INDIAN INSTITUTE OF REMOTE SENSING
Indian Space Research Organisation
Department of Space, Govt. of India

PROJECT REPORT
on

IDENTIFICATION OF SUITABLE SITES FOR GROUNDWATER RECHARGE USING RAINWATER HARVESTING

Submitted to-
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1. Introduction

1.1 Background

The practice of rainwater harvesting can be traced back to 3000 years ago. With the advancement of technology, these practices were lost in many urbanized regions. Recently, the water demands have increased due to population growth while the per capita water availability has decreased due to the changing climate. This has led to the revival and modernization of rainwater harvesting techniques. Major benefits of rainwater harvesting include efficient use of available natural resources, augmentation of existing supply capacity, reduced contaminant loads into water bodies, reduced load on the sewer network, reduced soil erosion, reduced flood and drought risks, and environmental protection.
India's utilizable water resource is 1122 BCM (billion cubic meters), out of which surface water and renewable groundwater account for 690 BCM and 432 BCM, respectively. The overexploitation of groundwater beyond naturally replenishable limits has led to groundwater depletion and degradation. Arid and semi-arid regions of the world are facing an imminent water crisis that can be mitigated by the technologically viable implementation of socially acceptable Rainwater harvesting techniques.
Comprehensive studies of subsurface geology and water contamination have been recommended before RWH can be utilized. Many researchers have worked to identify the potential sites for rainwater harvesting coupled with groundwater recharge using remote sensing and GIS tools.

1.2 Literature Review

The success of Rainwater Harvesting (RWH) depends on the selection of suitable and cost-effective sites. The remote sensing data and GIS-based decision support system help in identifying RWH sited (Mbilinyi et al., 2007). Different studies efficiently used Analytical Hierarchy Process (AHP) (Ammar et al., 2016; Krois & Schulte, 2014; Jothiprakash & Sathe, 2009) for the identification and optimization of the potential water harvesting sites. In some recent studies, AHP is integrated with Fuzzy Logic to standardize the factors and derive weights used as a total score for land suitability (Alwan et al., 2020; Al-Abadi et al., 2017).

Several criteria layers, including slope, stream order, soil type, precipitation, evaporation, roads, and the Normalized Difference Vegetation Index (NDVI) are used for this purpose. (Alwan et al., 2020). Mbilinyi et al. (2007) developed a GIS-based Decision Support System (DSS) for selecting RWH potential sites in Kilimanjaro Region, Tanzania by considering rainfall, slope, soil texture, soil depth, drainage, and land use/land cover. Singh et al. (2009) identified suitable sites for water harvesting structures like check dams and percolation tanks in the Soankhad watershed, Punjab using themes like land use, hydrological soil group, slope, and Digital

Elevation Model (DEM). The papers (Abdulla Umar Naseef & Thomas, 2016; Mahmoud & Alazba, 2015) focused on factors such as rainfall, slope, potential runoff coefficient (PRC), land cover/use, and soil texture. Most of the studies initially considered filled sinks of the digital elevation model (Alwan et al., 2020; Karani et al., 2019; Tiwari et al., 2018) and (Tiwari et al., 2018) made proper use of depression sites as natural structures for rainwater harvesting. Various researches suggested the runoff estimation through the water balance approach (Jasrotia et al., 2009), Soil Conservation Service - Curve Number (SCS-CN) method (Tiwari et al., 2018; Krois & Schulte, 2014; Kadam et al., 2012; Ramakrishnan et al., 2009) Artificial Neural Network (ANN) based model (Sarkar & Kumar, 2012). The most widely used for the estimation of runoff is the SCS-CN method. Alataway & Alfy (2019) found an increase in groundwater recharge by 44% and decreasing evaporation loss by 86% by implementing artificial recharge drills in reservoirs of dams fed majorly by flash flooding and moderate precipitation.

The review of the literature indicated that the selection of suitable water harvesting and artificial recharge sites is of prime importance for planners and managers to tackle growing water scarcity and environmental problems. Although the application of RS and GIS techniques for rainwater harvesting is widespread in different parts of the globe, only a few studies considered an integrated framework of geospatial and Multi-Criteria Decision Analysis (MCDA) techniques in the Bhilwara region, Rajasthan for the evaluation of suitable sites for rainwater harvesting and artificial groundwater recharge.

1.3 Research Questions

1. What are the suitable sites for groundwater recharge in the Bhilwara district of Rajasthan using rainwater harvesting?

2. What is the estimated area of groundwater recharge from these potential sites?

1.4 Research Objectives

Major objective:

To identify suitable sites for groundwater recharge using rainwater harvesting and estimate the area of groundwater recharge.

Sub-objectives:

1. To find sites for rainwater harvesting structures.

2. To estimate the area with the potential for groundwater recharge from these sites.

1.5 Innovation

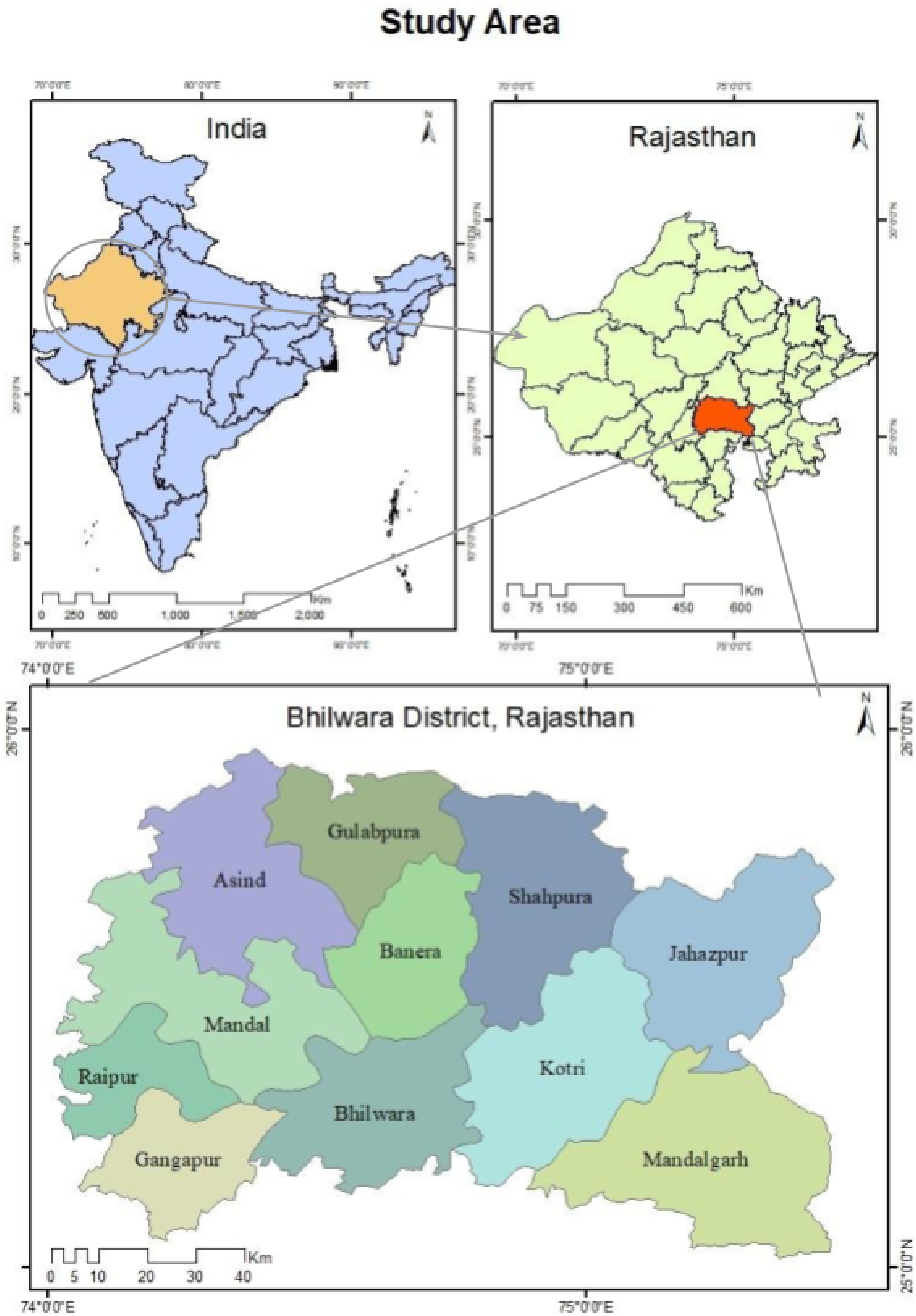
Bhilwara district is located in one of the seven states (Rajasthan) where the Ministry of Jal Shakti through a Central Sector Scheme i.e., Atal Bhujal Yojana (ATAL JAL) is trying to improve groundwater management and ensure its long-term sustainability. As per Atal Jal data, the Bhilwara district has a few artificial recharge and water conservation structures despite the deepening water crisis drawing our attention. Recent havoc caused by heavy rain in Bhilwara and adjoining areas which caused waterlogging issues is another reason why there is a crying need to make sustainable use of rainwater through harvesting.

This research attempts to integrate one of the best methods of identifying rainwater harvesting i.e., AHP to derive weights and SCS-CN (or NRCS-CN) method to estimate the runoff potential in the region.

2. Study Area

Bhilwara district, the Manchester of Rajasthan is situated between 25°01'N and 25°58'N; 74°01'E and 75°28'E covering a geographical area of 10,455 sq. km. There are 7 sub-divisions in the district- Bhilwara, Shahpura, Gangapur, Gulabpura, Asind, Mandalgarh and Jahajpur. There are a total of 1834 villages in the district. The decennial population growth rate of the district has been 19.27% since 2001. It is roughly equal to the population of Kuwait (Census, 2011). Most of the population resides in the rural part of the district.

The average temperature in Bhilwara is 25.3 °C. About 645 mm of precipitation falls annually and is mostly received during the southwest monsoon. It enters the district in the last week of June and withdraws in the middle of September. The atmosphere is generally dry except during the monsoon period. The area is drought-prone. Bhilwara district falls in the Banas (9157.2 sq. km), Chambal (1164.9 sq. km) & Luni basins (133.0 sq. km). The Major River of the district is Banas, which flows northeast to an easterly direction. Important tributaries flowing through Bhilwara are Berach, Kothari, Unli, Mendi, Nakadi, Chandrabhaga, and Khari River. All these are ephemeral. Soil is clayey loam found in the hilly areas in the central parts of the district while loam is found in the entire district. The groundwater level of all the 11 blocks of the district is 'Over Exploited'. Alluvial aquifers are not present in this district. Out of aquifer types, the spatial distribution of Schist is the most predominant covering 47.5% of the district whereas gneisses are next in the sequence with about 43% spatial coverage.



Study Area
India
Rajasthan
Bhilwara District, Rajasthan
Gulabpura
Asind
Shahpura
Banera
Jahazpur
Mandal
Kotri
Raipur
Bhilwara
Gangapur
Mandalgarh
Km
0 250 500 1,000 1,500 2,000
0 75 150 300 450 600
0 5 10 20 30 40
74°0'0"E
75°0'0"E
26°0'0"N
25°0'0"N

3. Materials and Methodology

Various sources have been used for acquiring data and different parameters like LULC, Soil, Drainage density, Runoff potential, etc as layers for final AHP. The methodology flowchart is as follows:

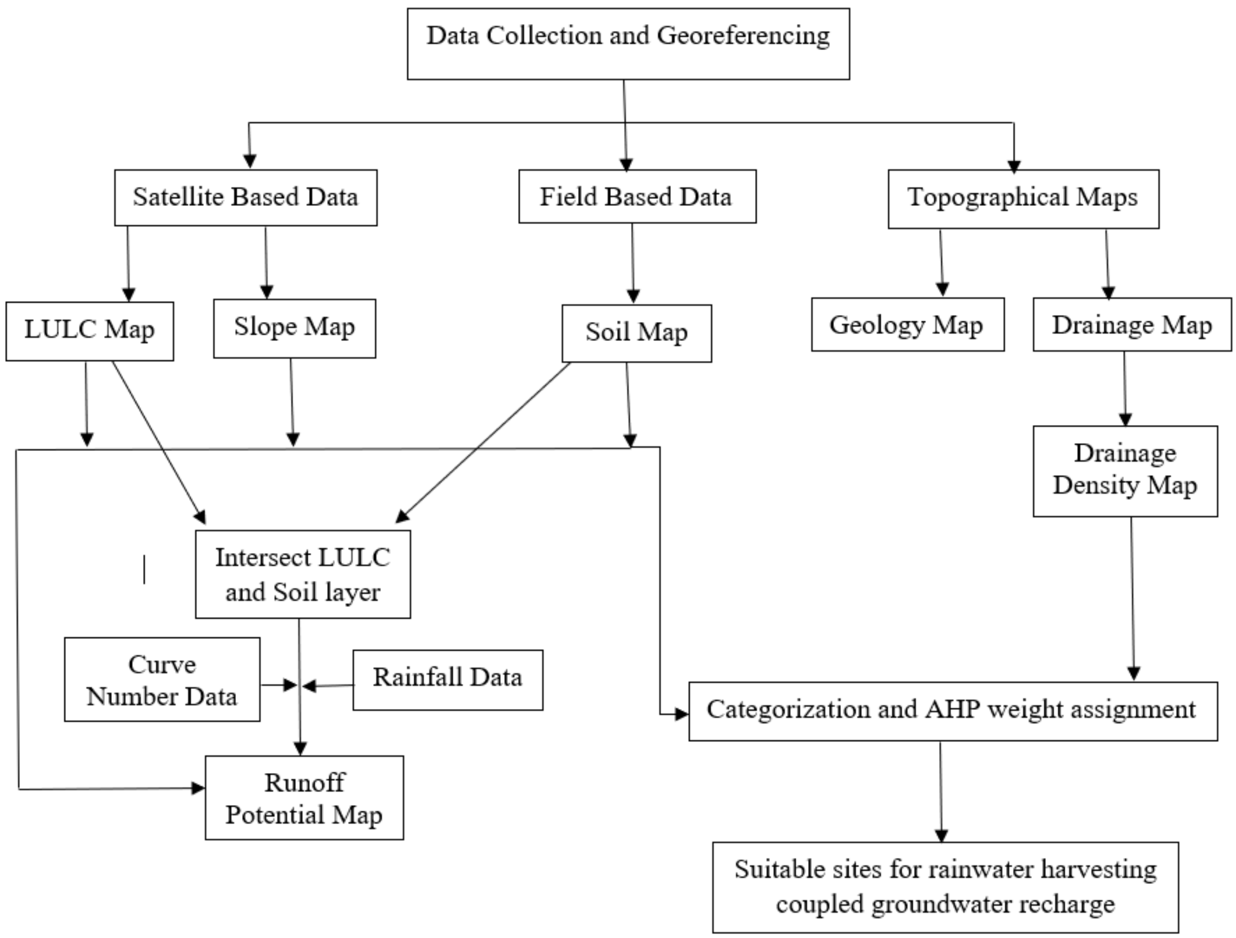
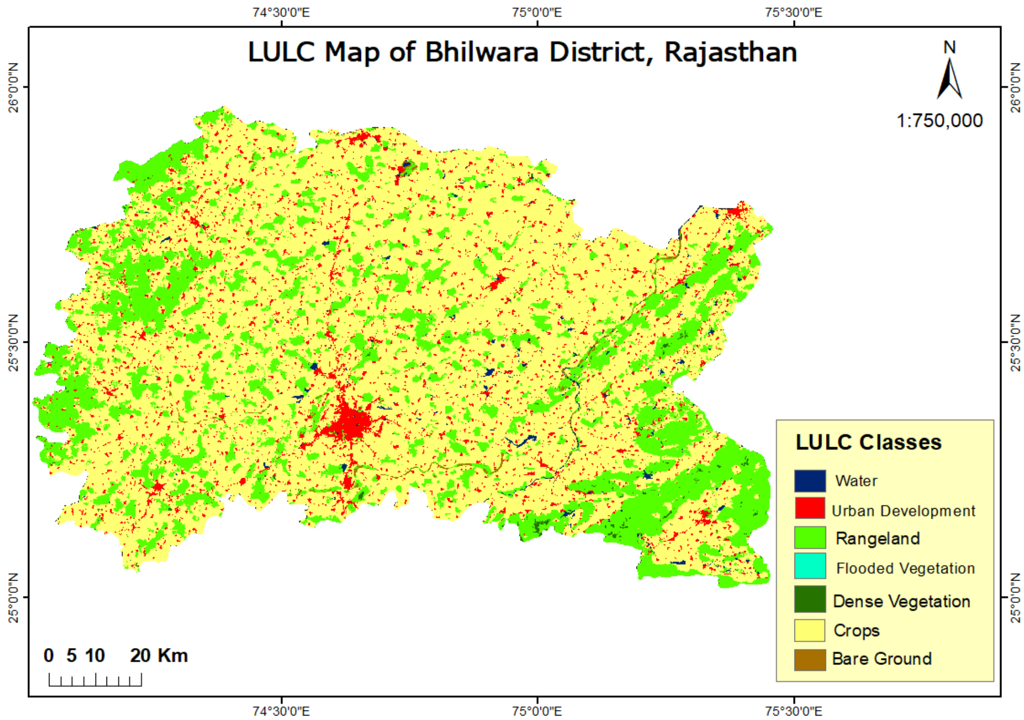


Fig.1: Methodology Flowchart

The details about data and its sources (Table 1):

S.No.	Data	Description	Sources
1.	LULC	Sentinel-2 (10m)	https://www.arcgis.com/home/item.html?id=fc92d38533d440078f17678ebc20e8e2
2.	Soil	Soil texture	https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/faounesco-soil-map-of-the-world/en/
3.	Rainfall	Monsoon Report 2021	https://www.water.rajasthan.gov.in/
4.	DEM	SRTM DEM (30m)	https://cmr.earthdata.nasa.gov/search/concepts/C1000000240-LPDAAC_ECS.html using Google Earth Engine
5.	Slope	Derived from DEM	-----Not Applicable------
6.	Geology	Digitized from toposheet	Geological Survey of India and Hydrogeological Atlas of Rajasthan, Bhilwara district
7.	Drainage Density	Considered both existing drainage and potential drainage sites	Derived from Drainage Map and DEM
8.	Runoff Potential	Calculated using CN, Rainfall, and the intersection of soil and LULC data in Python	------Not Applicable------

The satellite-based data like Sentinel-2 having 10m resolution have been used for Land use the Land cover map. The classified LULC map was available on the ArcGIS (ESRI) website.

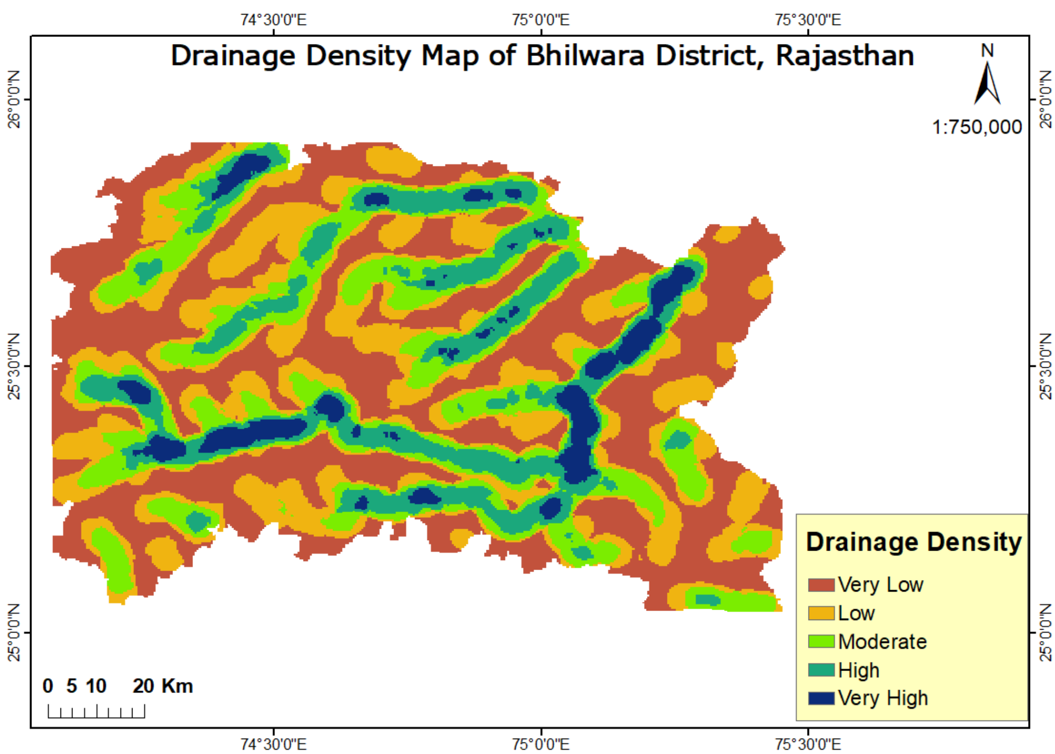


The LULC classes have been classified as follows for AHP:

S. No.	LULC Type	Suitability
1.	Water	Highly Suitable
2.	Flooded Vegetation	Highly Suitable
3.	Dense Vegetation	Highly Suitable
4.	Bare Ground	Moderately Suitable
5.	Rangeland	Moderately Suitable
6.	Crops	Least Suitable
7.	Urban Development	Least Suitable

Another satellite data was the Digital Elevation Model (DEM) obtained from the Shuttle Radar Topography Mission (SRTM) of 30m resolution. This data has been downloaded directly using Google Earth Engine. This DEM was further used for deriving slope and drainage maps in ArcGIS. For drainage map, fill DEM, flow direction, flow accumulation, basin, and watershed have been prepared using the Hydrology tool in ArcGIS. The flow direction and flow accumulation are obtained using the D8 algorithm. The D8 flow method models the flow direction from each cell to its steepest downslope neighbor. To calculate the drainage density, stream order using the Strahler method was also required beyond details about the watershed. The formula to calculate drainage density is

Drainage density = Total length of streams in a drainage basin / Area of the basin

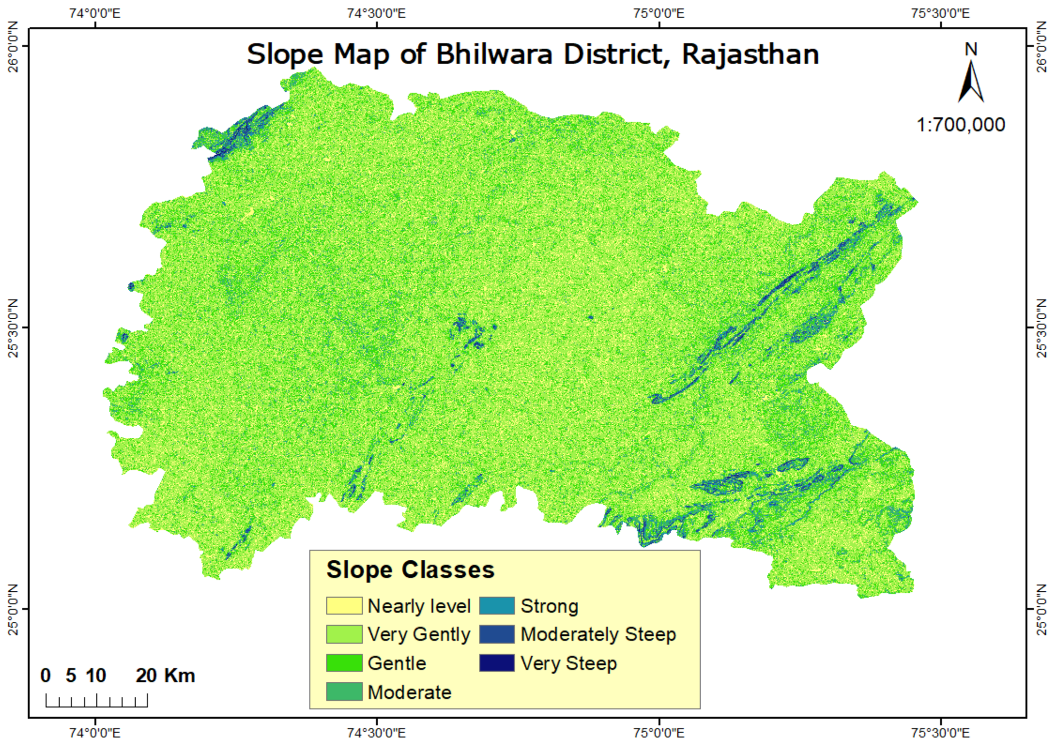


The classification of Drainage density for AHP has been done as follow:

S. No.	Drainage Density (m of channel per sq. m)	Suitability
1.	0.6 - 1.473418	Highly Suitable
2.	0.3 - 0.6	Moderately Suitable

3.	0 - 0.3	Least Suitable

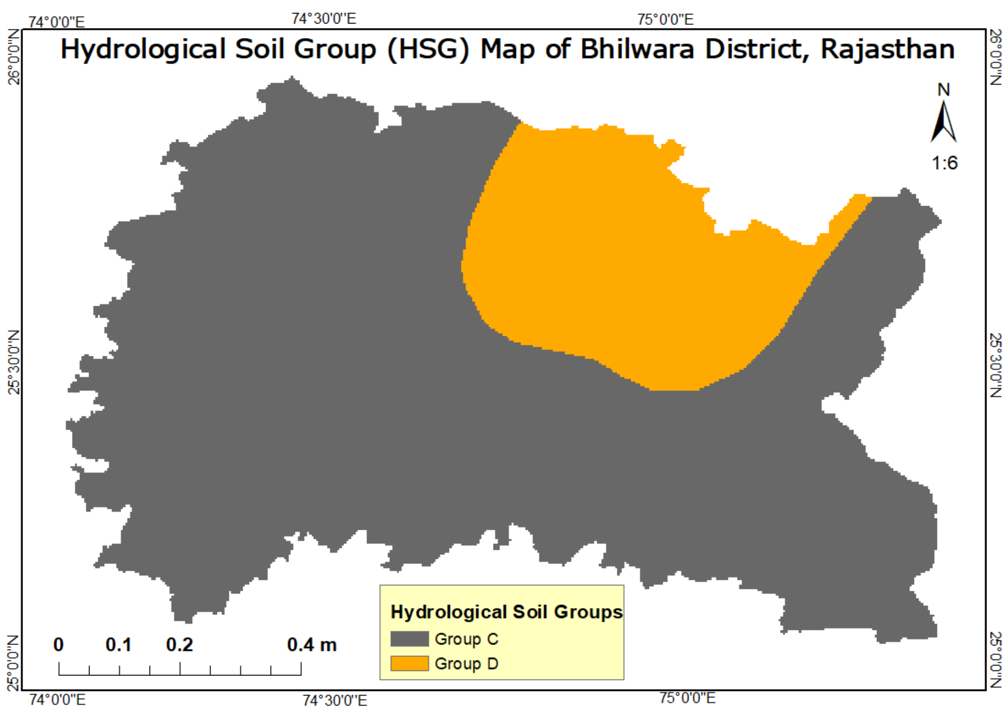
The slope is another important parameter to be considered for runoff and accumulation of water. It is derived from DEM raster and reclassified as follows:



S. No.	Slope (in degrees)	Description	Suitability
1.	0-1	Nearly Level	Highly Suitable
2.	1-3	Very Gentle Sloping	Highly Suitable
3.	3-5	Gentle Sloping	Highly Suitable
4.	5-10	Moderately Sloping	Moderately Suitable
5.	10-15	Strongly sloping	Moderately Suitable

6.	15-30	Moderately steep to steep sloping	Least Suitable
7.	>35	Very steep sloping	Least Suitable

The soil texture shapefile was downloaded from Food and Agriculture (FAO) soil portal which was categorized as Hydrological Soil Groups later based on the criteria given as follows:

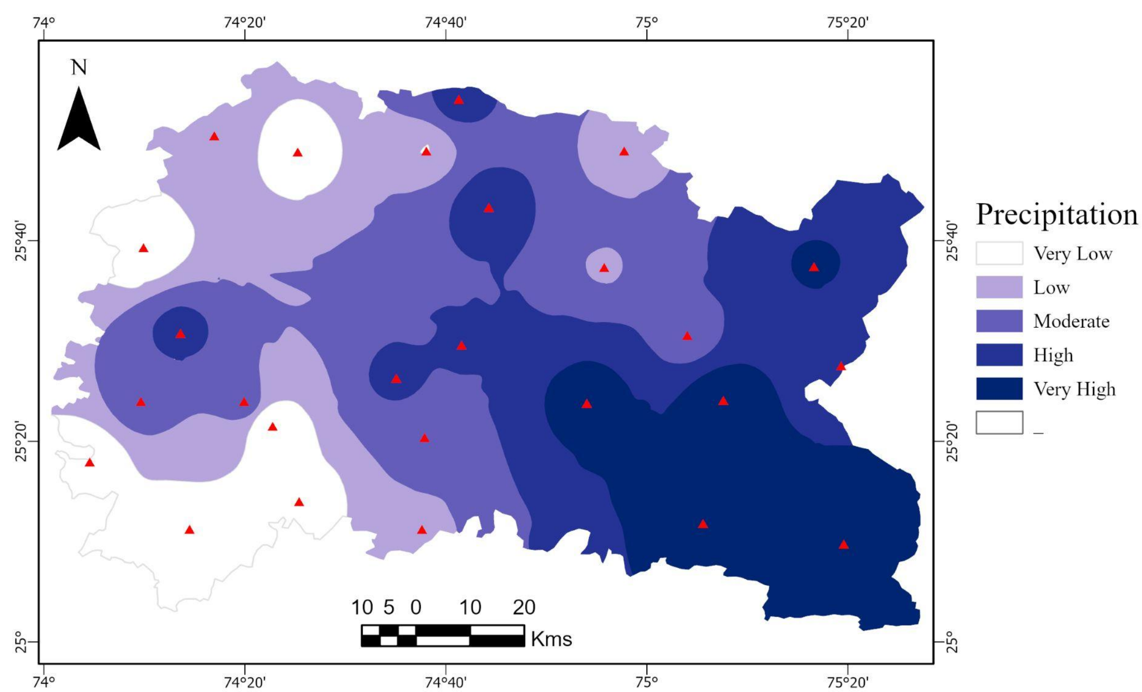


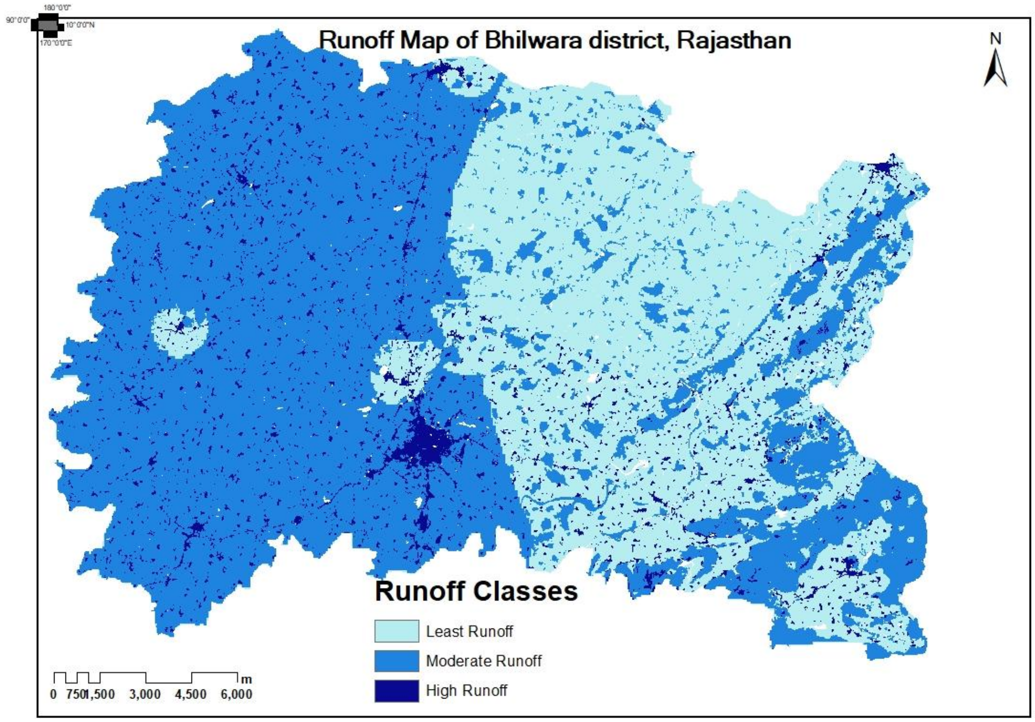
S.No.	Group	Soil Type	Bhilwara Soil Type	Suitability
1.	**C**	Slow Infiltration rates. Soils with layers, or soils with moderately fine textures	Loamy	Moderately Suitable
2.	**D**	Very slow infiltration rates. Clayey soils, high water table, or shallow impervious layer	Clayey Loam	Least Suitable

Soil Conservation Service (SCN) Curve Number (CN) Method or now called Natural Resources Conservation Service (NRSC) CN Method has been used to calculate the total runoff in Bhilwara district of Rajasthan. It is an empirical method used to estimate precipitation excess as a function of cumulative precipitation, soil type, land use, and antecedent moisture condition (AMC). It is developed for small basins.

After intersecting LULC and Soil Map using python, the CN value has been assigned to each pixel with reference to CN table. The average annual rainfall data of 2021 (Monsoon report, 2021) for all the tehsils in Bhilwara district has been computed and prepared a .csv file. The rainfall map has been prepared using Inverse Distance Weighting (IDW) interpolation tool in ArcGIS. The rainfall map is then combined with previous obtained layer of LULC and Soil along with the CN to get output as total runoff.

Rainfall Distribution of Bhilwara District, Rajasthan





S. No.	Runoff (mm/s)	Suitability
1.	0.000035 - 4.13475	Highly Suitable
2.	4.13475 - 8.269466	Moderately Suitable
3.	8.269466 - 12.40418	Least Suitable

The formula for runoff calculation is:
Runoff, R = (P-0.2S)^2/(P+0.8S)

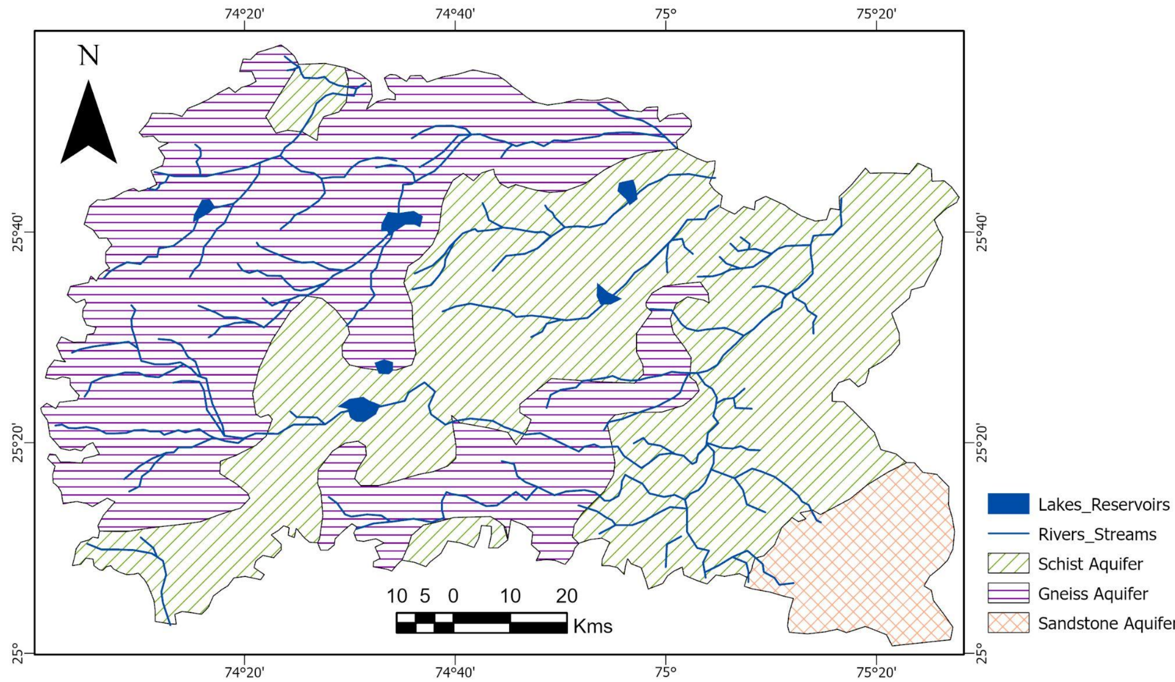
where P is the average annual precipitation and S is the soil storage capacity.

S = (25400/CN) -254, mm where is CN is curve number.

For dry condition, CN (I) = 4.2 CN (II)/(10-0.058 CN(II)) where CN (II) is the assigned CN to each pixel based on CN Table for different Landuse and Hydrological soil groups.

The aquifer map has been digitized from the toposheet (GSI) and reclassified into classes of highest to least suitablilty as below:

Geological Map of Bhilwara District, Rajasthan



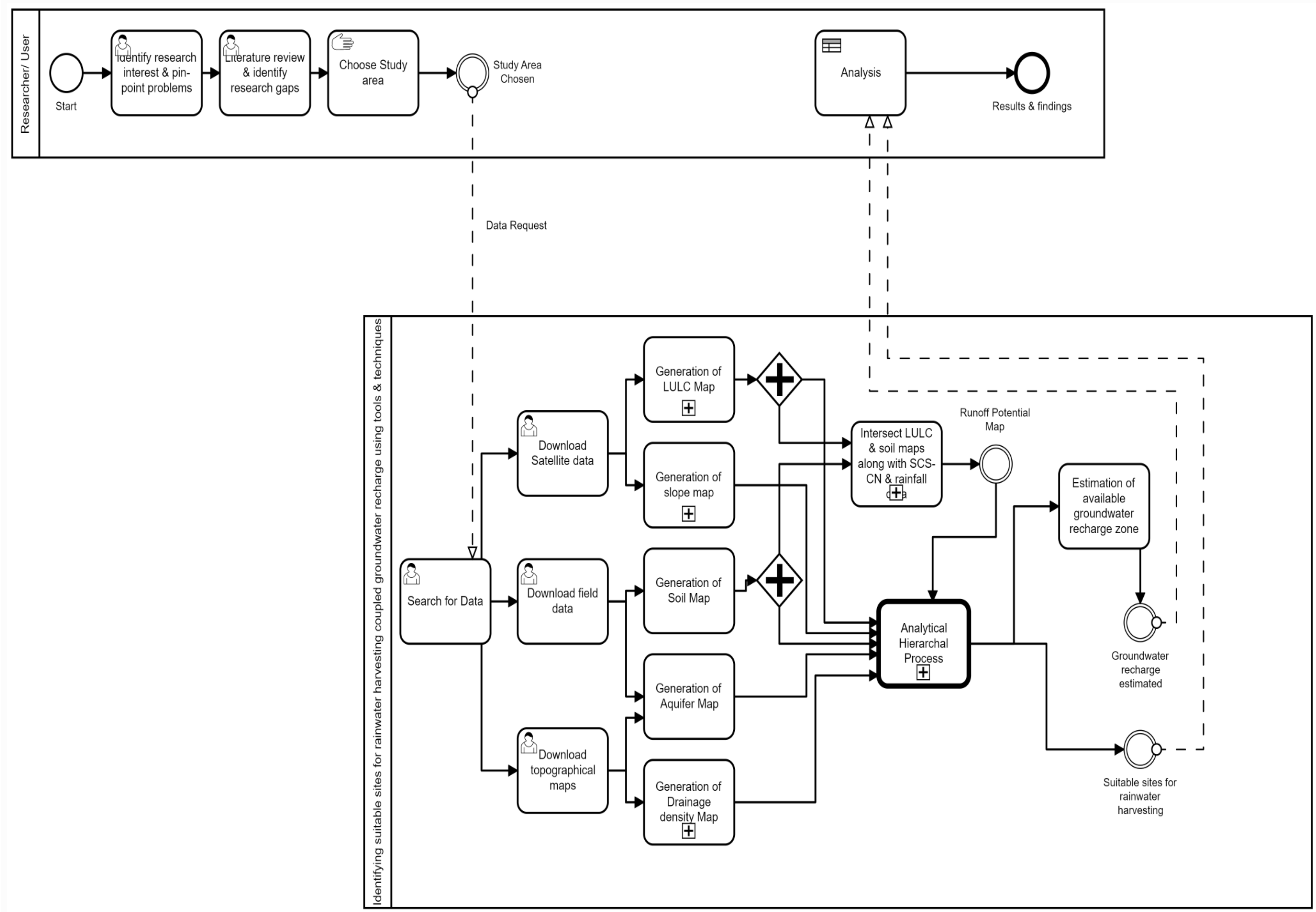
S. No.	Geology	Suitability
1.	Sandstone	Highly Suitable
2.	Schist	Moderately Suitable
3.	Gneiss	Least Suitable

The final AHP matrix prepared is follows:

Class	Geology	LULC	Drainage Density	Soil	Runoff	Slope	Priority Vector
Geology	1	4	5	7	8	9	**0.43906857**
LULC	0.25	1	4	5	6	7	**0.228725407**
Drainage Density	0.2	0.25	1	5	7	8	**0.165229988**
Soil	0.142857143	0.2	0.2	1	6	7	**0.098898243**
Runoff	0.125	0.166666667	0.142857143	0.166666667	1	4	**0.044423569**
Slope	0.111111111	0.142857143	0.125	0.142857143	0.25	1	**0.023654223**
Total	**1.828968254**	**5.75952381**	**10.46785714**	**18.30952381**	**28.25**	**36**	

4. Workflow Diagrams

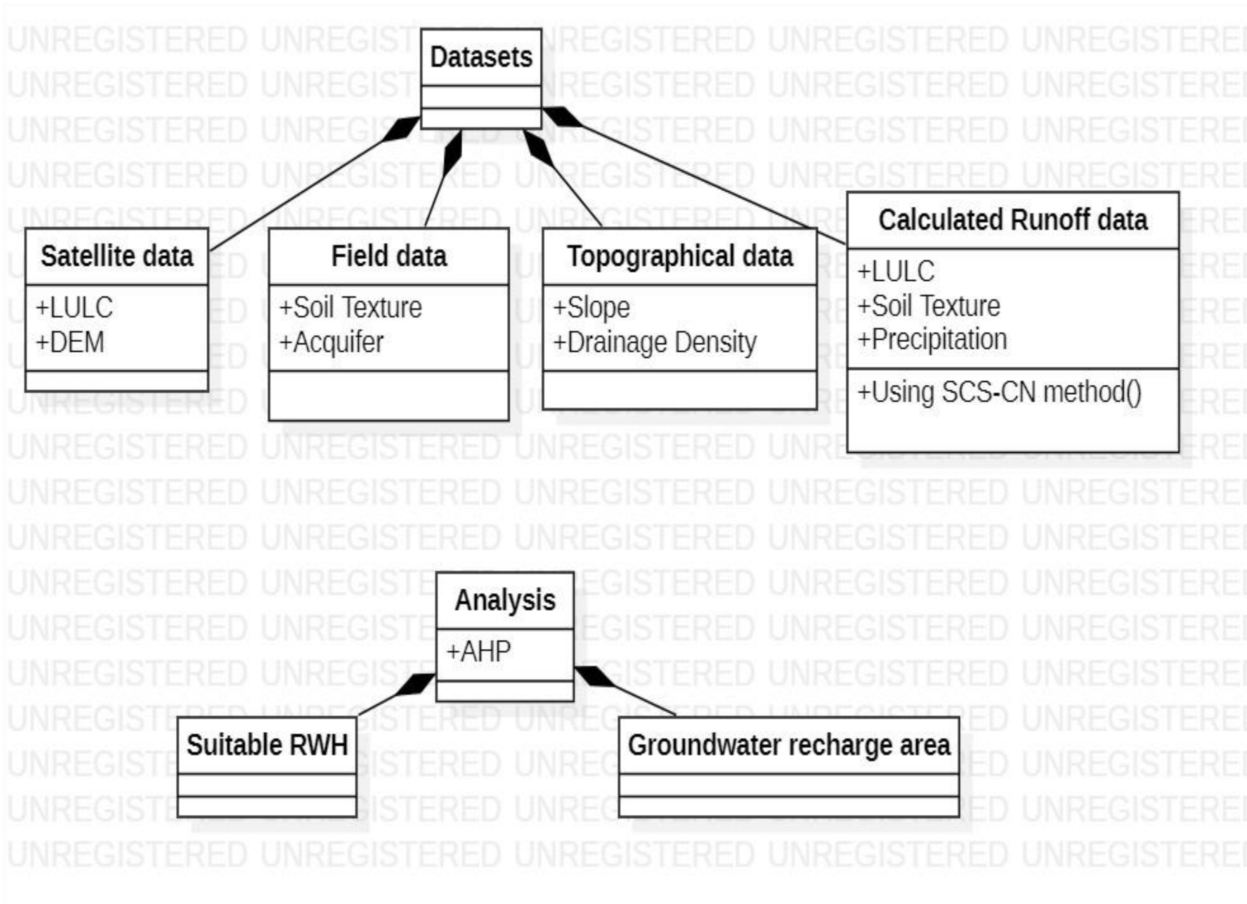
Business Process Modelling Notation (BPMN) Diagram



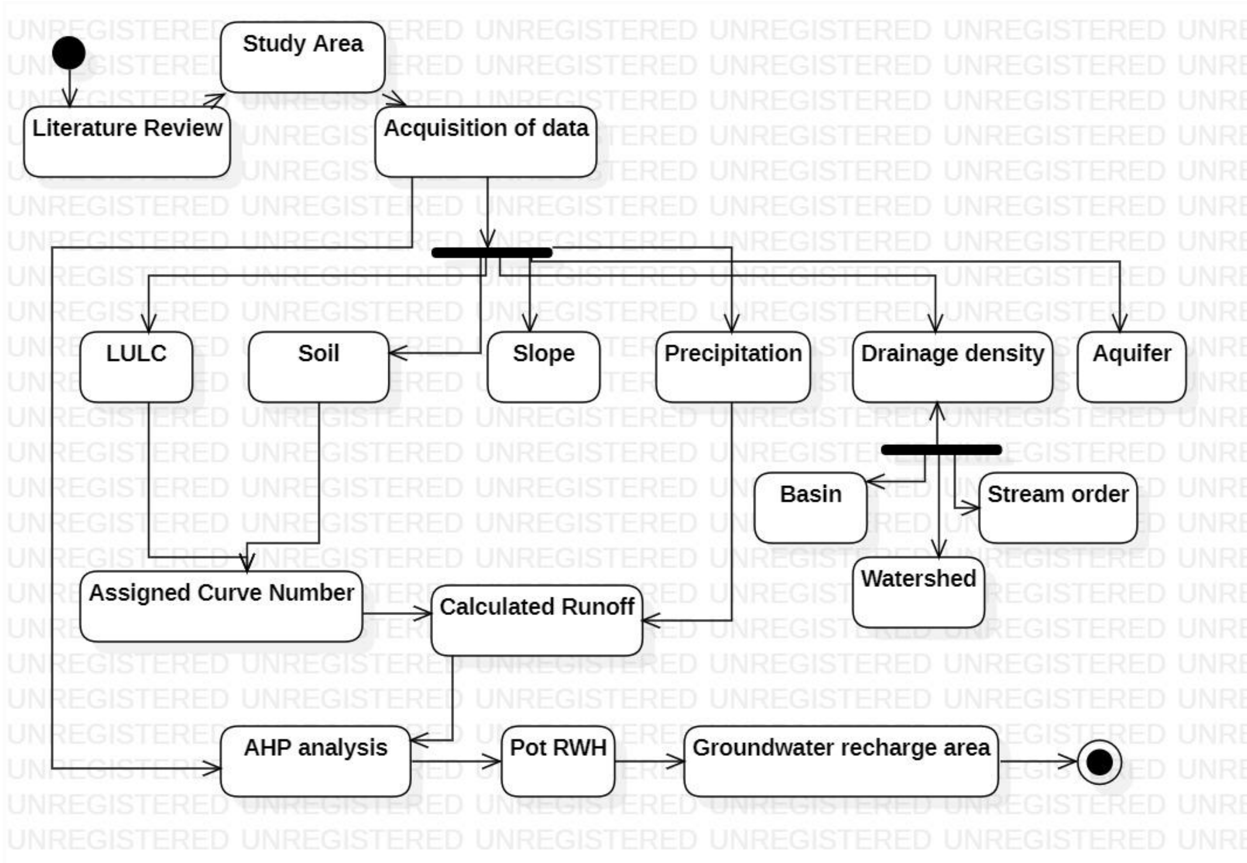
Researcher/ User
Start
Identify research interest & pin-point problems
Literature review & identify research gaps
Choose Study area
Study Area Chosen
Analysis
Results & findings
Data Request
Identifying suitable sites for rainwater harvesting coupled groundwater recharge using tools & techniques
Search for Data
Download Satellite data
Download field data
Download topographical maps
Generation of LULC Map
Generation of slope map
Generation of Soil Map
Generation of Aquifer Map
Generation of Drainage density Map
Intersect LULC & soil maps along with SCS-CN & rainfall data
Runoff Potential Map
Analytical Hierarchal Process
Estimation of available groundwater recharge zone
Groundwater recharge estimated
Suitable sites for rainwater harvesting

Unified Markup Language Diagram

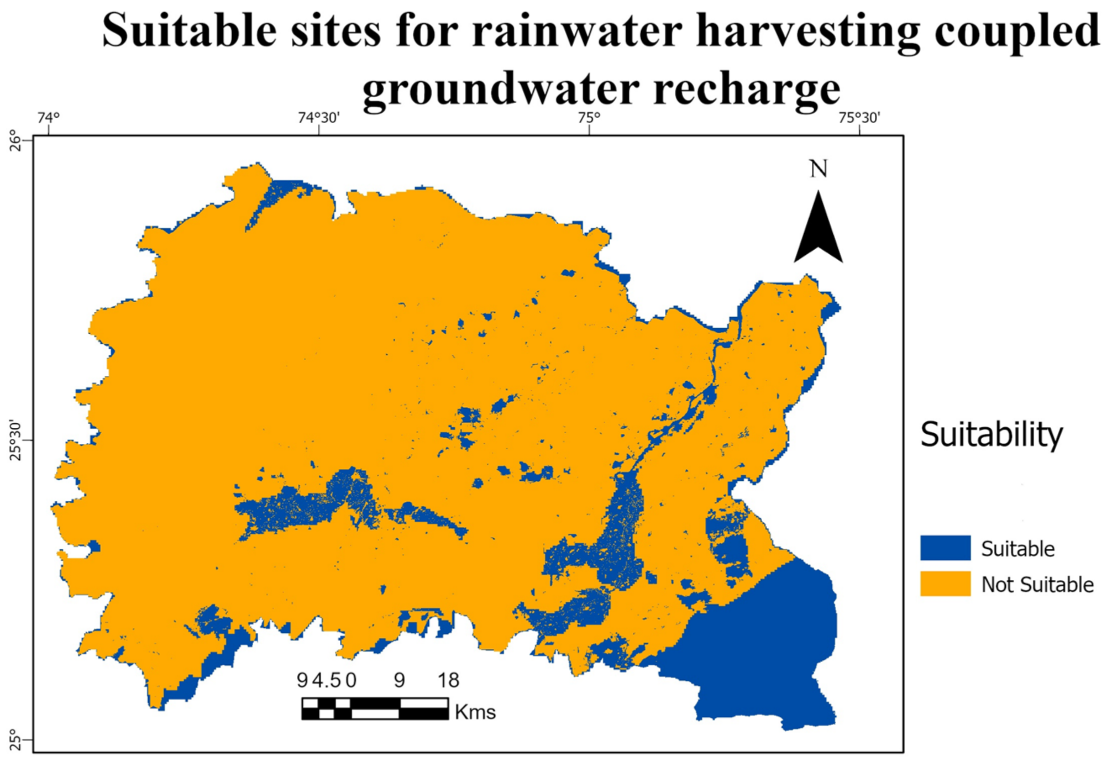
Composition Diagram



Activity Diagram



5. Result and discussion



The area having sandstone aquifer near the Chambal basin and Banas basin are the most suitable sites. The basin of Kothari river also shows potential sites where rainwater harvesting can be done. Total groundwater recharge area = 16.58 sq. km in identified suitable sites. The obtained Consistency Ratio (CR) through AHP is 0.03081751 which is less than 0.1. It depicts the good CR.

The final output of our analysis gives us sites in the study area which are most suitable for rainwater harvesting coupled with groundwater recharge. The factors affecting the potential for groundwater recharge in this arid region are given below:

- Geology of the area (aquifer characteristics) contributes 43.9%
- LULC of the area as it controls the amount of infiltration and recharge potential. It contributes 22.87%
- Drainage density contributes 16.52% and slope is the least contributor which is around 2.4%.

6. Conclusions

This study provides a solution to the Bhilwara district in the Rajasthan water crisis. The groundwater recharge, not only fulfills the demand of the population but additionally suppresses the concentration of contaminants in the groundwater which may further cause fatal health ailments to the public.

The study can contribute to Atal Bhujal Yojana. However, the results of AHP can be paired with Fuzzy logic to standardize the factors and get better results. The study can further find the natural depression sites for construction of rainwater harvesting structures to avoid extra cost burden. Specific rainwater harvesting techniques for the area can also be explored.

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