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Impact of Geological Controls on Change in Groundwater Potential of Recharge Zones due to Watershed Development Activities, Using Integrated Approach of RS and GIS

Akanksha Pandey[1]*, Ritesh Purohit[2]

[*1] Department of Geology, Faculty of Earth Sciences, Mohanlal Sukhadia University, Rajasthan, India. pandey.akanksha1191@gmail.com
[2]Department of Geology, Faculty of Earth Sciences, Mohanlal Sukhadia University, Rajasthan, India. riteshpurohit72@gmail.com

Abstract: **The available water used for different purposes is utilized from the groundwater sources and their availability is limited. The present study was carried out to delineate the groundwater recharge potential zones in the Puniyakundi Watershed of Banswara, Rajasthan, India using the technique of remote sensing and geographical information system. For such studies, various factor maps or thematic maps of the watershed have been prepared using the RS and GIS which includes geology, lineament and lineament density, physiography, slope analysis, soil thickness, drainage and drainage density, and land use land cover (LU/LC) maps. All the prepared thematic layers were integrated using the Weighted Overlay Analysis Tool of the ArcGIS in which weightage and ranks have been provided to every class of every thematic map. Thereafter groundwater recharge potential zones maps have been generated for the years 2013 and 2016 in which the maps have been classified into low to very high potential recharge zones classes. The two-year maps represent the variation in the potential recharge zones of the groundwater. The comparative studies showed changes in the classes of the potential recharge zones of groundwater area-wise. The moderate to high classes recorded the increment while low and very high classes recorded the decrement in the area of potential zones.**

Index Terms: **Groundwater, Potential zones mapping, Remote Sensing, GIS, Weighted Overlay Analysis, Groundwater recharge.**

I. Introduction

In Kushalgarh block of Banswara district, only groundwater is used for irrigation, so the groundwater resource potential is semi-critical, therefore, sustainable use of this underground resource water harvesting structures should be constructed and installed carefully at the suitable sites as this area in the geological past has undergone many polyphase deformations that have caused complex structure (folded, faulted, and jointed), might not be favorable for harvesting structures as mentioned in the District Groundwater brochure 2013 (District at a glance- Banswara, Rajasthan by Government of India, Ministry of water resources, Central Groundwater Board).

The watershed development program in Puniyakundi watershed of Kushalgarh block situated in the south-east of Banswara district (Fig. 1A) under the Indo-German Watershed Development Programme (IGWDP) was implemented by National Bank for Agriculture and Rural Development (NABARD), supported by the German Government through Kfw and executed by Gramin Vikas Trust (GVT) from 2010 to 2016. It is evident that this innovative approach of watershed development not only combats soil erosion by checking run-off but also recharges aquifers and makes them available for daily needs and most importantly for agricultural activities.

Watershed improvement activities such as forestry plantation, grass-seeding, etc., and water harvesting structures like field bund, stone outlets, stone gully plugs, stone bund, continuous contour trench, cattle protection trench, etc. were developed to restore the underground water by recharging aquifer.

In the present study, RS-GIS data has been used to delineate and detect the changes in the groundwater recharge potential zones under the impact of a specific set of geological controls during a time period of ~2.5 years after-sanction of a project (14th April 2013) and post-implementation of the developmental activities (22ndApril 2016). The major factors taken into account in this study are lithology of the area, lineaments, drainage, and drainage density, geomorphic landforms, slope, soil depth, and Land use/ Land cover (LU/LC) pattern of the area (Roy, 1991;

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Greenbaum, 1992; Mukherjee, 1996). Shaban et al. (2006) pointed out that the type of rock exposed to the surface significantly affects groundwater recharge. Lithology affects groundwater recharge by controlling the percolation of water flow (El-Baz & Himida, 1995). The use of the geospatial technique in delineating the underground water recharge zone is very important for strategic management of this resource as the probable occurrence and storage of groundwater varies from place to place. The spatial distribution and varying trends of sub-surface linear structures have shown that the movement and occurrence of groundwater are governed by landforms, structural features, and topography (Suryabhagavan, 2017).

The metrological aspects were taken into account and overlay analysis by integrating various thematic layers using GIS were performed to delineate the Groundwater potential recharge sites and to state the important changes brought by watershed development activities under the impact of geological controls in the study area.

The spatial imageries are being highly used in finding out numerous ground attributes which directly or indirectly indicate the existence of groundwater (Bahuguna et al., 2003; Das et al., 1997). Remote sensing plays an important role in identifying the ground features like geology, lineaments, etc. which can be utilized to investigate underground recharge (Sener et al., 2005). The groundwater potential mapping is done extensively by combining Remote Sensing (RS) with Geographical Information System (GIS; Srinivasa et al., 2003; Elbeih, 2015). The morphology and related properties of the Eru river Basin- a micro-watershed of Mahi river, Rajasthan were identified and analyzed using GIS and Image processing techniques by Shaikh & Birajdar (2015). Substantial work has been done in applying geospatial techniques in the investigation and delineation of the groundwater potential areas (Magesh et al., 2012; Senanayake et al., 2016; Ahmed, 2016; Ahirwar et al., 2020).

The present study was undertaken focuses on (i) delineating the groundwater potential recharge zones of Puniyakundi watershed using RS-GIS (ii) studying the influence of geological controls on potential zones (iii) comparing the recharge zones during- and post-watershed management activities and validating those changes by a field visit.

II. STUDY AREA

The Puniyakundi watershed is located around 20 km east of Kushalgarh on Ratlam road near the town of Chhoti Sarwa. The watershed feeds in the River Mahi through its tributary. Puniyakundi watershed covers an area of approximately 1177 ha. The area falls in the Survey of India Toposheet No. 46 I/12 and lies between 23°12’30" to 23°15’00” N and 74°30’00” to 74°33’00” E. The watershed falls in Agroclimatic Zone IV-B (Humid Southern Plains).

The average annual rainfall is around 900mm. The climate of the watershed is dry except S-W monsoon season. The cold season is from December to February and is followed by summer from March to June. From mid of September to the end of November constitutes post-monsoon season.

The litho-units exposed in the area are basaltic flows of the Deccan trap that belongs to the Upper Cretaceous to Eocene epoch (Fig. 3).

The general slope of the area is from west to east and the landscape is controlled by gentle sloping upland plateau region and gently sloping fields along the streams. The selected watershed rises to a maximum elevation of 445m above MSL while the minimum elevation is 300m above MSL as shown in a physiographic map of the Puniyakundi Watershed (Fig. 1B).

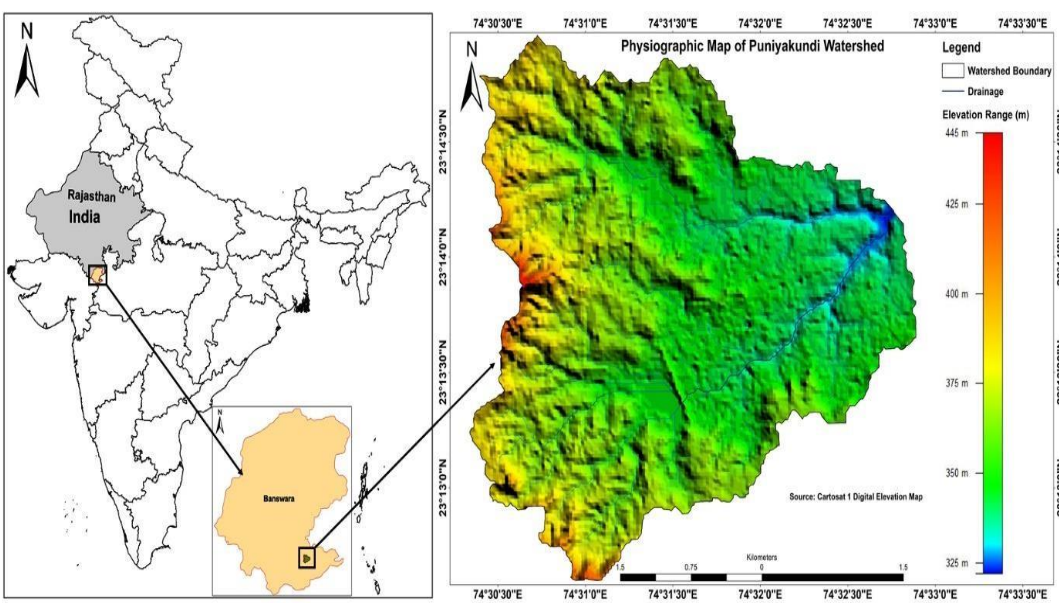

Fig. 1: A. Location map of the Puniyakundi. **B**. Physiographic distribution map of the Puniyakundi Watershed.

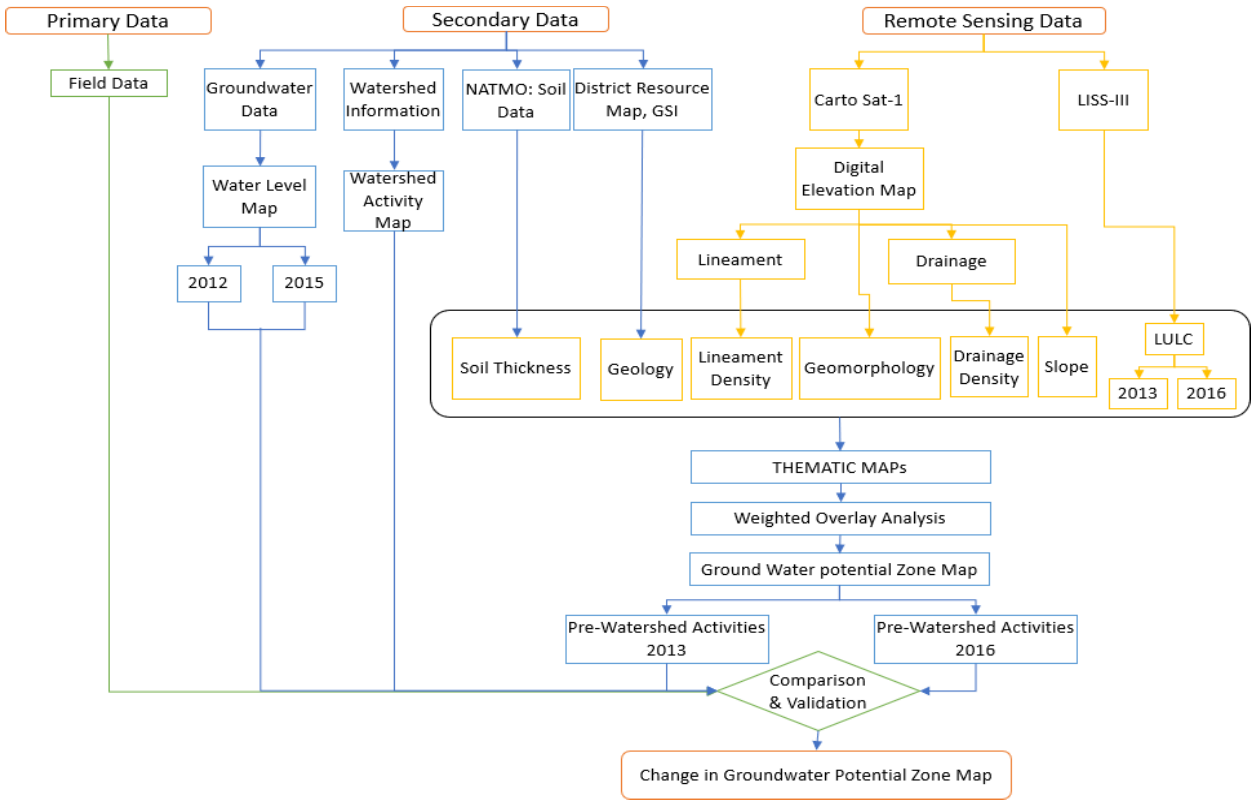

Fig. 2: Flow chart showing adopted methodology.

III. DATA COLLECTED AND METHODOLOGY

The thematic layers for LU/LC were extracted from ResourceSat-2 data of LISS III. Cartosat-1 Digital Elevation Model (DEM) was used to extract thematic layers like slope, drainage, and drainage density. District Resource Maps (DRM) of Geological Survey of India (GSI), Hyderabad was used for preparing the geological map. Cartosat-1 DEM was utilized to extract the lineaments and derivation the lineament density and geomorphology maps. Soil depth map was prepared from Primary data of the National Atlas and Thematic Mapping Organization (NATMO). ArcGIS software was used as the processing tool to prepare and integrate various thematic layers. The attributes in the thematic maps were assigned with different weightages and ranks and these layers were overlaid and analyzed to delineate the groundwater potential recharge zone. The results were then compared and correlated by visiting and meeting locals, learning their experience about the changes in groundwater recharge pre- and post-watershed development activities, and checking out the minor changes that cannot be covered in the remote sensing data due to the resolution during fieldwork. The flow chart is showing the overall adopted methodology for the preparation of various thematic maps and derivation of the groundwater recharge potential zones (Fig. 2).

IV. RESULTS

A. PREPARATION OF THEMATIC LAYERS AND ASSIGNING RANK:

The thematic layers are showing the lithological setup, lineament and lineament density, drainage and drainage density, geomorphological landforms, slope analysis, type and thickness of soil and LU/LC during and post-watershed development in the area. Various tools of ArcGIS software were used to prepare these maps. Weighted Overlay Index (WOI) tool of ArcGIS was used to integrate these thematic layers by assigning them ranks and weightages to each layer according to their significance which it holds in the groundwater recharge and then final groundwater recharge potential maps of pre-monsoon season of 2013 (during) and 2016 (post) development scenarios were derived and changes were compared and validated by fieldwork.

B. GEOLOGY:

The rock type in the Puniyakundi watershed is the Deccan trap of the Upper Cretaceous to Eocene epoch (Fig. 3). The rock type is Basalt of different densities and hardness. These are generally dark green to steel grey, fine to medium-grained, and porphyritic at places. It varied from very hard to vesicular or amygdaloidal varieties. The basalt is found in different flows, though a detailed study is not undertaken observations indicate the occurrence of about two flows controlling geomorphology of distinct levels. Geology is an important factor for the recharge of the groundwater and their hydrological properties along with the structural features have a versatile influence on the existence and flow of the groundwater. A high degree of lateral variation was noticed in the form of hard rock, weathered basalt, and the occurrence of columns of basalt. Primary porosity is found in the form of vesicles, but to a limited extent, normal water flow is available in secondary fractures and joints of open nature. The rank, weightage, and area assigned to the rock type of the selected watershed are listed in table 1:

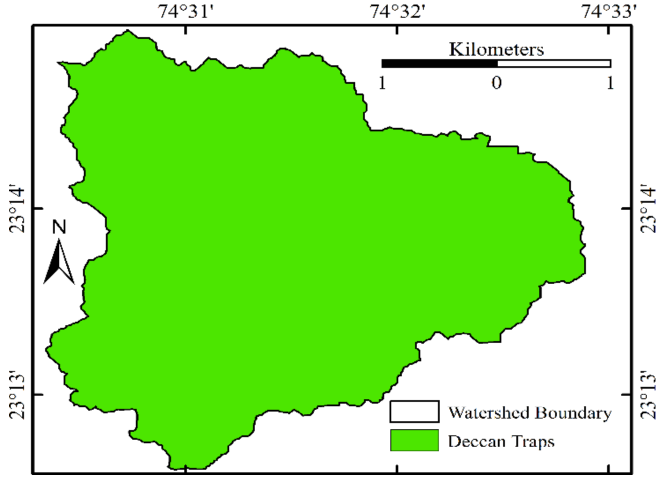

Fig. 3: Geology Map of Puniyakundi Watershed.

Table 1. Geology type, rank, weightage, and area

Category	Formations	Rank	Weightage	Area (in Ha)
Geology	Deccan Traps	1	10	1177

C. LINEAMENTS AND LINEAMENT DENSITY:

A Linear feature is indicative of the basic structure like Joints, fractures, and faults in a landscape (Navane & Sahoo, 2017). Criss-Cross in fig. 4A are the lineaments present in the watershed which supports subsurface infiltration and storage, thus region with high lineament density is good potential sites for groundwater. The majority of the lineaments are occupying the NW peripheral part of the Puniyakundi. Directional analysis of lineaments is shown through the rose diagram (Fig. 4A). The mean trend of the lineaments is showing the NNW-SSE direction while on observing the rose directions major lineaments are occupying the N-S directions and a few of them in E-W directions also. The Line density tool of the ArcMap was used to develop the lineament density layer (Fig. 4B) which is further classified into six categories. The derived lineament density map is governing the higher lineament density at the NW to the central part of the region. The rank, weightage, and area assigned to all the sub-classes are listed in table 2:

Table 2. Lineament density type, rank, weightage, and area

Category	Class	Rank	Weightage	Area (in Ha)
Lineament Density	1.36 to 2.03	1	20	16.4
	2.03 to 2.54	2	20	54.4
	2.54 to 3.05	3	20	292.9
	3.05 to 3.56	4	20	421.4
	3.56 to 4.07	5	20	320.2
	4.07 to 4.36	6	20	71.7

D. SLOPE ANALYSIS:

The slope map of the region has been prepared using the Caretosat-1 DEM. The slope map (Fig. 5) is classified into seven sub-categories, i.e. 0–1, 1–3, 3–5, 5–8.5, 8–16.5, 16– 24, and >24, shows that the Puniyakundi is highly suitable for rainwater infiltration as the maximum area is under slope category 1-3% making the watershed a potential zones for groundwater recharge. The visible changes in the slope during the study period are very minute and cannot be traced through the remote sensing data of acquired resolution. The rank, weightage, and area assigned to all the sub-categories are listed in table 3:

Table 3. Slope class, rank, weightage, and area

Category	Class	Rank	Weightage	Area (in Ha)
Slope Degree	0 to 1.1	6	20	116.5
	1.1 to 3	5	20	350
	3 to 5	4	20	286.5
	5 to 8.5	3	20	273.5
	8.5 to 24	2	20	147.9
	> 24	1	20	2.6

E. DRAINAGE AND DRAINAGE DENSITY:

In the Puniyakundi watershed, drainage occurs in the basaltic terrain and exhibits dendritic to sub-dendritic patterns showing the uniformity in the lithology (Fig. 6A). Drainage density map (Fig. 6B) was prepared and classified into five classes 0.95 - 1.01 (very low), 1.01 - 1.13 (low), 1.13 - 1.18 (moderate), 1.18 - 1.30 (high) and 1.30 - 1.63 (very high). The lower drainage density classes are mostly found in and around the plateau region of low relief, making it a highly permeable, infiltration zone thus a good site for groundwater recharge. The classes indicating high drainage density are the zones of excessive run-off thus low infiltration. The rank, weightage, and area assigned to all the sub-categories of drainage density are listed in table 4:

Table 4. Drainage density class, rank, weightage, and area

Category	Class	Rank	Weightage	Area (in Ha)
Drainage Density	0.72 to 1.01	5	12	119.6
	1.01 to 1.13	4	12	256.7
	1.13 to 1.18	3	12	350.2
	1.18 to 1.3	2	12	413.5
	1.3 to 1.63	1	12	37

F. GEOMORPHOLOGY:

The Geomorphological map of the watershed has been prepared using the Cartosat-1 DEM and it is divided into three categories (Fig. 7):

1) Structural Origin: Moderately Dissected Lower Plateau

The highly fluid basaltic lava through numerous successive eruptions during cretaceous has formed the plateau. Basalt is a hard, massive amygdaloidal to vesicular type which indicates the low viscosity of lava with a small amount of trapped gases. In an extensive, flat-topped plateau region bordered by escarpment and having gentle to steep slopes, primary porosity is found in the form of vesicles, but to a limited extent, normally water flow is only available in secondary fractures and joints of open nature making it poor-moderate site of groundwater recharge.

2) Denudational Origin: Pediment-Pediplain Complex

The Pediment-Pediplain complex is in the study area is with low relief and highly covered with weathered material and relatively thick topsoil cover due to differential weathering and erosion. Almost flat topography and linear features like faults, fractures, and columnar joints present in the dense and massive litho-unit of this complex generating secondary porosity supports infiltration and movement of groundwater thus making it a good zone for potential recharge.

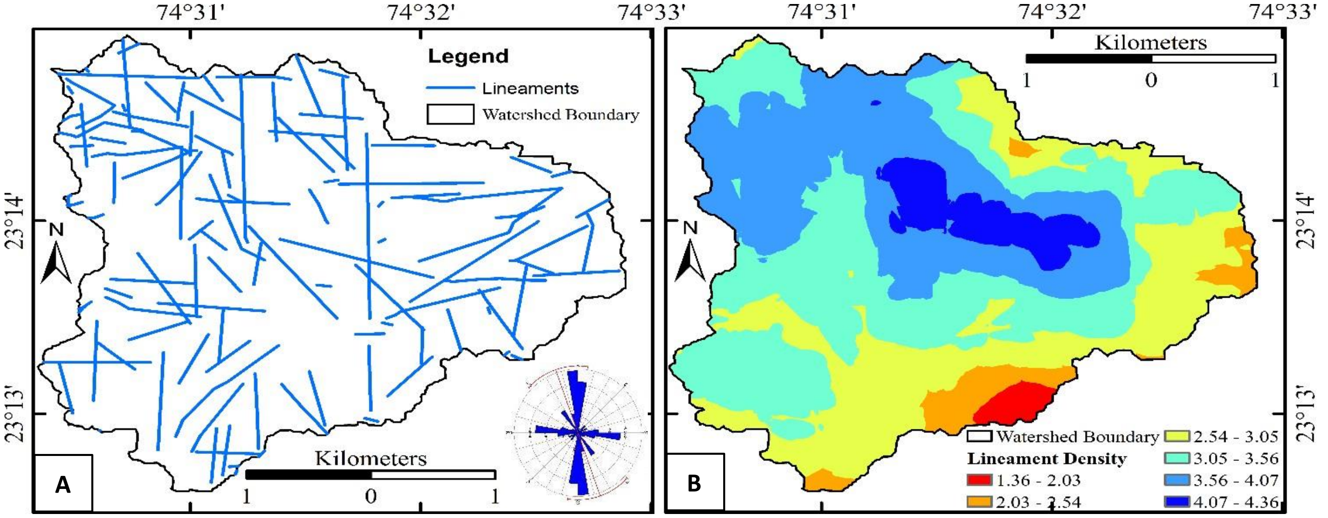

Fig. 4: **A.** Extracted lineaments of the watershed and the rose diagram of lineaments which is showing the mean trend as NNW-SSE. **B.** Lineament density map of the watershed representing the higher density at NW to the central part of the region.

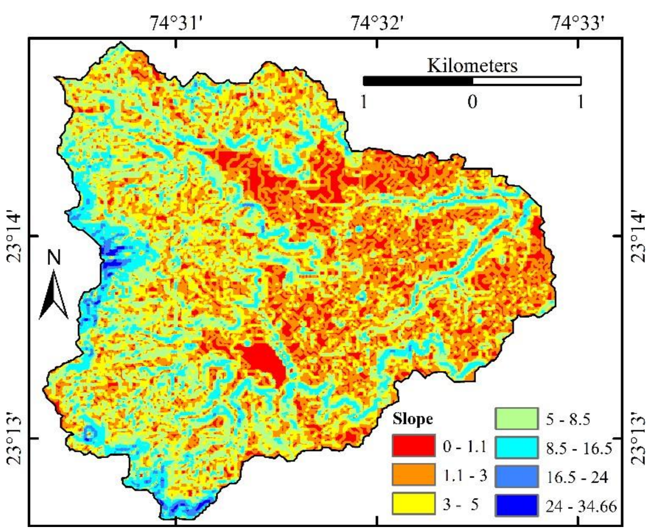

Fig. 5: Slope map of the watershed.

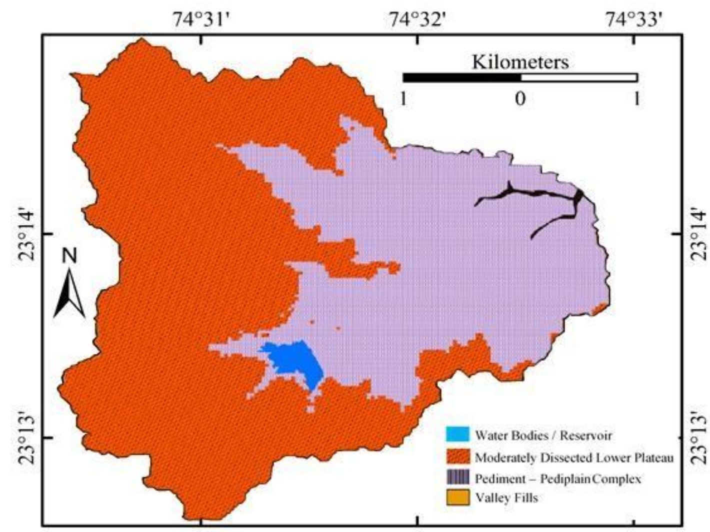

Fig. 7: Geomorphological divisions of the watershed.

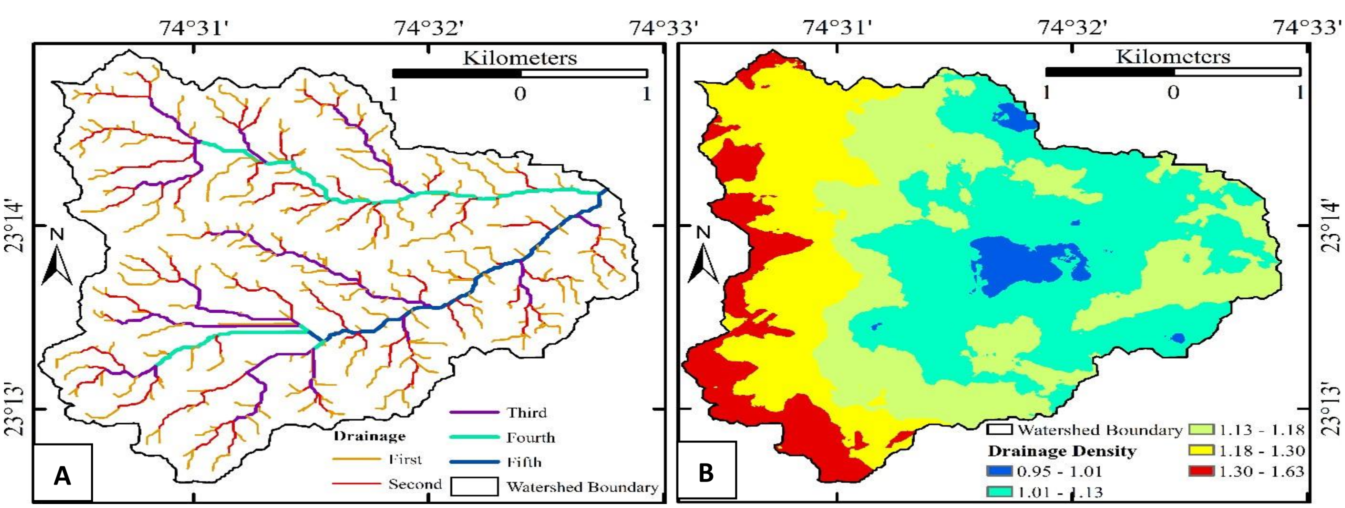

Fig. 6: **A.** Drainage map of the watershed showing dendritic to sub-dendritic drainage pattern. **B.** Drainage density map of the watershed.

3) Valley fill

Valley fills occupies very less region in the study area. As these are fluvial deposits and their unconsolidated nature makes them a good potential zone for groundwater.

The rank, weightage, and area assigned to all the geomorphic features are listed in table 5.

Table 5. Geomorphology type, rank, weightage, and area

Category	Type	Rank	Weightage	Area (in Ha)
Geomorphology	Structural Origin: Moderately *Dissected Lower Plateau*	1	10	711.8
	Denudational Origin: *Pediment-Pediplain Complex*	2	10	460.8
	Valley Fills	3	10	4.4

G. SOIL DEPTH / THICKNESS

The data from NATMO and field visits suggest that there are majorly two types of soils present in the area particularly yellowish-brown to black, and are classified as Red soil and Black soil. They are broadly explained by further dividing them into shallow black soil i.e. black soil with thickness <30cm, medium black soil i.e. black soil with thickness range between 50cm to 100cm, and mixed red soil and black soil (Fig. 8A). Primary data has been used to derive the soil thickness (in cm) and further classified into four sub-categories i.e. 6-10, 10-5, 5-50, and >50cm (Fig. 8B). The presence of more than one variety of soil in the watershed and the difference in their texture (from clay to sandy loam), thickness (from 10cm to >50cm), porosity, and permeability strongly suggest that the groundwater recharge capacity differs from place to place in the watershed.

The rank, weightage, and area assigned to all the sub-classes are listed in table 6:

Table 6. Soil depth class, rank, weightage, and area

Category	Class	Rank	Weightage	Area (in Ha)
Soil Depth	6 to 10	1	15	408.4
	10 to 25	2	15	288.3
	25 to 50	3	15	136.2
	50 to 62	4	15	344.1

H. LAND USE / LAND COVER (LU/LC) PATTERN

The pre-monsoon imageries dated 14th April 2013 and 22nd April 2016 from IRS ResourceSat-2 LISS-III have been used to generate LU / LC maps (Fig. 9A, 9B) which is showing the during and post-watershed development scenario in the Puniyakundi watershed. These are classified under five categories i.e. settlement and barren land, open land, rainfed land, irrigated land & trees, and water bodies. Groundwater recharge is highly affected by the LU/LC pattern of the area and the comparison of the two maps suggests the changes that have been brought during the study period in the potential zones of watershed due to the development activities. The settlement and barren land retards infiltration whereas the vegetative cover and water body supports it, thus, proving to be good groundwater potential zones. The rank, weightage, and area assigned to all the sub-classes are mentioned in table 7:

I. GROUNDWATER RECHARGE POTENTIAL ZONE (GWPZ) MAPS

The final maps for the years 2013 (Fig. 10A) and 2016 (Fig. 10B) of Groundwater Recharge Potential Zone were prepared in ArcGIS by integrating all the layers. The potential zones were further classified into (i) poor (ii) moderate (iii) high and (iv) very high. The changes in potential sites are listed in table 8. There is an increase in the moderate and high recharge zones category but a slight decrease is seen in the very high recharge zone.

V. DISCUSSIONS

According to rain gauge station data from 01.06.2015 to 30.09.2015 at tehsil/sub-tehsil level from Water Resources Department, Government of Rajasthan, Kushalgarh has received 717mm actual annual rainfall which is less than the normal average annual rainfall which plays an important role in the generation of new groundwater prospects. Meteorological as well as geological controls in an area determine the sites for groundwater recharge.

The geological properties of the rocks like porosity, permeability, weathering, fractured, etc. are useful for groundwater recharge. the single type of litho-unit i.e. Deccan basalt has the properties for the formation of the vesicles which is utilized for the accumulation of the water and worked as a perched aquifer. The zone of weathering and highly fractured region of the lithology worked as a great source for the percolation of the groundwater for accumulation and movement.

The slope is another factor for groundwater storage. Groundwater recharge enhances through the low to gentle angle of slopes of the region due to the accumulation of the water for a longer duration while in the case of the steep slope the water gets runoff and percolation of the water gets minimized. Therefore, the whole region is covered under the low to moderate slope except the western and southern peripheral parts.

Drainage is a factor that is used for the calculation or determination of run-off water. The drainage with high values can't hold the water and water flows from those locations while those locations are having low to moderate drainage can hold the water and useful for the percolation of the water from the surface to recharge the groundwater. The drainage density map shows the low to moderate density at the western peripheral part of the watershed while the central part is having a high drainage density which means water flows from this region to the peripheral part of the watershed.

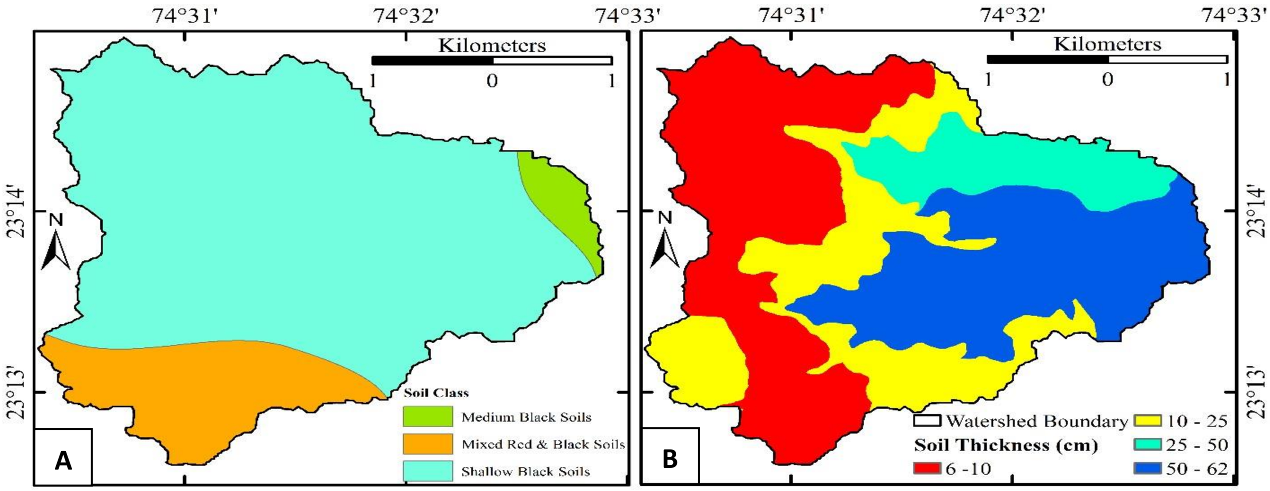

Fig. 8: **A.** Soil Map of the watershed. Source: NATMO. **B.** Soil thickness map of the watershed.

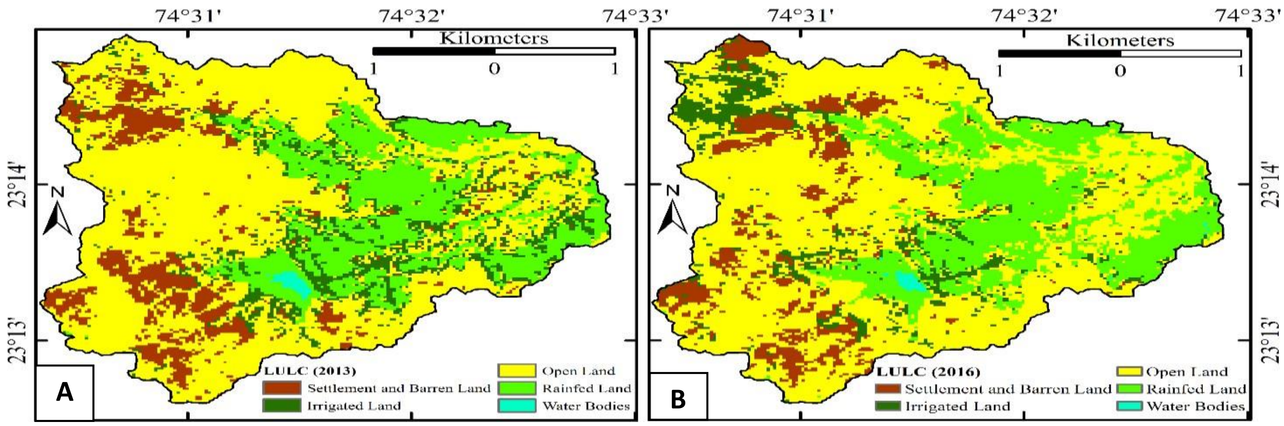

Fig. 9: **A.** LU/LC Map of the watershed of the year 2013. **B.** LU/LC Map of the watershed of the year 2016.

Table 7. Land use/land cover (LU/LC) type, rank, weightage, and change in the area

Category	Type	Rank	Weightage	Area in 2013 (Ha)	Area in 2016 (Ha)	Change in Area (Ha)	Change in Area (%)
Land Use / Land Cover	Water Bodies	5	8	4.8	4	-0.8	-0.0
	Irrigated Land and Trees	4	8	124.1	96.3	-27.8	-2.4
	Rainfed Land	3	8	236.6	268.4	31.8	2.7
	Open Land	2	8	676.6	692.5	15.9	1.3
	Barren Land and Settlement	1	8	134.9	115.8	-19.1	-1.6
Total				1177		0.0	0.0

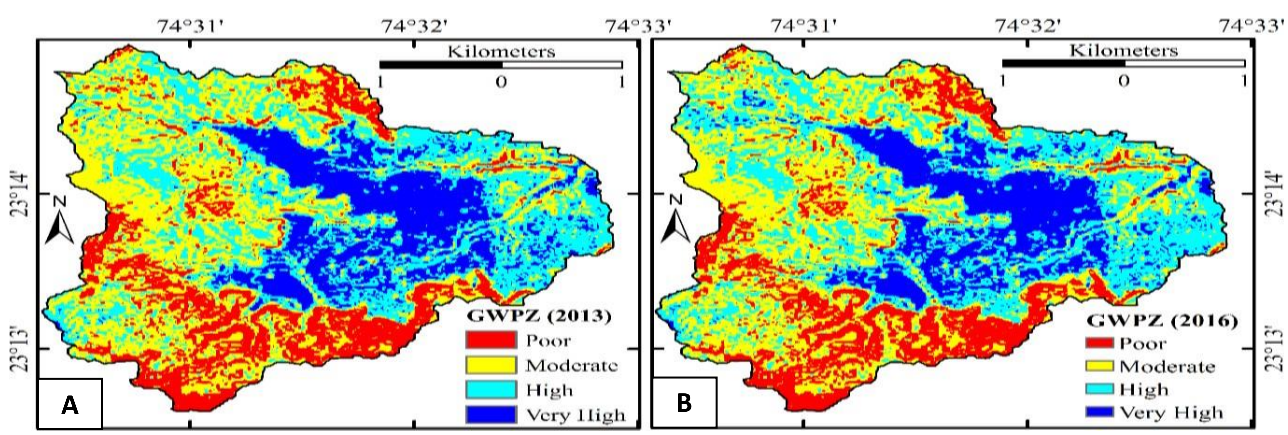

Fig. 10: **A.** Groundwater recharge potential zones of the watershed of the year 2013. **B.** Groundwater recharge potential zones of the watershed of the year 2016.

Table 8. GWPZ class, rank, weightage, and change in the area

Category	Class	Area in 2013 (Ha)	Area in 2016 (Ha)	Change in Area (Ha)	Change in Area (%)
GWPZ	Poor	341	333.3	-7.7	-0.6
	Moderate	401.9	413.7	11.8	1.0
	High	239.7	247.6	7.9	0.6
	Very High	194.4	182.4	-12	-1.0
Total		1177		0.0	0.0

Soil datasets are used from the NATMO, the map has been derived using the secondary data and confirmed during the field visit. The groundwater recharge capabilities also depend on the type of soil and their thickness present in the watershed. The soil here is with loose texture is having good percolation and adherence properties for the capillary action of the water for groundwater recharge. The area is having thick soil cover mainly black soil and mixed black and red soils particularly of clayey and loamy nature with immense moisture-holding capacity. The soil mainly at lower reaches is mixed with “Kankars” which enhances the water percolation, thus checking the soil erosion and runoff.

LU/LC map is a very important component for the determination of the various classes present in the watershed region. The map has described the presence of settlement and barren land which has less infiltration of the water while in the case of open land, irrigated land and rainfed land are the prime locations for the use of rainfall water as well as useful in the percolation of the water to recharge the groundwater. As per the LU/LC maps of the year 2013 and 2016, the settlement and barren land class have been reduced while the rainfed land class has been increased. Therefore, it shows the increase in the land for the recharge of the groundwater.

The groundwater potential zones in the year 2016 have been increased in the class from moderate to high and observed the decrement in the low class from the year 2013. The central and eastern parts have high groundwater recharge zones some peripheral parts of the western region of the watershed is also showing high recharge potential zones. These zones are also having a high lineament density, physiographically low elevation, lower values for the slope, moderate to high drainage density, and favourable classes of LU/LC have been observed. The overall groundwater potential marking different zones namely good, moderate, and poor zones are done by overlying of different layers geological units, slope, geomorphological units, lineament, slope, and soil-depth along with the ground-truthing (Fig.11, A, B, C, D) has revealed about the increase in area under a different category of GWPZ, also there were reflection from the community about the increased water-table, increased yield, increased period of water availability and decreased reoccurrence time of groundwater in the well. Thematic maps showing the pre-monsoon water level from ground, of April 2012 (Fig. 12 A) and 2015 (Fig. 12 B) from the available data were prepared to confirm the results, and area details of groundwater potential zones during this period is demonstrated in table 9. These criteria have shown that the potential zones for groundwater recharge have been precisely identified and demarcated for the watershed.

Table 9. Change in the area with respect to water level

Category	Depth (m)	Area in 2012 (Ha)	Area in 2015 (Ha)
Water Level	2 to 2.2	653.74	
	2.2 to 2.4	448.55	
	2.4 to 2.6	50.7	
	2.6 to 2.8	24.03	
	2.5 to 3		390.23
	3 to 3.5		400.79
	3.5 to 4		346.59
	4-4.36		39.41
Total		~1177	~1177

VI. Conclusions

The current study is demonstrating the role of the RS-GIS in the field of hydrology and its role in the demarcation of the groundwater potential zones of the region.

1. Various factors such as geology, slope, lineament density, drainage density, geomorphology, soil depth/thickness, LU/LC are governing their role in the demarcation of the potential zones of the groundwater in the Puniyakundi Watershed.

2. The major factors like geology, lineament density, drainage density, the slope of the watershed, LU/LC, showed their favourable conditions for the delineation of the groundwater recharge potential zones.

3. Western, central and eastern part of the watershed showed the moderate to very high potential zones for the groundwater recharges.

4. Geology generally is a key factor for the groundwater recharge, but the recharge in the study area is governed primarily by lower slope as the area is has characteristic table top topography. The water holding capacity and thickness of the soil is other major factor governing the recharge zones. Thick vegetative cover is also supporting potential groundwater recharge.

5. A comparison between the groundwater potential zones of the year 2013 and 2016, observed the change in the classes of moderate, high, and very high potential zones. Moderate to high potential zones of groundwater recharge recorded the increment in these classes of the watershed while very high potential zones recorded the decrement by area wise.

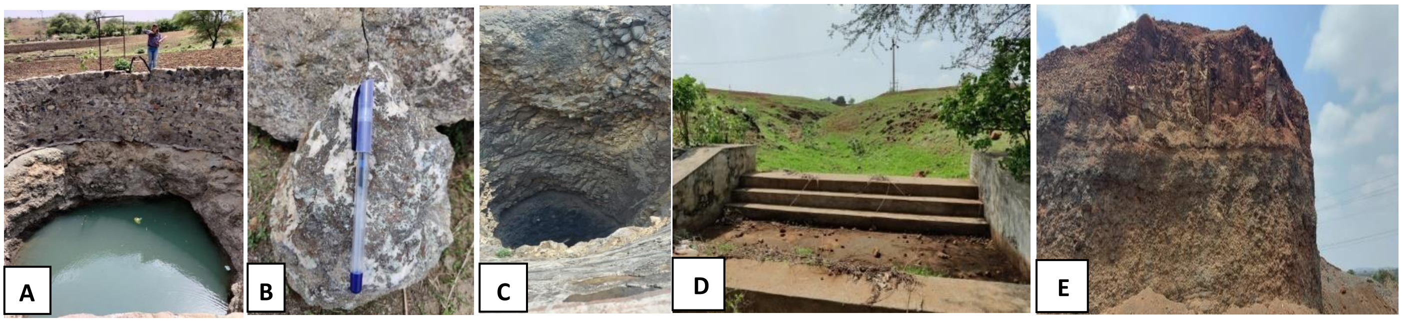

Fig. 11: **A.** Shallow well near the outlet of the watershed; upper soil and weathered part (lined), middle fractured, and lower hard. **B.** Secondary mineralization in lower reaches; sample from well digging. **C.** Highly fractured layer followed by a hard layer on the lower side. **D.** Protection of gully formation using check-dams. **E.** Basalt mound showing flow and amyloid.

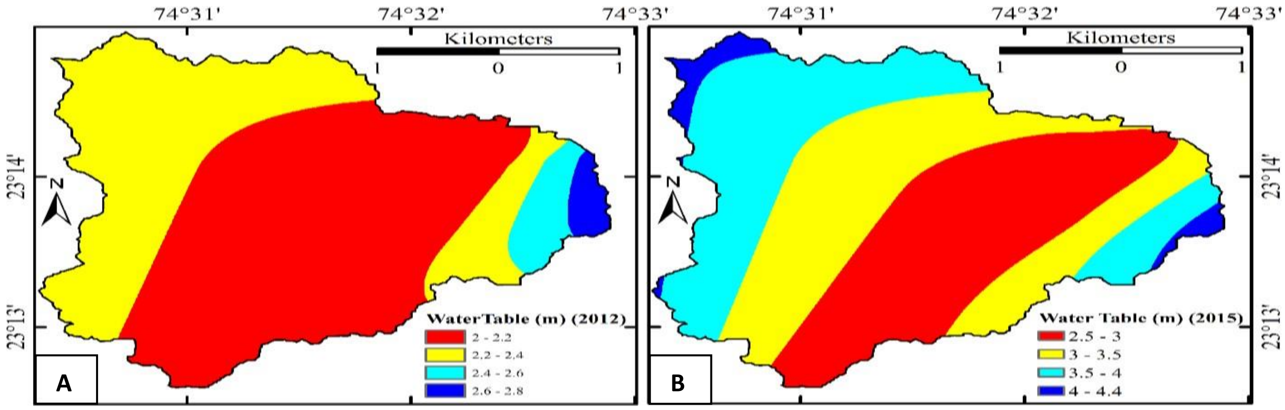

Fig. 12: **A.** Water level map of the watershed of the year 2012. **B.** Water level map of the watershed of the year 2015.

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