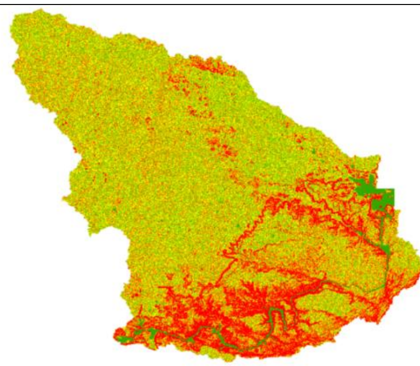
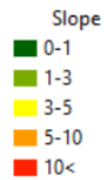
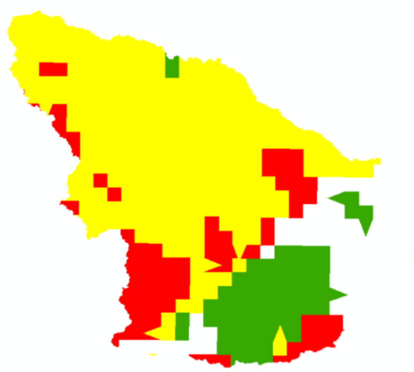
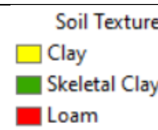
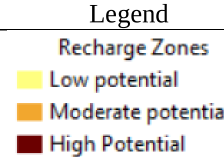
Aquifer Transmissivity		
Slope		
Soil Texture		

Table 8

Water-shed	Map	Legend
Sub-Watershed 1		

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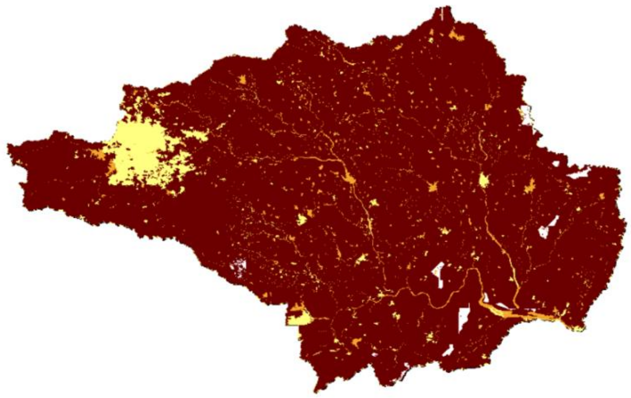
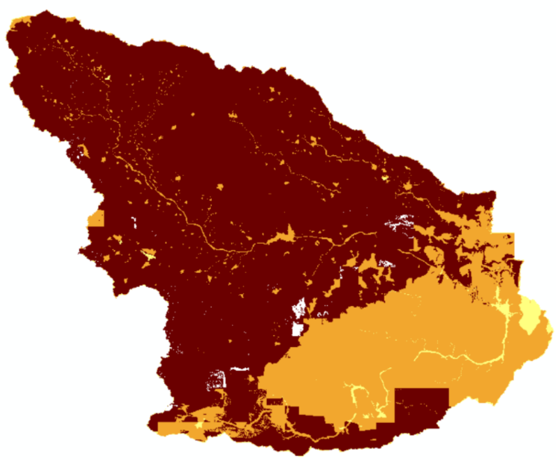
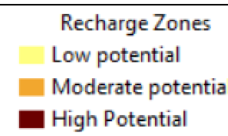
		
Sub-watershed 2		

Watershed	Zone	Area in Square. Km
Sub-watershed 1	Low Potential	168.07
	Moderate Potential	2877.55
	High Potential	7967.54
Sub-watershed 2	Low Potential	1721.35
	Moderate Potential	1335.82
	High Potential	33535.07

VI. CONCLUSION

It is evident from the study that all of the data required for mapping artificial recharge zones is readily available with free access on the internet. The process of mapping too is quite simple to follow for anyone familiar with any GIS interface. It therefore costs us nothing except a little time to map the recharge zones. This mapping will go a long way in effective implementation of Artificial Groundwater Recharge projects and relevant policies.

It can be observed from the derived statistics that a relatively large area amounting to almost 87% of the area in both watersheds fall under zones with high potential. This could be due to the intensive large-scale agriculture that is practiced in the entirety of the Krishna Basin, especially in the lower basin part. The aquifer and soil types allow for successful groundwater recharge. It must be worth noting that even zones with moderate potential can adequately accommodate artificial groundwater recharge.

The main drawback to the study is the possible inaccuracy of the data being used or sometimes low-quality results. Large area studies require low resolution data; hence the quality of the results may be of diminished nature. It is hence recommended to validate the results with reference to ground data obtained manually for the best possible implementation of Artificial Groundwater Recharge.

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The practice of Artificial Groundwater Recharge must be therefore widely encouraged. Governing bodies can make use of the maps generated so as to maximize the efficiency of AGR. It would prove economical and efficient for such AGR zone mapping to be done on a large scale so planned action can take place.

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