Jour. Geol. Soc. India (2022) 98:961-970
https://doi.org/10.1007/s12594-022-2101-3

ORIGINAL ARTICLE

Application of RS and GIS to Capture the Interplay of Geological Units and Watershed Development Activities: Implications on Change in Groundwater Potential with Reference to Anjeni Micro-watershed

Akanksha Pandey[1]*, Ritesh Purohit[1] and Deepak Sharma[2]

[1] Department of Geology, Faculty of Earth Sciences, Mohanlal Sukhadia University, Udaipur - 313 001, India
[2] Development Consultant, Natural Resources Management, Udaipur - 313 001, India
E-mail: *pandey.akanksha1191@gmail.com*; riteshpurohit72@gmail.com; deepakpal33@gmail.com*

Received: 18 March 2021 / Revised form Accepted: 31 January 2022

ABSTRACT

In the dryland areas watershed development is one of the major programs of the Government of India. Ever since its initiation (1981), large tracts of degraded lands are treated through this approach. Remote sensing (RS) is a tool that has been successfully applied to capture groundwater potentials in different regions and geological units. In this study RS & GIS tools are applied to correlate groundwater potentials with various geological controls and watershed development activities at Anjeni watershed, Udaipur district, Rajasthan, India. In the study reference periods taken are year 2013 (pre-project) and 2016 (post-project). A hydro-geomorphological approach integrating remote sensing applications, field investigations, geological and hydrological studies were undertaken to delineate and study the groundwater potential along with recharge dynamics before and after intervention situation. Thematic maps were prepared through linking the RS data with morphometric characteristics, topographic analysis, land use/cover assessment and groundwater conditions. Geographical Information System (GIS) was used to integrate all the contributing factors like lithology, geomorphology, LU/LC, lineaments, drainage, and slope with the help of weighted overlay analysis. Merging the characteristics of groundwater potential, hydro-geomorphology, geology, water harvesting structures, morphometric analysis, lineament density studies, and water balance elements provide an effective approach for the delineation of potential sites for groundwater. This integrated approach has successfully captured the changes that occurred in groundwater situation of the Anjeni watershed in form of poor to very high groundwater potential zones. It establishes the importance of application of RS-GIS in flagship development program of the watershed management.

INTRODUCTION

National Bank for Agriculture and Rural Development (NABARD) initiated a wider program of watershed development in Rajasthan, India under IGWDP (Indo-German Watershed Development Programme) during 2011-2018. Action for food production (AFPRO) planned, and implemented watershed development activities at the Anjeni micro-watershed (Macro No.: 130105, Micro no.: 13010502), located in southeast of Udaipur district in Rajasthan (Fig.1). As reflected in the Central Ground Water Board report (2013) titled 'ground water scenario in Udaipur district, the groundwater development status in the Lasadiya block is critical (91.23%) indicating limitation for further development. Therefore, to improve groundwater recharge, the existing development status is improved through enhanced rain-water harvesting by constructing conservation structures and artificial recharge.

The key components of watershed treatments included various soil conservation and water harvesting works (Fig.2) during the period from 2013 to 2015. Geographic information system (GIS) based data for pre- implementation (April, 2013) and post- implementation (April, 2016) watershed development programme is available for the study area and is used extensively in present study to interpret the impact of geological controls. Geological factors such as topography, lithology, structures, depth of soil, extent of fractures, secondary porosity, slope, drainage pattern, landforms, LU/LC, climatic conditions and interrelationship between these factors control occurrence of movement of groundwater (Roy 1991, Greenbaum 1992, Mukherjee 1996). Exposed litho-units affects groundwater recharge (Shaban et al. 2006) by controlling percolation of water flow (El-Baz and Himida 1995).

Geological controls have been linked with watershed development activities like staggered contour trench (SCT), boulder gully plug (BGP), stone bund (SB), earthen field bunds (EFB), water absorption trench (WAT), earthen nala bund with uutlet (drain) and stone pitching, forestry plantation, grass-seeding etc. to save precipitation and harvest surplus water to recharge aquifer fully to arrest declining water levels of groundwater. Delineation of the groundwater potential zones for recharge is one of the key processes for enhancement, management and development of groundwater resources. The spatial distribution and varying trend of sub-surface linear structures have shown that the movement and occurrence of groundwater is governed by landforms, structural features and topography (Suryabhagavan, 2017).

Development related activities in micro-watersheds have been identified by the usage of RS and GIS. Satellite imageries are increasingly used in groundwater exploration because of their utility

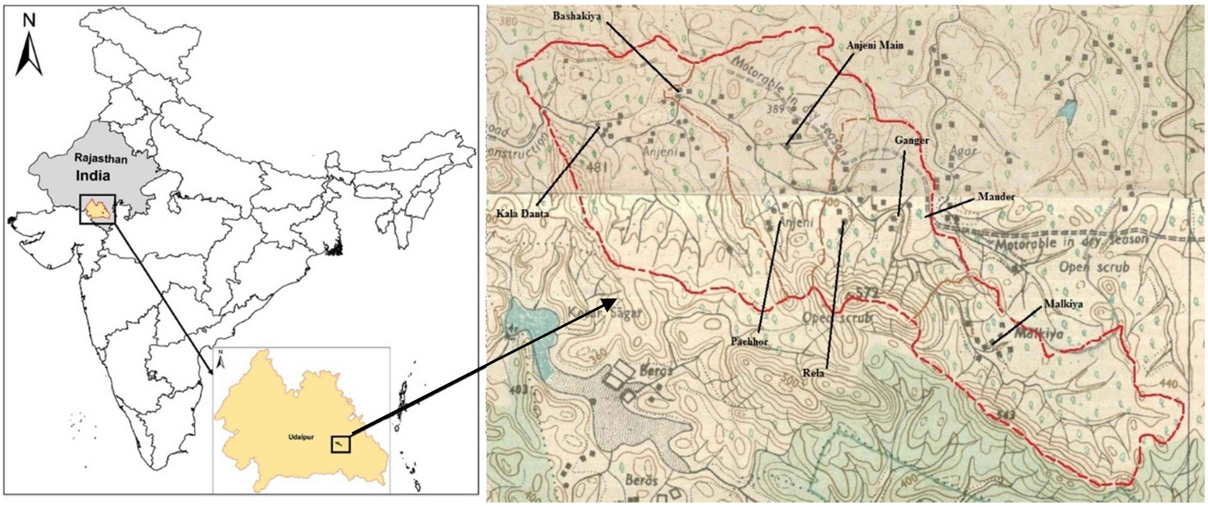
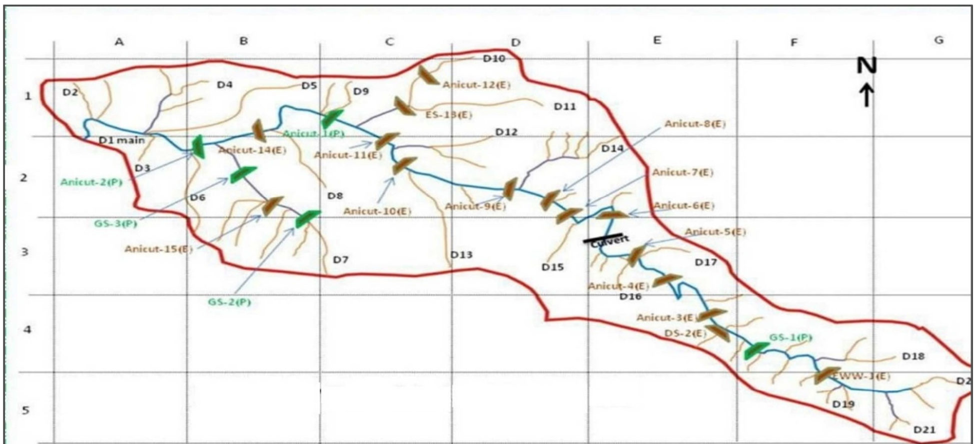


Fig.1. Location map of the Anjeni watershed, Lasadia block, Udaipur.

in identifying various ground features, which may serve as either direct or indirect indicators of presence of groundwater (Das et al., 1997; Bahuguna et al., 2003). Sener et al. (2005) pointed out that RS can effectively identify the characteristics of the surface of the earth (such as lineaments and geology) and can also be used to examine groundwater recharge. RS in combination with GIS, has been widely used for groundwater prospect mapping (Srinivasa et al. 2003; Elbeih, 2015). Khadri et al. (2013) used RS and GIS techniques for PT-6 watershed in Akola district, Maharashtra, with reference to watershed management. Shaikh and Birajdar (2015) adopted GIS and image processing techniques for the identification of morphological features and analyzing their properties of the Eru river basin, sub-watershed of



Sl. No.	Drain No.	Identification	Location on drainage ma
1	D1	Main Nala	GS-A1
2	D2	Tamatiya Weli	A2
3	D3	Parpata Weli	B1-A1
4	D4	Kodiya Weli	B1-A1
5	D5	Maadaweli	B3-B2
6	D6	Amarwali Weli	C3-B2
7	D7	VanBhivag Valley	C3-B2
8	D8	Nathu Babji Weli	C2-B1
9	D9	Baishakhiya Nala	C1
10	D10	Badla Weli	D1-C1
11	D11	Badla Weli(Sub Nala)	D1-C1
12	D12	Bhagghati Weli	D2-C2
13	D13	Pachore Weli	C3-C2
14	D14	Naka weli	E2-D2
15	D15	Relaweli	D3
16	D16	Rela Weli	E3
17	D17	Kalki Magri Weli	E3
18	D18	Anda Weli	G4-F4
19	D19	Dolaghata Weli	F5
20	D20	Amli Ghati	G5
21	D21	Shamshan Weli	G5

Fig.2. Map showing watershed development activities at Anjeni watershed (photo courtesy: AFPRO).

Mahi River, Rajasthan, India. Considerable amount of work has been carried out employing geospatial techniques in exploration and delineation of the potential areas of groundwater (Magesh et al., 2012; Senanayake et al., 2016; Ahmed, 2016; Ahirwar et al., 2020). Kumar et al. (2019) delineated groundwater potential zones by adopting a standard methodology using remote sensing, geospatial modeling, geographic information system (GIS) and multi criteria decision analysis (MCDA) techniques.

Present study concentrates mainly on three components viz., (a) generation of different layer of thematic maps, (b) impact of geological controls on generation of suitable sites for recharge, (c) delineation groundwater potential zones within watershed and compare situations during pre and post watershed management activities using field data and multi-source satellite data through a comprehensive approach of remote sensing and GIS. All these aspects of the study are point towards the application of RS-GIS technology as a viable and effective tool to assess the ability of watershed development activities to implement such structures on water-conservation and water harvesting.

WATERSHED STUDY AREA

The Anjeni watershed covers an area of approximately 982 ha, and falls in the Survey of India Toposheet No. 45 L/3 and L/4 (Fig.1), and lies between 24°14'00" to 24°15'35" N and 74°06'22" to 74° 09'56" E. The average annual rainfall of Lasadiya block which comprises the study area is 653.7 mm as per Hydrological Atlas of Rajasthan Udaipur district 2013 (www.phedwater.rajasthan.gov.in). Most of the soils are sandy and sandy loam. Anjeni watershed generally has slope from south-east to north-west and comes under the Aravalli mountain ranges which are moderately metamorphosed and belong to Paleoproterozoic Aravalli Supergroup. The watershed falls under the category of hard rock area of phyllites and schist with bands of quartzite and quartz veins, intruding into Archean gneissic basement rocks. The area shows an undulating topography and gentle to steep slopes, dendritic to sub-dendritic drainage system with high drainage density. The watershed comprises of a tributary of Gomti river in the catchment area of the 'Mahi' basin, which finally drains into the Jaisamand lake south of Udaipur. A good number of primary streams originating from various hillocks join the main stream passing through the central line of watershed. The elevation in the selected watershed varies from 543 m to 481 m above mean sea level as shown in physiographic map of the Anjeni watershed (Fig.3).

DATA COLLECTED AND METHODOLOGY ADOPTED

The ResourceSat-2 data of LISS III acquired in 2013 and 2016 were gathered from NRSC for preparation of land-use / land-cover (LU/LC) maps. Digital elevation model (DEM), slope, drainage, drainage density, geomorphology, lineament and lineament density maps were derived using the Cartosat-1 data (2015). Geological map was prepared from District Resource Map of GSI, Jaipur. Soil Thickness Map was prepared using the National Atlas and Thematic Mapping Organization (NATMO) data. All the data were collected and processed using ArcGIS. To delineate the groundwater potential recharge zone map, different weightages and ranks were assigned to each thematic map and all their attributes. The most important part of the study was to meet the people living in and around the study area who have witnessed the changes in groundwater availability zones and quantity of water available and their linkages with the watershed development works. The information then was correlated and the results were confirmed with more accuracy. The flow chart of the data acquired and methodology adopted is shown in Fig. 4.

PREPARATION OF THEMATIC LAYERS AND ASSIGNING RANK

The spatial data were obtained from various sources to prepare different thematic maps such as geology, lineament, lineament density, slope, drainage, drainage density, geomorphology, soil depth and LU/LC pre- and post-watershed development activities. These maps were prepared and integrated using weighted overlay index (WOI) method in ArcGIS to generate the final maps of groundwater recharge potential zone of pre-monsoon season of 2013 and 2016, and the changes were compared in terms of watershed management activities and controls of various geological factors on the generation of recharge zone. Each category in thematic layers is assigned by a numerical rank between 1-10 and weightage is given to the individual thematic map according to their importance in delineating the groundwater potential recharge

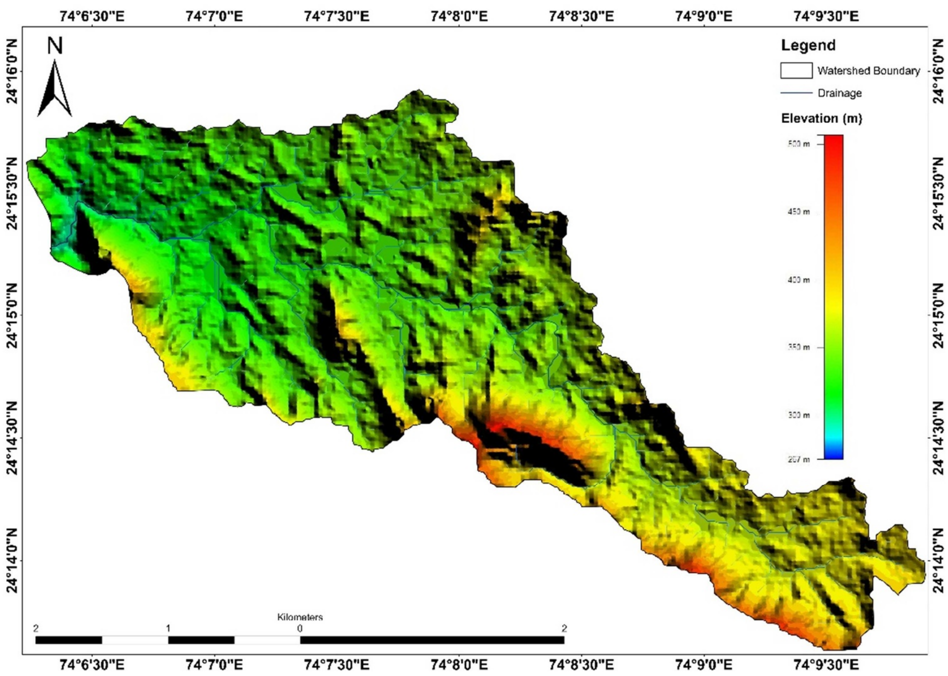


Fig.3. Physiological map of the Anjeni watershed area.

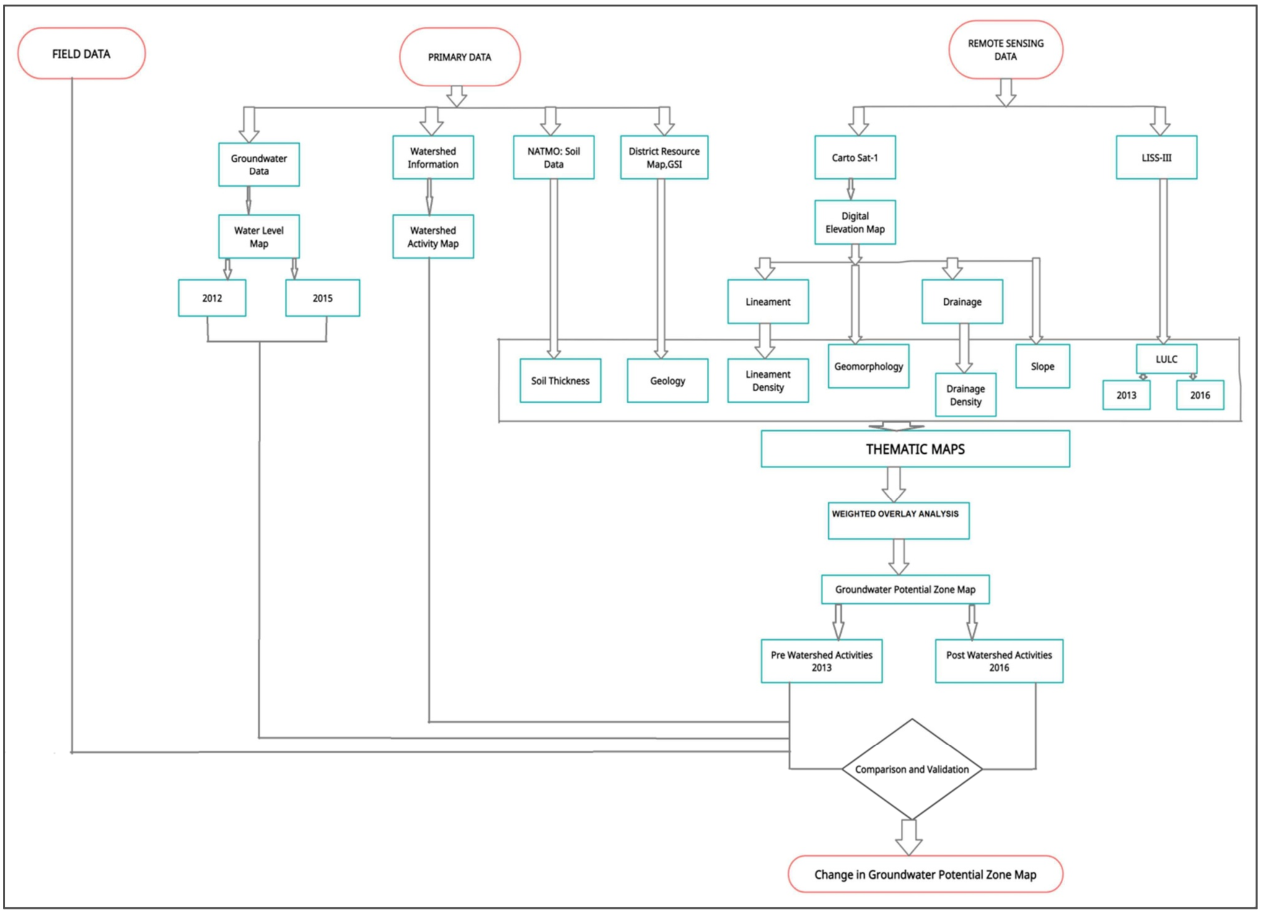


Fig.4. Flow chart showing adopted methodology

zone. Each layer and their role in the identification of recharge zones are explained in the following paragraphs.

Geology

The watershed study area has underlying rocks of banded gneissic complex (BGC). The study area has a basement cover relationship between granitic gneisses and supracrustal metasedimentary rocks like carbonates, quartzite, phyllite, conglomerates and schist belonging to Aravalli Supergroup and also have quartz veins intrusion as shown in Fig.5. Western dipping and north-south striking rock formations

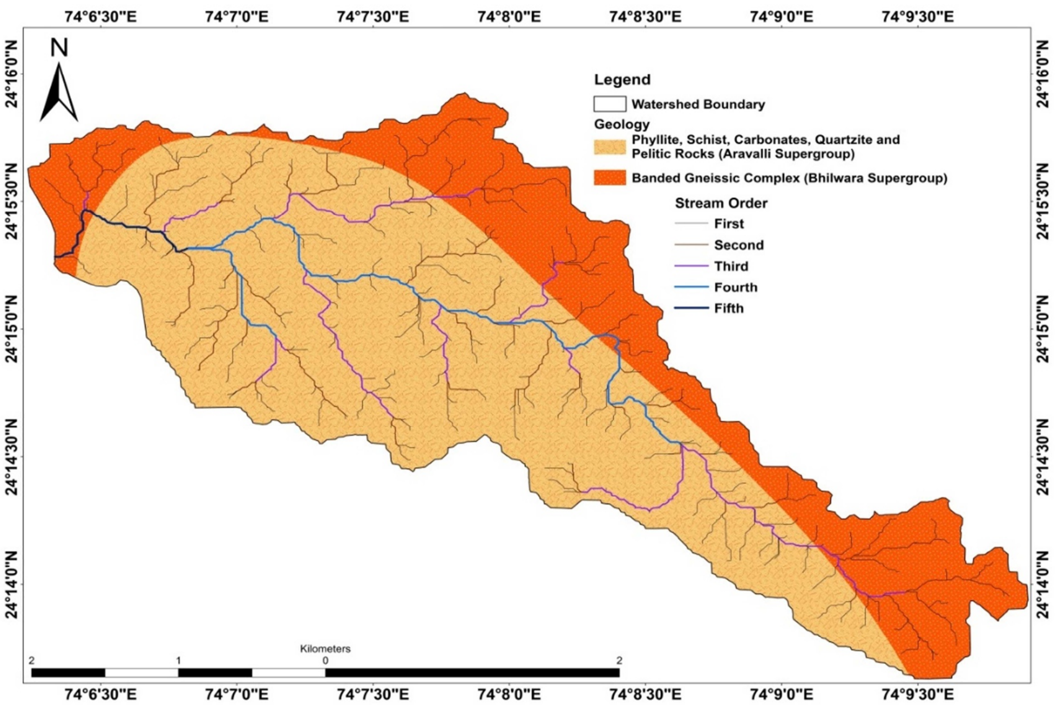


Fig.5. Geological map of the Anjeni watershed area (GSI, Jaipur).

commonly have fracture sets which included bedding plane fractures, vertical fractures and horizontal fractures with good openings. The groundwater movement in these rocks is mainly through fractures, joints and openings. Quartz veins are quite common in the area and have role in increasing the porosity. The rank, weightage and area assigned to rock type is listed in Table 1.

Lineaments and Density

A lineament is a linear feature in a landscape which is an expression of an underlying geological structure such as a fault, fracture, and joint (Navane et al., 2017). Significant lineaments present are those in and around the valley fill and pediplain. The linear features present in areas with high slope and high drainage density are of minimal importance due to high runoff rate and these plays as a medium of transmitting the infiltrated rain water.

The lineament density layer developed using the line density tool in the Arc Map is divided into six classes (Fig.6). The rank, weightage and area assigned to all the sub-classes listed in Table 2.

Slope

Slope map of the study area (Fig.7), classified further into sub-categories, shows that maximum area is covered by slope category 5-8.5%. Since, this slope category is favorable for infiltration of rainwater; this area has potential groundwater zones. The rank, weightage and area assign to all the sub- class is listed in Table 3.

The comparison of land slope in pre and post watershed scenarios does not indicate a significant jump in area from one category to another. Thus it is not noticeable in terms of change in slope category on this scale of RS-GIS data.

Drainage and Drainage Density

Drainage in the study area mostly occurs in the gneissic terrain and exhibits typical dendritic to sub-dendritic pattern indicating homogeneity in lithology which clearly points out the traits of sub-surface and surficial attributes (Fig.8A). Drainage density is defined as the closeness of spacing of stream networks because of its relationship with surface runoff and permeability (Mangesh et al., 2012). Drainage density is inversely proportional to permeability. High drainage density is an indicative of high runoff which relates to less infiltration of rainwater, therefore, poor groundwater prospects whereas low drainage density supports infiltration by controlling the run off rate hence producing fair prospects for groundwater. The drainage density in the study area is divided majorly into 5 sub-categories (Fig.8B). The rank, weightage and area assigned to all the sub-category of drainage density is listed in Table 4.

Table 1. Geology type, rank, weightage and area

Category	Formations	Rank	Weightage	Area (in Ha)
Geology	Banded Gneissic Complex	1	10	304.38
	Aravalli Supergroup	2	10	677.42

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	1.3
	2.03 to 2.54	2	20	13.1
	2.54 to 3.05	3	20	22.9
	3.05 to 3.56	4	20	61.9
	3.56 to 4.07	5	20	355.6
	4.07 to 5.15	6	20	527

Table 3. Slope class, rank, weightage and area

Category	Class	Rank	Weightage	Area (in Ha)
Slope (degree)	0 to 1.1	6	20	29.0
	1.1 to 3	5	20	133
	3 to 5	4	20	189.3
	5 to 8.5	3	20	268.8
	8.5 to 24	2	20	215.5
	> 24	1	20	146.2

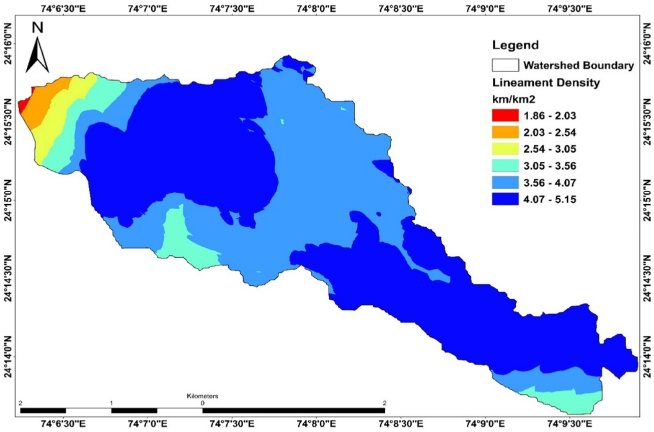


Fig.6. Map showing lineament density in Anjeni watershed.

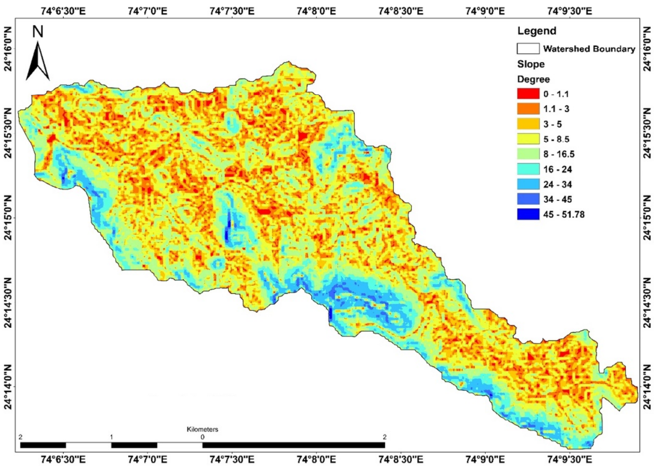


Fig.7. Map showing slope classification in Anjeni watershed.

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	50.5
	1.01 to 1.13	4	12	164.1
	1.13 to 1.18	3	12	113.5
	1.18 to 1.3	2	12	352
	1.3 to 1.63	1	12	301.6

Geomorphology

The study area is divided into following three categories on the basis of geomorphological features present (Fig.9).

Structural Origin

The uplands with high elevation and moderate to steep slope having rough textured soil and escarpments with varying hardness, and dense to scarce plantation are key features of hills of structural origin. These hills are high run off zones in context to groundwater. The recharge here is poor and only confined along linear structures like, fractures,

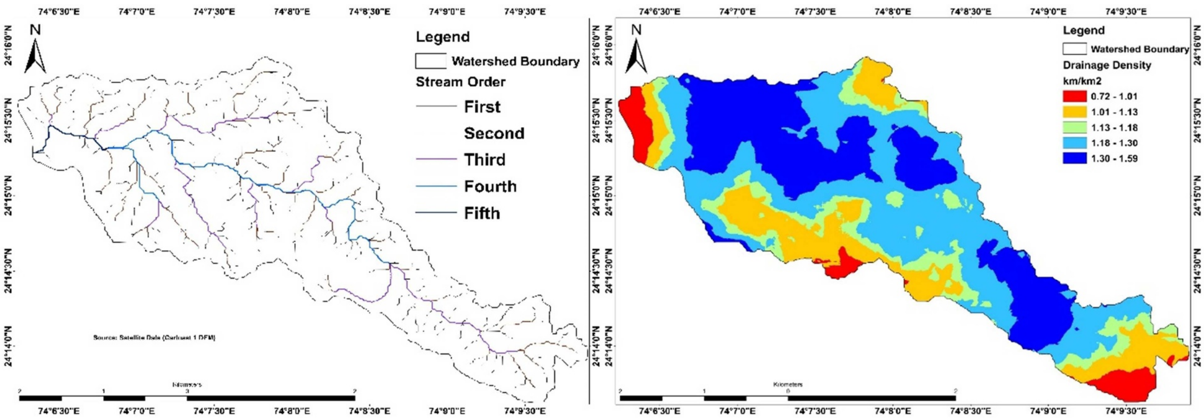


Fig.8. (A) Map showing drainage of Anjeni watershed. (**B**) Map showing drainage density of Anjeni watershed.

fault zones and joint planes and these are considered good for groundwater movement and storage (Ndatuwong and Yadav, 2014).

Denudational Origin

The weathered material found in low lying terrain which is generally covered with top soil. Study area with gentle slope in nearly egg-basket topography is also overlain by weathered material and formed due to differential weathering and erosion. The occurrence of groundwater depends on the weathered zone thickness due to its low relief by erosion (Deepika et al., 2013). The shallow weathered pediplain in the study area generally has low vegetation indicating low moisture content and low runoff due to flat topography of pediplain, thus poor to moderate groundwater recharge prospect. The moderately weathered pediplain have better infiltration capacity and considerably recharge the groundwater as it is densely covered with vegetation, so have good water retention and less run-off as compared to the gently sloping terrain.

Valley Fill

These are unconsolidated fluvial deposits in narrow valleys seen all along the drainage in almost the entire course of stream in the study area. These are covered with fairly moderate vegetation and coincide with the lineament. The rank, weightage and area assigned to all the geomorphic feature is listed in Table 5.

Soil Depth / Thickness

The study area is generally covered with sandy soil particularly reddish yellow sandy and murum (Fig.10A). It is basically the weathered material as data provided by NATMO, survey reports of AFPRO and field work. The depth (in cm) as derived by primary data

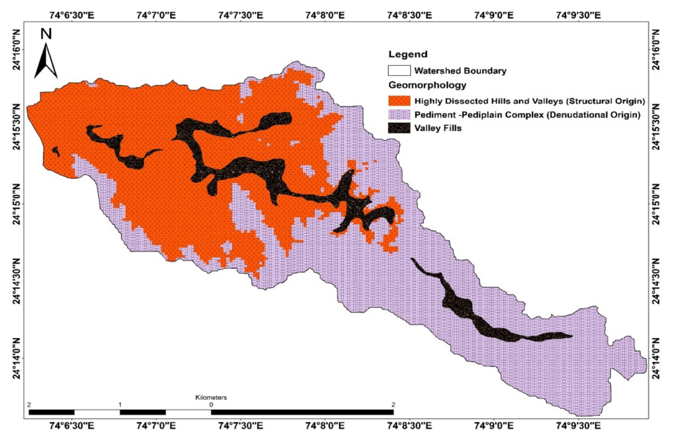


Fig.9. Map showing geomorphology of Anjeni watershed.

Table 5. Geomorphology type, rank, weightage and area

Category	Type	Rank	Weightage	Area (in Ha)
Geomorphology	Structural Origin	1	10	467.5
	Denudational Origin	2	10	428
	Valley Fills	3	10	86.3

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

Category	Class	Rank	Weightage	Area (in Ha)
Soil Depth	6 to 10	1	15	82.8
	10 to 25	2	15	490
	25 to 50	3	15	391.1
	50 to 67.91	4	15	17.8

of soil is divided into four sub-ranges (Fig.10B). Soil texture, type, depth and permeability to transmit the surface water to recharge the underground aquifer system. To be a good groundwater recharge medium, soil should be of high infiltration capacity area whereas in fine grained soils like clay infiltration rate is low which leads to surface runoff. The rank, weightage and area assigned to all the sub-classes listed in Table 6.

Land use / Land cover (LU/LC) Pattern

LISS-III data of pre-monsoon season i.e. April, 2013 (Fig.11A) and April, 2016 (Fig.11B) were used for the preparation of LU/LC maps. The analysis of LU/LC has a great impact on groundwater recharge of an area. The comparison of change in the LU/LC pattern of the study area Pre- and Post- watershed activities was made using the following 5 sub-categories: Settlement and barren land, open land, grasses and bushes, rainfed land, irrigated land and trees. Settlement and barren land hinder the infiltration of water into ground, on the other hand irrigated land and land with good vegetative cover supports the water to infiltrate into the ground. So, the maximum rating is given to irrigated land and trees and settlement and barren land is assigned with the minimum rating (Table 7).

Groundwater Recharge Potential Zone (GWPZ) Maps

Groundwater recharge potential zone maps of year 2013 (Fig. 12A) and 2016 (Fig.12B) were generated by the integration of all the thematic layers using the WOI in ArcGIS. The potential recharge zones of groundwater as identified from the maps were further categorized into (i) poor (ii) moderate (iii) high and (iv) very high zones. The change in the recharge area due to water watershed development activities are shown in Table 8 suggests that the area with high potential zones have increased, also there is a slight increase

Table 7. LU/LC type, rank, weightage and change in area

Category	Type	Rank	Weightage	Area in 2013 (Ha)	Area in 2016 (Ha)	Change in Area (Ha)	Change in Area (%)
Land Cover	Irrigated Land and Trees	6	8	62.6	39.3	-23.3	-2.37
	Rainfed Land	5	8	165.7	283.2	117.5	11.97
	Grasses and Bushes	4	8	273.7	148	-125.7	-12.80
	Open Land	3	8	430	447.3	17.3	1.76
	Barren Land	2	8	49.7	63.8	14.1	1.44
	Settlement	1	8	0.06	0.16	0.1	0.001
	Total			981.8		0.0	0.0

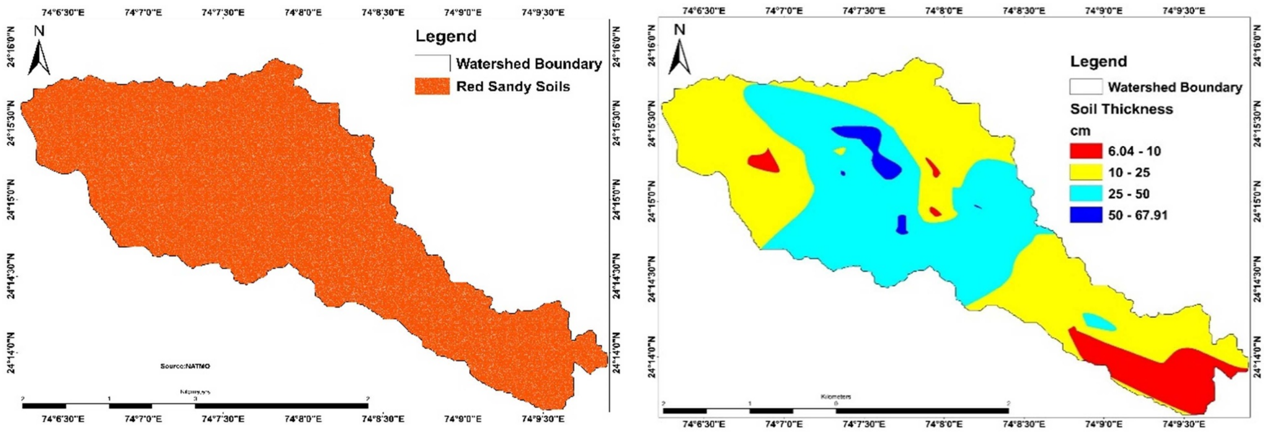


Fig.10. (A). Map showing soil type of Anjeni watershed. **(B)** Map showing soil thickness of Anjeni watershed.

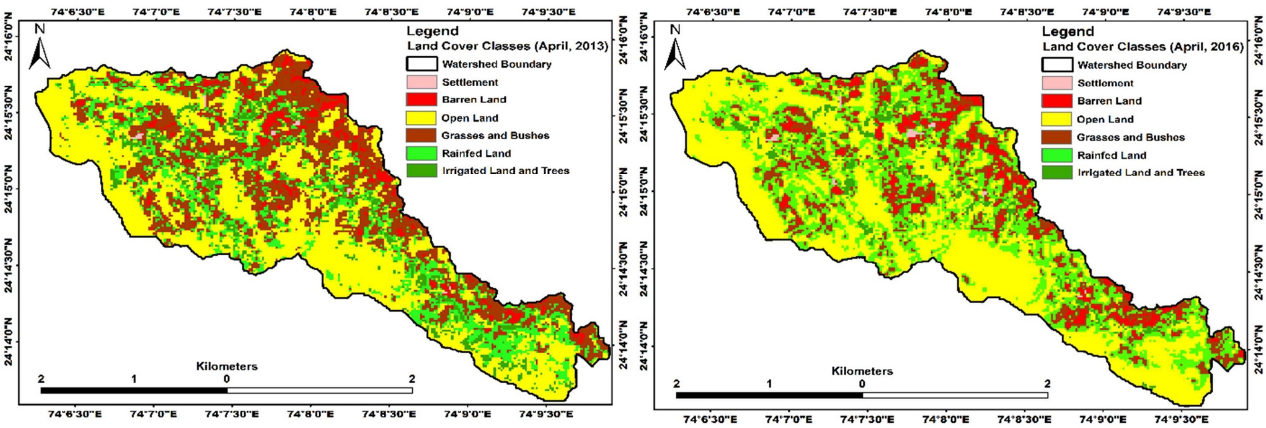


Fig.11. (A). Map showing land-use/ land-cover (2013) of Anjeni watershed. **(B)** Map showing land-use/ land-cover (2016) of Anjeni watershed.

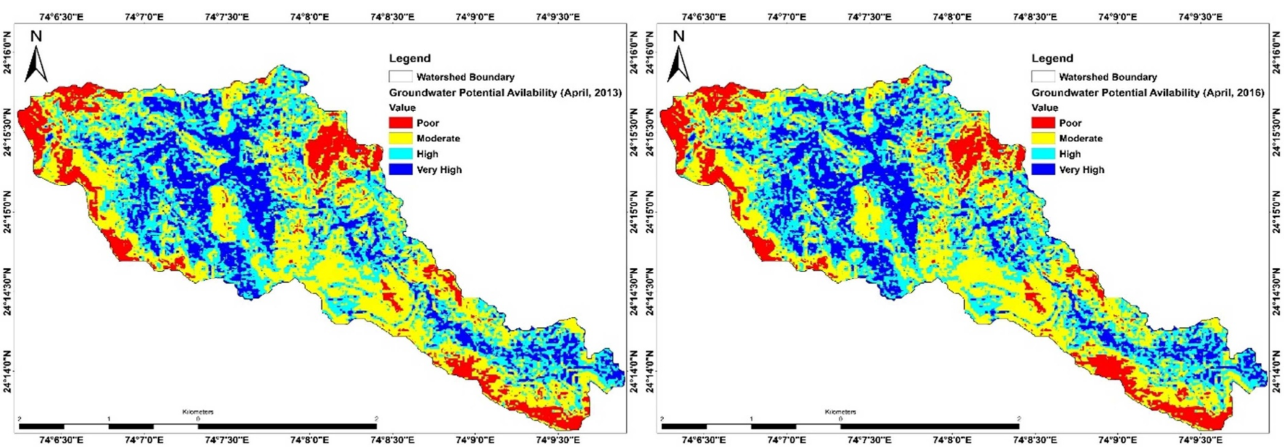


Fig.12. (A) Map showing groundwater potential zone (2013) of Anjeni watershed. **(B)** Map showing groundwater potential zone (2016) of Anjeni watershed.

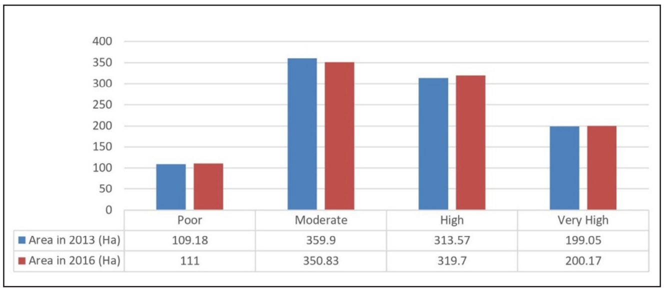


Fig.13. Graph showing the changes in groundwater potential zones in Anjeni watershed.

in the zones with poor and very high groundwater prospects (Fig.13).

The results were correlated with changes during 2012 (Fig.14A) and 2015 (Fig.14B) in the water level of the wells present in the watershed with help of available data as provided by AFPRO. The water level (in metres) divided in to four categories 1.5-3.9 (very shallow), 3.9-4.7 (shallow), 4.7-7.1 (moderate) and 7.1-8.5 (deep). The data indicates a rise of water level to the tune of 1.5 meters between the reference year 2012 and 2015 (Fig.15). Also, the number of well present in very shallow depth has considerably increased, indicating fast replenishment of water and successful impact of water harvesting structures constructed during watershed development activities.

RESULTS AND DISCUSSIONS

The watershed development programs are implemented focusing on improving water-holding capacity of an area, both in terms of surface-water and groundwater.. The amount of water in watershed is estimated through visible bands by direct measurement, but variation in terms of soil-moisture can be captured by Near Infrared band observations. The groundwater prospects and its occurrence in an area is controlled by various climatic factors like rainfall as well as geological factors such as slope, lithology, linear structures, landforms, soil and drainage.

The rainfall pattern data as shown from 01.06.2015 to 30.09.2015 at tehsil / sub-tehsil rain-gauge station of Water Resources Department, Government of Rajasthan shows that the Lasadiya has received 749mm annual rainfall in the monsoon period which could be an important reason for generation of new groundwater potential recharge zones in the area. In 2015, 31 days out of 365 days were recorded to be total annual rainy days, from which rainfall during the non-monsoon period is ~ 4 percent of total rainfall i.e. 783mm as stated in the Rainfall 2015 report of Water resource department, Government of Rajasthan (water.rajasthan.gov.in). When compare to rainfall data in 2013 as stated in the Rainfall 2013 report of Water resource department,

Table 8. GWPZ class, and change in area

Category	Class	Area in 2013 (Ha)	Area in 2016 (Ha)	Change in Area (Ha)	Change in Area (%)
GWPZ	Poor	109.2	111	1.8	0.18
	Moderate	360	350.8	-9.2	-0.93
	High	313.6	319.8	6.2	0.63
	Very High	199	200.2	1.2	0.12
	Total	981.8		0.0	~ 0.0

Government of Rajasthan (water.rajasthan.gov.in) among total 41 annual rainy days the monsoon period receives 669mm and non-monsoon period receive ~3 percent of total rainfall i.e. 694mm.

The intensity, amount, duration and temporal variation of rainfall regulated the infiltration and runoff of the surface water into ground. Physical hydro-meteorological factors act along with geological factors to recharge groundwater and generate new prospects for its occurrence. Geological controls over the potential recharge zone are very significant and are described as follows:

(A) Factors that remains unchanged due to anthropogenic actions

These are the key factors those controls movement of water over and underground and decide over extent of potential groundwater zones in an area. In the study following aspects were covered.

- Availability of groundwater is governed by lithology along with topographic influences. It helped to assess the underlying weathered zone, increased secondary porosity and conduits for groundwater movement in hard rock terrain.
- Higher lineament density indicates a higher possibility of groundwater movement resulting in good to very good potential for in-situ groundwater combining it with other geological controls as nearly 90% area in the watershed falls under the two categories of higher lineament density (Table 2).
- The indicator of drainage density also remains unchanged in the pre- and post- watershed scenario; thus, the influence of watershed development work remains unchanged. More than ~67% of the study area is under very high to high drainage density as shown in Fig.7. Geomorphically ~48% and ~44% of the total study area falls under structural origin and denudational origin category respectively. Mainly northern and central part of the study area contributes to highly dissected hills and valleys of structural origin, where drainage is following the fracture and joint pattern flows through topography with high slope giving the area a sharp relief and reducing the groundwater prospects. In study area pediments of denudational origin reflect moderate to poor groundwater recharge prospect probably due to low soil

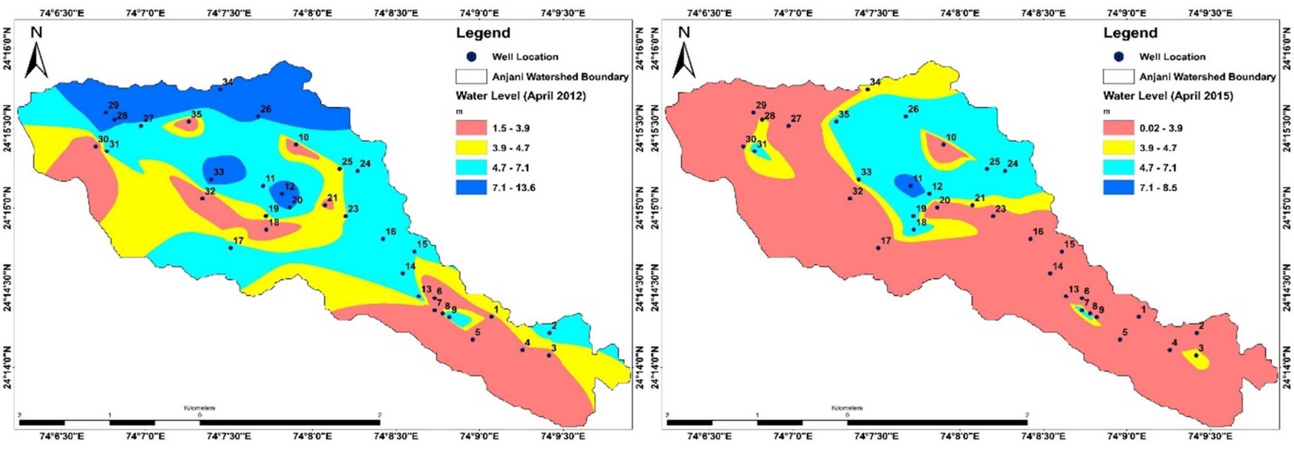


Fig.14. (A) Water level map of Anjeni watershed of year 2012. **(B)** Water level map of Anjeni watershed of year 2015.

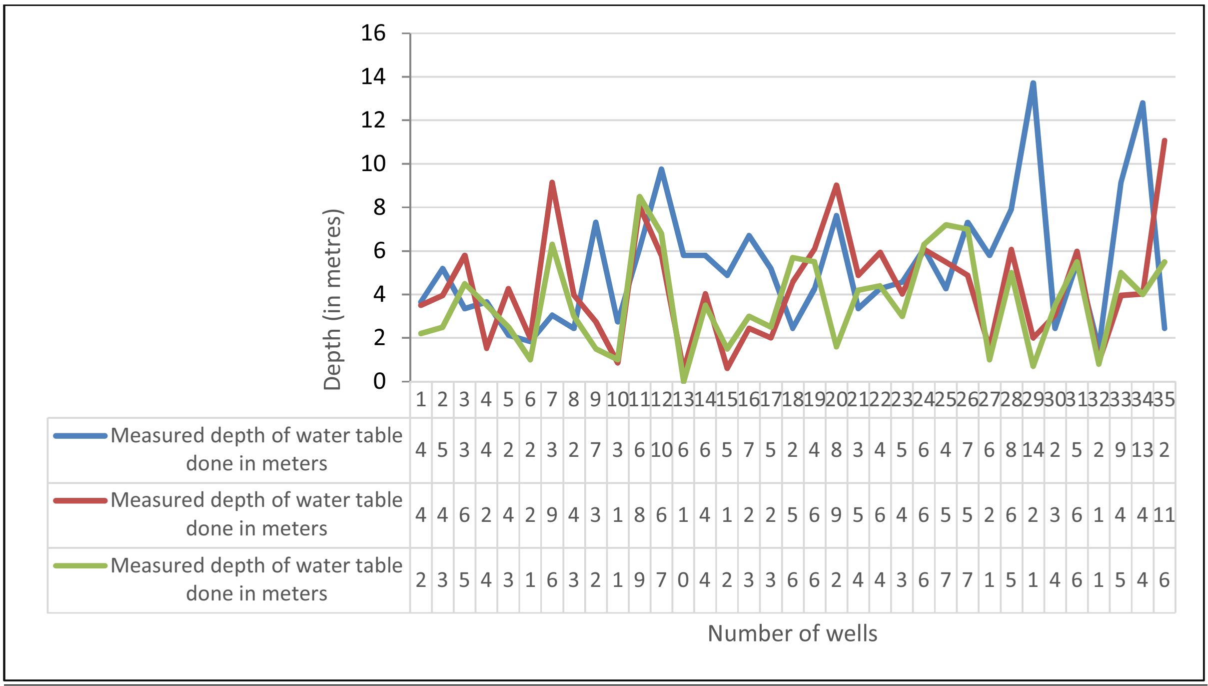


Fig.15. Graph showing the changes in water level depth in April analysis during project duration.

cover leading to less moisture retention and high drainage density resulting into high run off in the area. Valley fills covers ~8% of total study area expected to show moderate to good groundwater prospects as the infiltration rate speeds up due to the presence of unconsolidated sediments.

- Infiltration and groundwater recharge are promoted generally by gentle and flat slopes and little or no infiltration with higher rates of run-off in steeply sloping areas. RS-GIS study at Anjeni Watershed indicates that 69% land in the watershed is under the slope percentage less than 8.5%. This indicates moderate surface water movement better prospects of ground water as it is one of the considerable factors which determine the groundwater infiltration into subsurface. 31% area with high slope allow limited residence time to the rainwater for percolation, hence resulting in high runoff; as compare to the region with gentle slope where the percolation time of rainwater is more, hence less runoff. Comparison of the two imageries (pre and post development) does not indicate measurable changes in slopes, even at the precise measurement of resolution. Very minor changes can be seen at some newly developed agriculture fields only but in very limited areas.
- Soil with maximum infiltration rate as seen in sand or gravel is found predominantly in the study area. Approximately 90% of the area is covered with soil thickness between 10cm-50cm that turns out to be a supportive medium for the groundwater recharge.

(B) Factors that remains unchanged due to anthropogenic actions

- The most remarkable changes observable in LU/LC patterns of watershed suggests that there is a significant decrease in the irrigated land and vegetative cover in the area and on the other hand, the rainfed, open, barren land and settlement have increased over the years (Table 7).
- The GWPZ maps prepared using GIS techniques were compared to yield potential in different rock-formation using groundwater report by CGWB. The observations were further confirmed using sample well inventory data supplied by implementing agency.
- Correlations were made with the contact zone where the lithology changes, major lineament present. The geomorphologic features present in the area were physically marked to validate in maps. Also, the coordinates of the developed structures were noted for better understanding.
- The overall groundwater potential marking different zones namely good, moderate, and poor zones done by overlying of different layers geological units, slope, geomorphological units, lineament, slope and soil-depth along with the ground truthing (Fig.16, A, B, C, D) has revealed about the increase in area under different category of GWPZ. The results of GIS study in terms

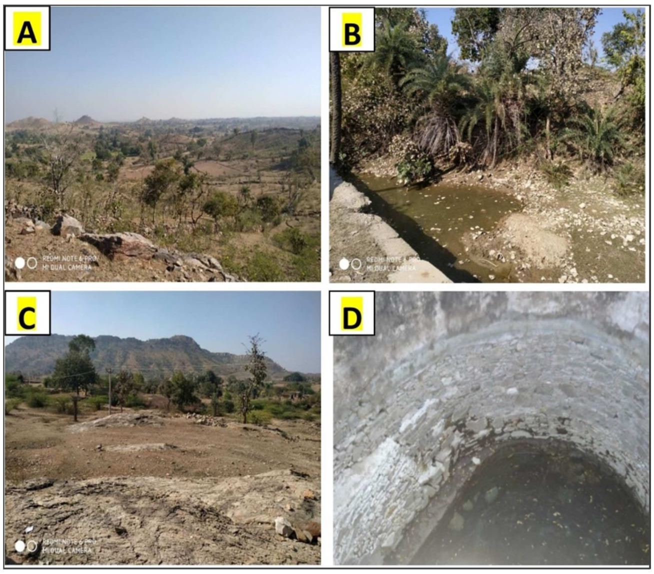


Fig.16. (A) Photo from the water-divide line in south boundary of Anjeni micro-watershed - camera facing north-east direction towards outlet. **(B)** Photo showing the presence of base-flow (6th February 2021) in the upper parts of the watershed indicating improved groundwater regime due to conservation and harvesting works in upper reaches. **(C)** Typical gneissic topography and outcrop in the forefront, while camera facing south, quartzite escarpment (lineament) in background forming the water-divide line. **(D)** Photo showing increased water level in well located central parts of Anjeni micro-watershed.

of less changes in ground water potential zones were discussed with local community. The community reflected that changes are not in terms of the increase in area or zones, but they indicated changes in water level during different months, increase in pumping time, and increase in availability of water in wells. This was beyond the scope of study, but to confirm the community observations study analyzed the well inventory data for the month of April for the study period. Figure-15 shows prominent changes up to 13.5 meters depending on the location and hydrogeological zones.

CONCLUSIONS

The present study reveals that remote sensing and GIS techniques can effectively be utilized/applied to delineate groundwater potential zones can be effectively delineated with. It also helps to capture qualitative and quantitative changes even in a short duration of 3years that resulted in groundwater availability due to different development interventions including watershed development interventions. Properly designed activities and sustainable management of the watershed under right set of geological controls for inducing groundwater recharge slowly improves in overall groundwater potential zones, but is a function of climatic factors such as precipitation pattern.

In this study geology, geomorphology, lineament density, drainage density, slope, soil thickness, LU/LC, and soil thickness were utilized for the preparation of GWPZ maps using WOI. The comparative study of between groundwater recharge potentials in pre-watershed activities and post-watershed activities give the explicit difference and showed the major variation in high and very high GWPZ. Though, the comparative analysis (Table 7) indicates that more area has come under barren, settlement and open land in the post scenario against the pre-project situation of irrigated land. The observations obtained in study were discussed with community and compared with the data from AFPRO with regards to water level changes. The study also indicates need for inclusion of seasonal variations in terms of months (time) as variable for GIS based studies.

The study indicates that GIS interpretations and field level observations are comparable to provide before-hand potential about the recharge zones. As most of the watersheds projects operates on smaller area, the study also opens up scope to explore potential for application of DRONE technology-based RS-GIS in the micro regime level impact studies on soil-types, land-slopes, vegetation growth, and diversity due to watershed development works. It can focus on changes in moisture-retention, water-holding capacity, runoff reduction, increased moisture utilization, and overall groundwater recharge.

Acknowledgement: Authors acknowledge the www.sentinel.esa.int and NRSC-ISRO for providing data for this research work. The authors are also thankful to Action for Food Production (AFPRO) the implementing agency, NABARD for their acceptance and time to time support, and members of watershed management committee at Anjeni for active participation and sharing their experiences during ground truthing works which were critical for taking-up this study. We are very thankful to the Head, Department of Geology, M.L Sukhadia University for providing the research facilities to conduct the work.

References

Ahirwar, S., Malik, M.S., Ahirwar, R. and Shukla, J.P. (2020) Application of Remote Sensing and GIS for Groundwater Recharge Potential Zone Mapping in Upper Betwa Watershed. Jour. Geol. Soc. India, v.95(3), pp.308-314.

Ahmed, S.A. (2016) Geospatial technology for delineating groundwater potential zones in Doddahalla watershed of Chitradurga district, India. Egyptian Jour. Rem. Sens. Space Sci., v.19(2), pp.223–234.

Annexure "2", Monsoon 2015, Water Resources Department, Government of Rajasthan.

Bahuguna, I.M., Nayak, S., Tamilarsan, V. and Moses, J. (2003) Groundwater prospective zones in basaltic terrain using remote sensing. Jour. Indian Soc. Rem. Sens., v.31(2), pp.101-105.

Das, S., Behera, S.C., Kar, A., Narendra, P. and Guha, S. (1997) Hydro geomorphological mapping in ground water exploration using remotely sensed data—a case study in Keonjhar district, Orissa. Jour. Indian Soc. Rem. Sens., v.25(4), pp.247-259.

Deepika, B., Avinash, K. and Jayappa, K.S. (2013) Integration of hydrological factors and demarcation of groundwater prospect zones: insights from remote sensing and GIS techniques. Environ. Earth Sci., v.70(3), pp.1319-1338

El-Baz, F., Himida, I. (1995) Groundwater potential of the Sinai Peninsula. Egypt, Project Summary, AID, Cairo

Elbeih, S.F. (2015) An overview of integrated remote sensing and GIS for groundwater mapping in Egypt. Ain Shams Engg. Jour., v.6(1), pp.1-15.

Greenbaum, D. (1992) Structural influences on the occurrence of groundwater in SE Zimbabwe. Geol. Soc. London, Spec. Publ., v.66(1), pp.77-85.

Groundwater scenario Udaipur district, Rajasthan, Central groundwater board, Ministry of water resources (http://cgwb.gov.in/District_Profile/Rajasthan/Udaipur.pdf)

Hydrological atlas of Rajasthan Udaipur District, 2013 (www.phedwater.rajasthan.gov.in)

Khadri, S.F.R. and Pande, C.B. (2013) Hydrogeological Investigations of Pt-6 Watershed in Akola District, Ms, India Using Remote Sensing and GIS Techniques with Reference to Watershed Management. Internat. Jour. Scien. Engg. Res., v.4(12), pp.1-7.

Kumar, S., Machiwal, D. and Parmar, B.S. (2019). A parsimonious approach to delineating groundwater potential zones using geospatial modeling and multicriteria decision analysis techniques under limited data availability condition. Engg. Repts., v.1(5), p.e12073.

Magesh, N.S., Chandrasekar, N. and Soundranayagam, J.P. (2012) Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques. Geosci. Front., v.3(2), pp.189-196.

Mukherjee, S. (1996) Targeting saline aquifer by remote sensing and geophysical methods in a part of Hamirpur-Kanpur, India. Hydrogeol. Jour., v.19, pp.53-64.

Navane, V.S. and Sahoo, S.N. (2017)) A review of integrated RS and GIS techniques in groundwater potential zone mapping. Hydro-2017 International, L.D. College of Engineering Ahmedabad, India, pp.1-10.

Ndatuwong, L.G. and Yadav, G.S. (2014). Integration of hydrogeological factors for identification of groundwater potential zones using remote sensing and GIS techniques. Jour. Geosci. Geomat., v.2(1), pp.11-16.

Rainfall report (2013), Water resource department, Government of Rajasthan (water.rajasthan.gov.in).

Rainfall report (2015), Water resource department, Government of Rajasthan (water.rajasthan.gov.in).

Roy, A.K. (1991) Hydromorph Geology for groundwater targeting and development in Dehradun valley, UP. Mountain Resource Management and Remote Sensing, Surya Publications, Dehradun.

Senanayake, I.P., Dissanayake, D.M.D.O.K., Mayadunna, B.B. and Weerasekera, W.L. (2016). An approach to delineate groundwater recharge potential sites in Ambalantota, Sri Lanka using GIS techniques. Geosci. Front., v.7(1), pp.115-124.

Sener, E., Davraz, A. and Ozcelik, M. (2005) An integration of GIS and remote sensing in groundwater investigations: a case study in Burdur, Turkey. Hydrogeol. Jour., v.13(5-6), pp.826-834.

Shaban, A., Khawlie, M. and Abdallah, C. (2006) Use of remote sensing and GIS to determine recharge potential zones: the case of Occidental Lebanon. Hydrogeol. Jour., v.14(4), pp.433-443.

Shaikh, M. and Birajdar, F. (2015) Analysis of watershed characteristics using remote sensing and GIS techniques. International Jour. Innovative Res. Sci., v.4(4), pp.1971-1976.

Srinivasa Rao, Y. and Jugran, D.K. (2003) Delineation of groundwater potential zones and zones of groundwater quality suitable for domestic purposes using remote sensing and GIS. Hydrolog. Sci. Jour., v.48(5), pp.821-833

Suryabhagavan, K.V. (2017) Application of remote sensing and GIS for groundwater potential zones identification in Bata river basin, Himachal Pradesh, India. Jour. Geomat., v.11(1), pp.66-76.