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Planning of Suitable Soil and Water Conservation Structures Using Remote Sensing and GIS Approach: A Case Study of Madar Watershed

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Abstract: The present study was conducted for Madar watershed of Udaipur Rajasthan, India to plan appropriate water conservation structures on the basis of Drainage map and Land Capability Classification (LCC) using remote sensing and GIS. The objective of the study was to decide the optimal locations for conservation measures and water harvesting structures. In this study, location of puerto-rico terraces, contour trenches, staggered trenches and contour bund were planned for soil conservation measures, while check dams, gully plugs, and farm ponds for water harvesting structures. SRTM data has been used for extracting necessary geomorphologic parameters, while Lands at 8 data has been used for LCC. The results revealed that the Madar watershed must be treated with appropriate conservation measures and water harvesting structures. The results suggest for twelve check dams, fifteen gully plugs, and three farm ponds can be constructed for Madar watershed.

Keywords: Land capability classification, Water harvesting, Drainage map, Madar watershed

Due to anthropogenic causes, now agricultural land and natural water resources on earth are no more in plenty of amount. Almost every country of Asia has water scarcity problems. Besides having twenty river basins in India (http://nca.gov.in/nb_basin.htm), India has very uneven distributions of water in every state. States with low monsoonal rainfall, such as Rajasthan has severe water scarcity problems. Water harvesting planning and management can help a region to use water resources in a more judicial way. Countries like Israel have adopted many methods for water harvesting such as roof water harvesting on every governmental and school building. For India, water harvesting technology is important, since about 60 percent of total arable land (142 million ha) in the country is rain-fed (Panhalkar et al 2014). Water harvesting planning should be properly done to avoid unnecessary economic loss due to the failure of structures. Thus, while planning Water harvesting structures, the soil, the slope of land, the land cover, etc. should be optimally studied. Through Land capability classifications, the lands could be demarked and classified on the basis of soil erosion and slope of that area (Amir et al 2010, Atalay 2016). According to the USDA (1973) guidelines, land capability class range from a I to VIII. Land capability class from I to IV is suitable for agriculture. The susceptibility of the land to erosion and limitation in use, however, become progressively greater from Class I to Class IV Capability classes ranging from V to VIII are generally not suitable for agriculture but can be used for controlled grazing, pasture, forest, woodland and wildlife purposes (Oluwatosin et al 2006, Maryati 2013, Gad 2015, Abdel Rahman et al 2016, Atalay 2016, Saranaathan and Vaishaly 2021, Jeelani et al 2022). For locating water harvesting and conservation techniques surveying techniques will require time-consuming fieldwork and also it requires a large number of technical experts working in the field. These watershed action plans were adopted in the past because at that time, remote sensing data was not available. But, nowadays, remote sensing coupled with GIS is used for natural resources management (Agarwal 2003). In the present study, water harvesting and conservation measures planning have been done on the basis of LCC.

MATERIAL AND METHODS

Study area: The study area (Madar) is a village situated in Badgaon Tehsil in Udaipur District of Rajasthan, India and lies between 73^{0}35' to 73^{0}36' E longitude and24^{0}40' to 24^{0}42' N latitude having a total geographical area of 35.239 km^2. It falls under agro-climatic zone-IV A of Rajasthan i.e. “Sub-humid Southern Plains of the Aravalli hills” (Fig. 1). Average annual rainfall of 607 mm received mostly during the monsoon months of July to September.. Distribution of the rainfall in monsoon season is uneven and erratic marked by prolonging rainless days. The temperature of the study area varies from 19-48 ºC during summer while during the winter season, the temperature varies between 3.2 to 28.90 ºC. The study area comprises of undulating uplands fields and hills. The general slope of the area is north-east to south-west direction and slope ranges are even more than 30 percent. The main rock formations of the area under study are phyllites, schist, and quartzite. maize, urd, moong, are the commonly grown crops in Kharif season whereas, wheat, mustard, gram, linseed, are grown in Rabi season.

Data acquisition: Topographic and drainage features were extracted from Digital Elevation Model (DEM) from Shuttle Radar Topographic Mission (srtm) data, and Geographical Toposheet at 1:50,000 scale which was procured from Survey of India (SOI) obtained from Panchayat Samiti Office, Udaipur, Rajasthan, India. The soil information and soil map of the area at 1:250,000 scale was gathered from the Regional Centre of the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Udaipur, Rajasthan (Jain et al 2005). Landsat satellites are considered a valuable source of observation and monitoring of global changes because of the medium spatial resolution and the availability of long-term data (Wulder et al 2008). The remote sensing data of the area was used from satellite imagery IRS-IC-LISS-III dated 3 March 2015 at Regional Centre of the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Udaipur, Rajasthan. The catchment boundary was delineated in GIS by using Universal Transverse Mercator (UTM) projection system. Annual rainfall data from 1986-2017 were obtained from the portal of Water Resource Department, Rajasthan. The thematic maps were prepared using ArcGIS 10.1 software.

Methodology: The present study was taken to use the puissance of the remote sensing and GIS technique in locating the site suitability for conservation measures and water harvesting structures. Due to hilly topography, the rainfall is not managed properly which leads to severe erosion in the site selected for the study and hence needs action for suitable conservation measures. The study was planned to make use of the freely available satellite data processed in a GIS environment. The flowchart for the methodology of the present study is given in Figure 2. The first stage includes collections of data from different sources and all the data have been converted into digital format, if it was not so, such as toposheet map for Madar area. The second stage comprises the development of a thematic layer of information from distinct sources. It includes digital image processing of satellite data, processed maps, and field data for the extraction of the necessary information. The third stages involve the integration of data and implementing the objectives of the study. For generating an LCC map of watershed, georeferencing, digitizing the drainage map using toposheet, FCC generation, ground-truthing, unsupervised and supervised classification has been done. DEM file, obtained from SRTM, was used for delineation of the watershed in the ArcGIS environment and further used for the preparation of the slope and drainage map (Minakshi and Verma 2014). The georeferenced toposheet was used for validating this delineated watershed and in the generation of streams map of the watershed. The satellite Landsat 8 data were used for classification of land use land cover using the shapefile of the watershed which was further validated by site visiting and using toposheet and google earth imagery. The soil map of the study area was obtained from NBSS & LUP, Udaipur, Rajasthan were used for textural class, depth and erosion hazard of the study area. The other thematic maps, including slope map, land use and land cover map, depth classes, and erosion hazards were also prepared in ArcGIS 10.1 for further analysis. The Integrated Mission for Sustainable Development (IMSD) given by National Remote Sensing Agency (NRSA) (currently NRSC), India, guidelines were used for suitable sites for water harvesting structures.

Data availability: For Digital Elevation Model (DEM) and Landsat 8 data were downloaded from site https://earthexplorer.usgs.gov/. Geographical Toposheet at 1:50,000 scale which was procured from Survey of India (SOI) obtained from Panchayat Samiti Office, Udaipur, Rajasthan, India. The soil information and soil map of the area at 1:250,000 scale was gathered from the Regional Centre of the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Udaipur, Rajasthan. "Data that support the findings of this study are available from the corresponding author upon reasonable request."

RESULTS AND DISCUSSION

Drainage: In the present study, the watershed was observed 5th order type and number of streams present in 1st, 2nd, 3rd, 4th, and 5th order streams were 93, 50, 23, 2, and 1 respectively for the study area. A check dam is suitable for 1-3rd order type (Sinha et al 2015). The 2nd, 3rd or 4th order streams are suitable for Storage Tank and Percolation Tank (Prasad et al 2014 (Fig. 4).

DEM and slope: The slope of the watershed was varied accordingly and classified into six categories i.e. 0-1 t, 1-3 t, 3-8 t, 8-15 and 15-30, greater than 30 percent. The area that comes under these categories was 918.137, 241.377, 336.645, 606.628, 426.3 and 994.11 ha respectively. Thus, the maximum area falls under the slope greater than 30 percent depict 28 percent of the total watershed area. The second highest area falls in the categories of the slope varies from 0-1 percent depicts 26 percent of the total area. Seven percent of the total area falls under 1-3 percent which accounts minimum area under this category (Fig. 5).

Soil: The depth of soil for study area classified into d_1(<25 cm soil depth), d_3 (50-75 cm), d_4 (75-100 cm)) having area of 3079.03, 99.2529, 261.237 and 84.4115 ha land respectively. Therefore, 87% area of the total area was dominated by the soil having a depth of less than 25 cm. The textural class of the study area was classified into loamy skeletal soils (lsk) and fine loamy soils (fl) (Fig. 6) having a contributing area were 3079.028 and 444.902 ha respectively. Therefore, dominated texture class in the study area was loamy skeletal soils having a contributing area was 87% of the total area. The other component is erosion hazards which were classified into severe (e_3), moderate (e_2) and slight erosion (e_1) (Fig. 7).

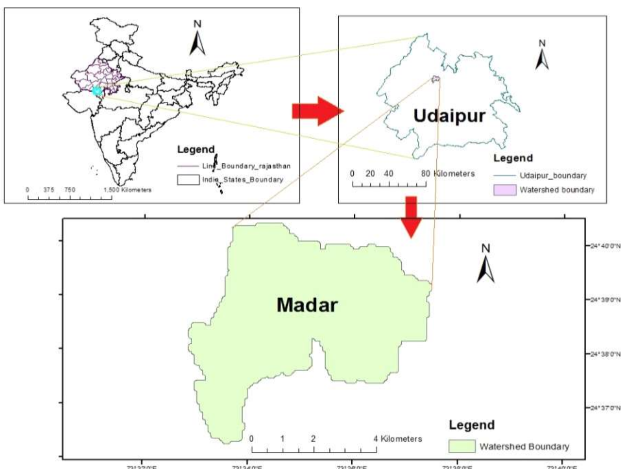

Fig. 1. Study area

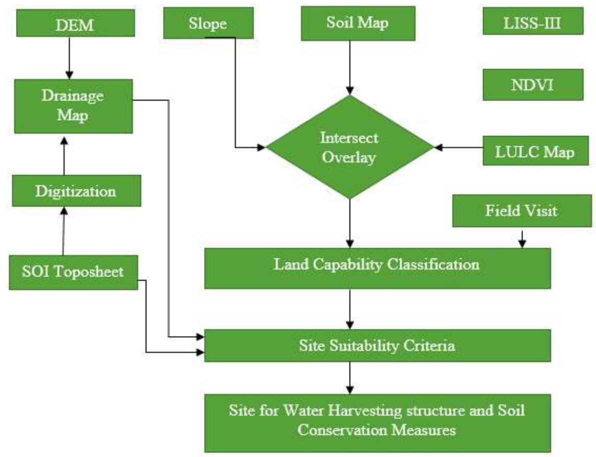

Fig. 2. Flow chart of the methodology of research work

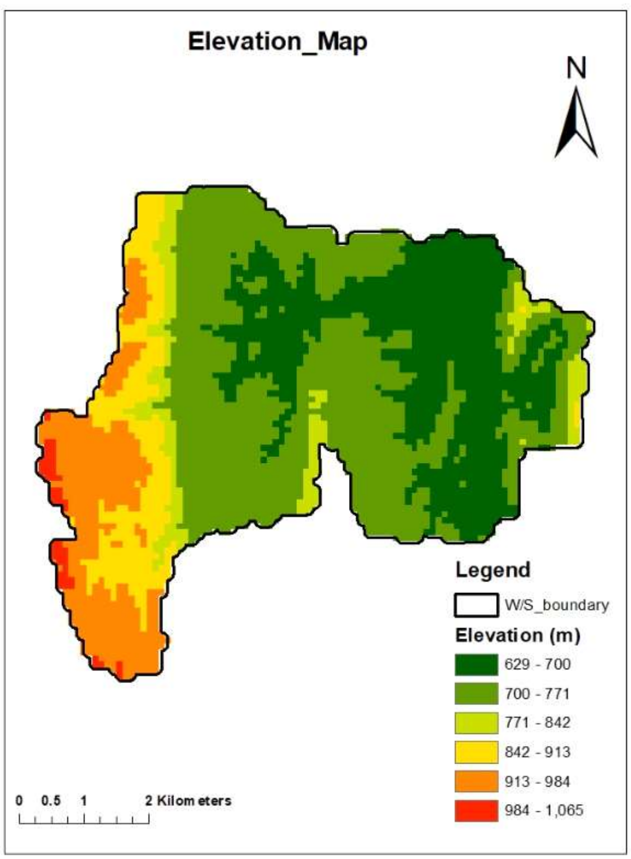

Fig. 3. DEM of the study area

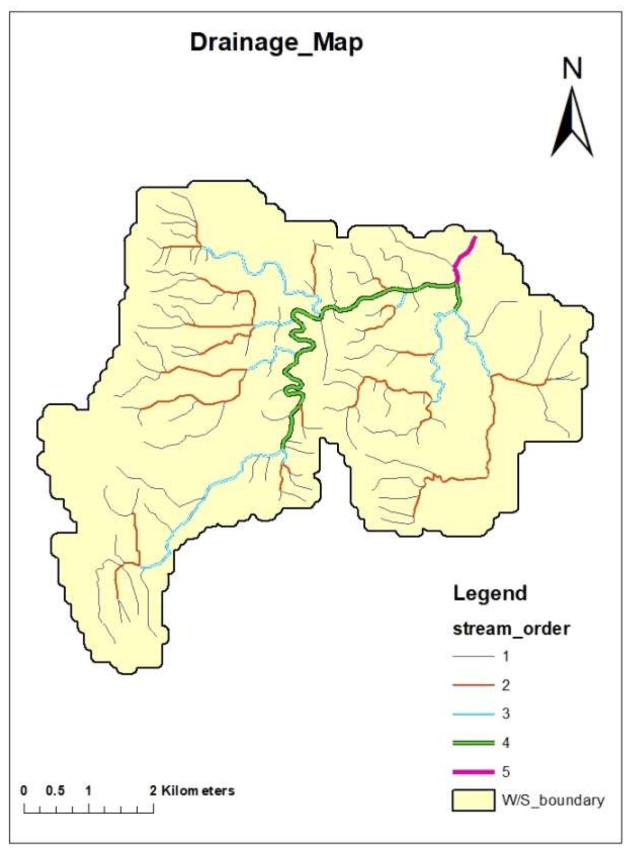

Fig. 4. Drainage map of the study area

Land use/land cover: First, unsupervised classification and then supervised classification was carried (Khalaf and Younis 2021; Fig. 8). The validation of these features, the site visiting with the help of GPS recorder (pixel-based) at several points and also used google earth imagery of dated 8 March 2015 to

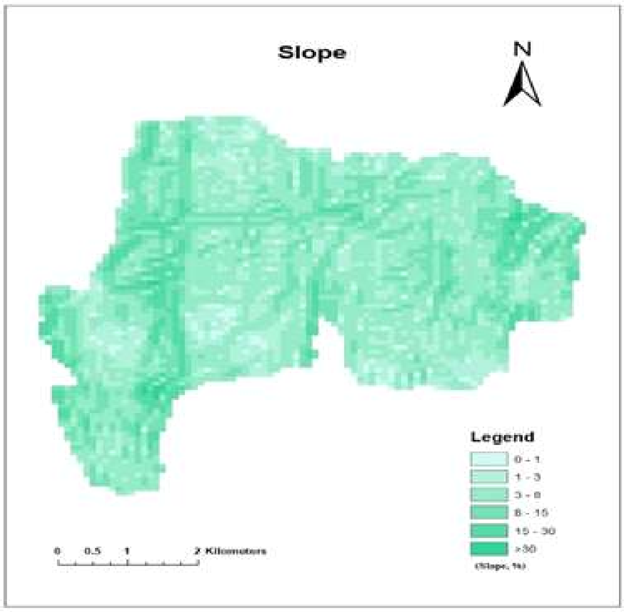

Fig. 5. Slope map of the study area

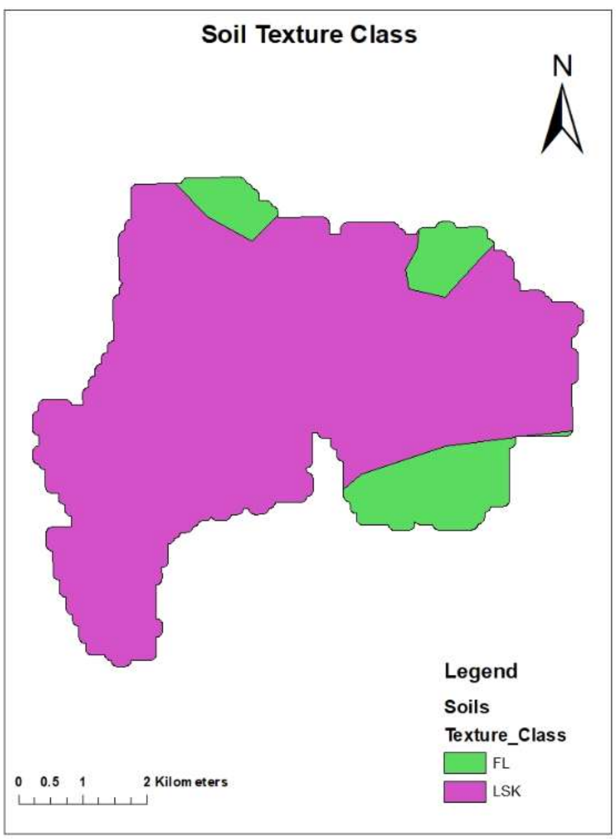

Fig. 6. Soil texture map of the study area

verify the accuracy of the results. the majority of land dominated by barren land, forest cover, cultivate the land, and water bodies. The area covered by cultivated land, forest cover, barren land, and water bodies were 1035.908, 1637.453, 689. 422, and 160.416 ha, respectively (Table 2). Therefore, most of the area was unused due to barren land and forest cover. Therefore, need to be a proper mechanism of conservation structures.

Land capability classification (LCC) : The study area was

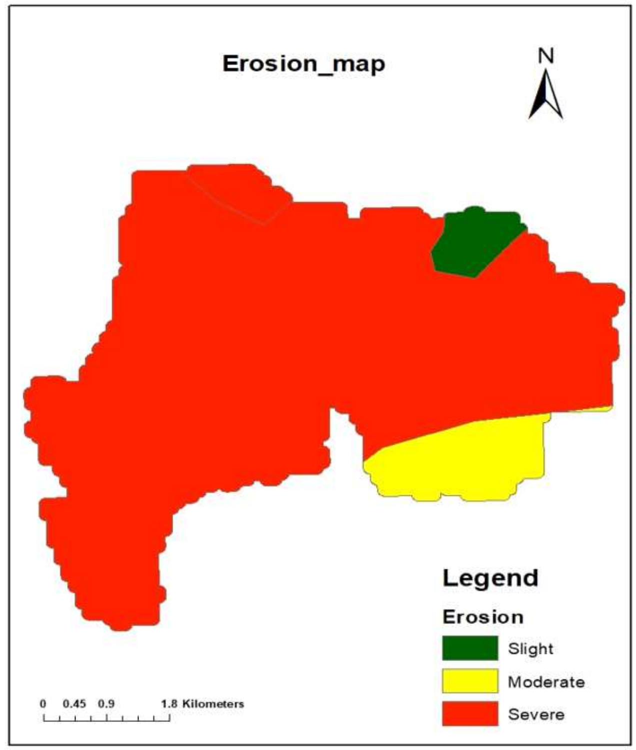

Fig. 7. Soil erosion hazard map

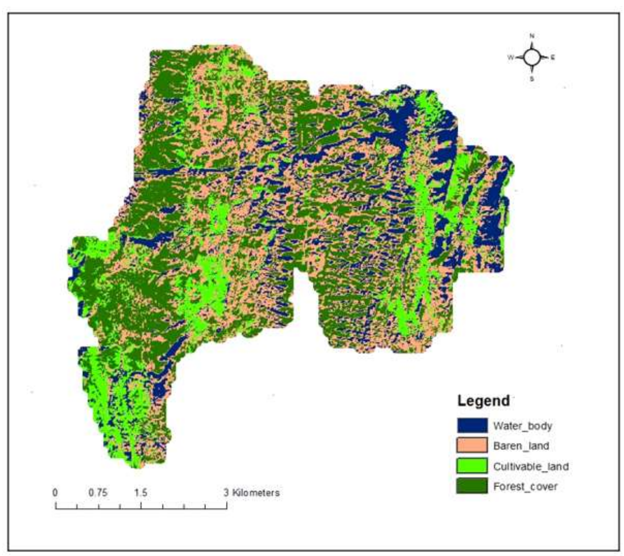

Fig. 8. Land use land cover map of the study area

classified into the class-II, class-III, class-IV, class-VI, class-VIII/ rock, and rest of areas into water bodies. The contributing areas to these classes are obtained in the range of 142.974 to 1235.885 ha (Table 3). In percentage of the total area of watershed, minimum contributing area of LCC is class-II 4 percent). This shows that the study area comes under less farming activities and there is a need for more mechanization to rejuvenate area into cultivated land. The highest contributing area is class-IV which comprises 35 percent of the total area. This shows this area may be treated

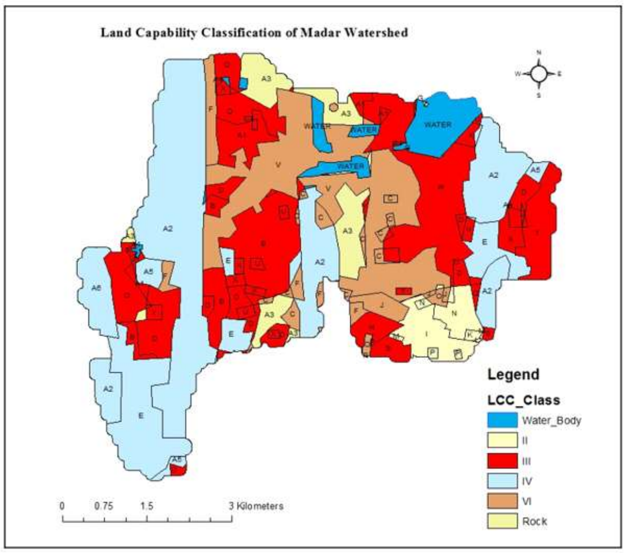

Fig. 9. Land use capability classification map of the study area

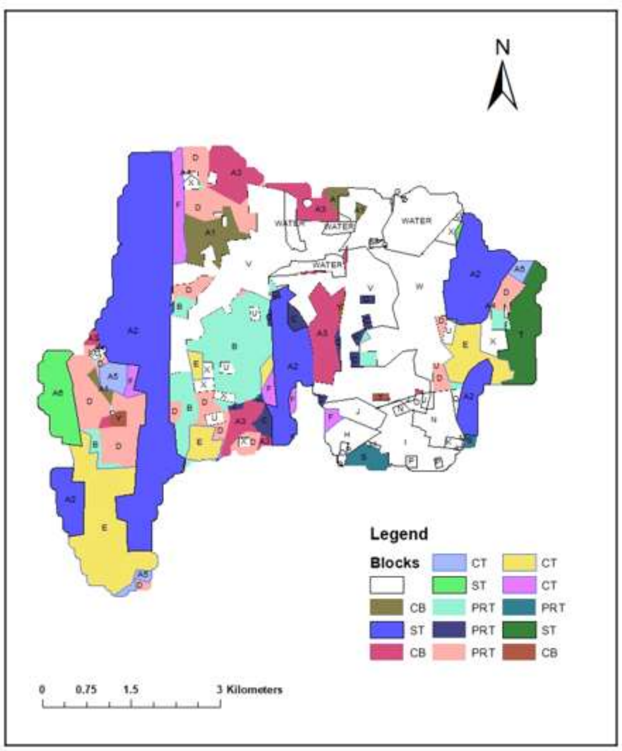

Fig. 10. Proposed area with conservation structures

with suitable conservation measures to having cultivation on them according to neediness. The next highest contributing area is 31 percent of the total study area falls in class-III categories. This also shows that the area was treated with

Table 1. Components of soil map obtained from NBSS, Udaipur

Erosion hazard	Texture class	Depth (cm)	Area (ha)
Severe	LSK	<25	3079.027794
Moderate	FL	75-100	261.23728
Slight	FL	50-75	99.252946
Severe	FL	Rock	84.411543

Table 2. Land use/land cover classification area

Type	Area (ha)	Area (%)
Cultivated land	1035.908	29.40
Barren land	689.4222	19.57
Waterbody	160.4161	4.55
Forest cover	1637.453	46.48

Table 3. Land capability classification area

Class	Area (ha)	Area (%)
II	142.974	4
III	1108.091	31
IV	1235.885	35
VI	677.112	19
VIII/Rock	197.999	6
Water bodies	160.416	5

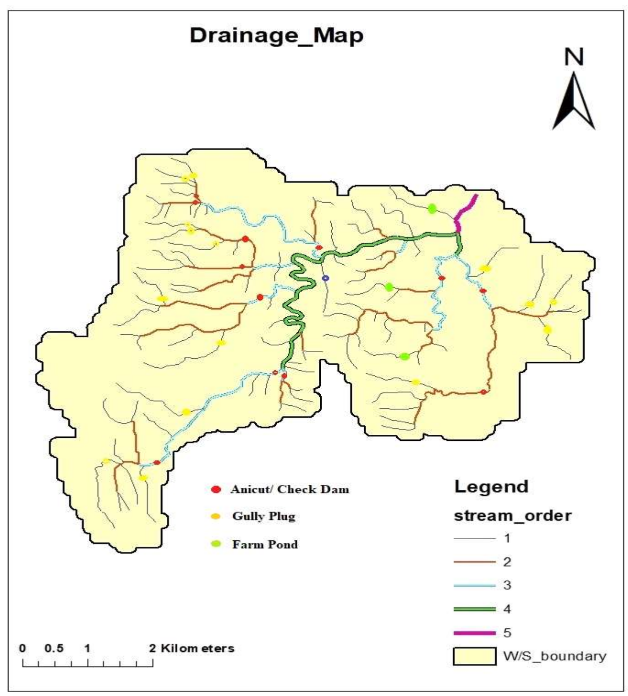

Fig. 11. Proposed site suitable for water harvesting structures

Table 4. Land use capability classification

Block	Area (ha)	Soil mapping unit	LCC	Limiting factor
A1	74.374	$\frac{lsk-d_1}{c-e_3}$	III	Land has been severe eroded (e_3)
A2	828.343	$\frac{lsk-d_1}{f-e_3}$	IV	Land has been severely eroded (e_3) and higher slope (e)
A3	197.999	Rock	VIII	Rock land
A4	2.089	$\frac{lsk-d_1}{b-e_3}$	III	Land has been severely eroded (e_3)
A5	37.391	$\frac{lsk-d_1}{e-e_3}$	IV	Land has been severely eroded (e_3) and highly slope (E)
A6	79.517	$\frac{lsk-d_1}{f-e_3}$	IV	Land has been severely eroded (e_3) and higher slope (E)
B	244.012	$\frac{lsk-d_1}{d-e_3}$	III	Land has been severely eroded (e_3) and moderately slope (D)
C	45.435	$\frac{lsk-d_1}{d-e_3}$	VI	Land has been severely eroded (e_3) and moderately slope (D)
D	285.598	$\frac{lsk-d_1}{d-e_3}$	III	Land has been severely eroded (e_3) and moderately slope (D)
E	290.634	$\frac{lsk-d_1}{e-e_3}$	IV	Land has been severely eroded (e_3) and highly slope (E)
F	67.736	$\frac{lsk-d_1}{e-e_3}$	VI	Land has been moderately eroded (e_2) and higher slope (E)
G	0.419	$\frac{fl-d_3}{b-e_1}$	II	Less erosive land
H	30.539	$\frac{fl-d_4}{e-e_2}$	III	Land has been moderately eroded (e_2) and moderately slope (D)
I	81.174	$\frac{fl-d_4}{a-e_2}$	II	Land has been moderately eroded (e_2)
J	32.821	$\frac{fl-d_4}{a-e_2}$	VI	Land has been moderately eroded (e_2)
K	4.475	$\frac{fl-d_4}{b-e_2}$	II	Land has been moderately eroded (e_2)
L	0.535	$\frac{fl-d_4}{b-e_2}$	II	Land has been moderately eroded (e_2)
M	2.077	$\frac{fl-d_4}{b-e_2}$	II	Land has been moderately eroded (e_2)
N	48.615	$\frac{fl-d_4}{c-e_2}$	II	Land has been moderately eroded (e_2)
O	10.367	$\frac{fl-d_4}{c-e_2}$	VI	Land has been moderately eroded (e_2)
P	5.290	$\frac{fl-d_4}{c-e_2}$	II	Land has been moderately eroded (e_2)
Q	4.561	$\frac{fl-d_4}{d-e_2}$	III	Land has been moderately eroded (e_2) and moderately slope (D)
R	0.148	$\frac{fl-d_4}{d-e_2}$	VI	Land has been moderately eroded (e_2) and moderately slope (D)
S	26.876	$\frac{fl-d_4}{d-e_2}$	III	Land has been moderately eroded (e_2) and moderately slope (D)
T	86.250	$\frac{fl-d_4}{f-e_2}$	III	Land has been moderately eroded (e_2) and highly slope (F)
U	25.779	$\frac{lsk-d_1}{a-e_3}$	III	Land has been severely eroded (e_3)
V	520.605	$\frac{lsk-d_1}{a-e_3}$	VI	Land has been severely eroded (e_3)
W	257.369	$\frac{lsk-d_1}{a-e_3}$	III	Land has been severely eroded (e_3)
X	58.333	$\frac{lsk-d_1}{b-e_3}$	III	Land has been severely eroded (e_3)
Y	12.311	$\frac{lsk-d_1}{b-e_3}$	III	Land has been severely eroded (e_3)
Z	0.389	$\frac{fl-d_3}{a-e_1}$	II	Less erosive land
Water	160.416		-	-

appropriate conservation measures before cultivation starts. The study area has 25 percent of the land in which cultivation cannot be possible according to the U.S. Soil conservation service (1958, 1959, 1963 and 1992). They have 19 percent class-VI, 6 percent class-VIII or rocky land. This area needs to reclaim with water harvesting structures to protect this land from wastage due to erosion. The study area has water bodies into patches at different places contributing 5 percent of the total land. Therefore, it is clear that there is an absence of class-I land which requires less or no treatment to land for cultivation. The study area has 70 percent of total cultivable land which needs to be treated with suitable soil and water conservation measures (Table 4 and shown in Fig. 9).

The criterion for their use is given in Table 5 (Singh 1998). With the help of information extracted from land capability classification, various thematic map, toposheet, google earth imagery and rainfall characteristics of the study area, the suitable conservation measures proposed for study area were puerto-rico terraces, contour trenches, staggered trenches, and contour bund in benefits for the conserving soil moisture, reducing soil erosion of the study area. The suitable site is shown in Figure 10.

Puerto-rico terrace (PRT): PRT is proposed along the contours with dry stone which further develops into level bench terraces because of ploughing. It is applicable for the area having more than 6 percent slope and also having shallow soil depth in arable land. e. Generally, PRT is constructed on the boundary of field because it is difficult to follow absolute contour in the real field conditions. The site for PRT and their contributing area is given in Table 6. The area planned to treated with PRT comes under the block-B, block-C, block-D, and block-S. The area proposed under these blocks is 231.92, 43.18, 271.46, and 25.54 ha respectively.

Contour trenches: Generally, contour trenches are suggested to be constructed for the area having slope up to 30 percent only, because of it is not stable above this slope and also, vertical interval between two contour trenches becomes less hence loss of area due to it is more. The parts of the study area planned to treat with contour trenches are block-A5, block-E, and block-F having proposed area 35.53 ha, 276.20 ha, and 64.38 ha respectively (Table 6).

Staggered trenches: Construction for staggered trenches are suggested in the area having slope greater than 30 per

Table 6. Proposed area for soil and water conservation structures

Block/conservation structures	Proposed area (Ha)
P.R.T.	
B	231.92
C	43.18
D	271.46
S	25.54
Contour Trenches	
A5	35.53
E	276.20
F	64.38
Staggered Trench	
A2	787.34
A6	75.57
T	81.97
Contour Bund	
Y	11.70
A1	70.70
A3	188.21

Table 5. Criterion for site selection of different soil and water conservation measures

Structure	Rainfall/ runoff (mm)	Slope (%)	Infiltration rate/seepage	Soil depth	Desired use
P.R.T.	400-800	> 6	Moderate	Shallow soil depth	Protection of valley slopes
Contour trench	400-1200	10-30	Good	-	In-situ moisture conservation
Staggered trenches	400-1200	> 20	Moderate	Shallow soil depth	In-situ moisture conservation
Contour Bund	< 600	< 6	Moderate	Must not be Black cotton soil	In-situ moisture conservation

Table 7. Criterion for site selection of different water harvesting structures

Structure	Runoff potential	Porosity & permeability	Stream order	Slope (%)
Anicut	Medium/High	Low	1-4	<15
Gully Plug	High	Low	1	15-20
Farm Pond	Medium/High	Low	1	0-5

The site selected for farm pond is such that there is less excavation and more runoff extracted can be possible. There are three sites proposed to be suitable for farm pond cent. The parts of study area planned to propose under this category are block-A2, block-A6, and block-T (Table 6).

Contour bund: Contour bunds are proposed in Block-Y, Block-A1 and Block-A3 having land capability class II with the slope range of 1.75 to 5.60 percent. The total area under contour bund is 270.61 ha (Table 6).

Water harvesting structures: The proposed site for different water harvesting is shown in Figure 11. The IMSD guidelines are used to identify the site for water anicut/ check dam, gully plug, and farm pond (Table 7). Check dams applied mostly in the Central India region are one of the popular water harvesting structures (Khonkaen et al 2011, Arnab et al 2018, Khattab and Basman 2021). It works as both for water-conserving structures as well as soil erosion.

CONCLUSIONS

The study was conducted for planning and designing of Madar micro-watershed using remote sensing and GIS. The project area lies between 73^{0}35' to 73^{0}36' E longitude and24^{0}40' to 24^{0}42' N latitude. Madar is a Village in Bargaon Tehsil in Udaipur District of Rajasthan State, India. The total geographical area of the delineated watershed was determined to be 3000 ha and divided into thirty-one different blocks on the basis of slope groups. The appropriate soil and water conservation measures for the watershed were planned on the basis of rainfall, land use capability classification and topography of the area. Contour bunds, Puerto rico terrace, staggered trench, and contour trench were proposed for soil and water conservation measures. Water harvesting structure such as anicut/ check dam, gully plug, and farm pond has been proposed in the watershed area on the basis of site condition and its functional utility.

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