

Role of Earth Observation (EO) Technologies in Dryland Management towards Adaptation to Climate Change

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Abstract: The use of climate information must be applied in developing sustainable practices for dryland management as climatic variation is one of the major factors contributing to or even a trigger to land degradation and diversified farming. Rainfall and temperature are the prime factors in determining the climate and therefore the distribution of vegetation types. There is a strong correlation between rainfall and biomass since water is one of key inputs to photosynthesis. It is essential to understand how climate induces and influences the land management in drylands. Simulation of crop production from dryland regions had several difficulties due to temporal and spatial variability in rainfall, high evapotranspiration rates and heterogeneity in land use. Advances in space-based Earth Observation (EO) technology and its applications have potential for improving the cultivation practices, and thus transforming the quality of human life indirectly. High resolution spatial and temporal satellite data from Indian satellites like RESOURCESAT-1 and CARTOSAT-1 are now available for creating various resource layers on 1:10,000 scale. This scale suffices the requirement of decentralized planning at grass root level. Overlay of cadastral boundaries will help in generating information in greater detail. Any change in land utilization pattern as well as hotspot areas due to climate change impact can be identified and monitored using multi temporal EO data. This paper is based on a technology demonstration for smart rainwater harvesting with the help of EO data. A case study was carried out in a cluster of 50 villages in Jodhpur and Barmer districts of Rajasthan to assess climate change variability and adaptation to it. It also identifies the potential sites for rainwater harvesting and also to assess the volume of harvestable rainwater with the help of remote sensing and GIS techniques. Daily rainfall and temperature data of the study area was analyzed to study their profile and variability. The high resolution satellite data were used to delineate land use/land cover, waste lands, land degradation and surface water bodies, etc. The integration of above thematic layers resulted in identification of potential rainwater harvesting sites at village level and also in calculating the volume of rainwater than can be harvested from a given field. The studies point to the importance of smart infield rainwater harvesting in drylands for food security, safe drinking water, introduction of agrohorticulture, agroforestry practices and high value crops for livelihood generation and achieving long term sustainability of local and regional populations.

Key words: Rainwater harvesting sites, digital elevation model, earth observation data and climate change.

The Office to Combat Desertification and Drought of the United Nations Development Program (UNDP) showed that globally 40% of the land area is occupied by drylands. Low annual rainfall with very high coefficient of variation and erratic distribution over the crop growing season, high atmospheric temperature with large diurnal and seasonal variation, and high evaporation are the main constraints of this area. People living in dryland areas are dependent on limited water resources to meet

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drinking water requirement and subsistence level farming. Dryland agriculture largely depends on rainfall through the adoption of different dryland farming techniques. The drylands in India are particularly vulnerable, as they have fragile soils, localized high population densities, and generally a low-input form of agriculture. Consequently, there are high crop water requirements. The weather conditions remain too dry, even in normal years, for most part of the year and are inhospitable for successful crop growth.

Sustainable development aims at optimal use of natural resources, protection and conservation of ecological systems, and improving economic efficiency (FAO, 2013). Making sustainable development a living reality requires integrated assessment of ecosystem and physical environment with the help of EO data to know the potential and constraints of the area, socio-economic analysis for need assessment and long-term planning and development of area-specific end-user technologies, which are affordable and adoptable by the people. Approach towards sustainable development should consider regional issues like environmental, physical factors and social and cultural practices followed in the area.

The most important characteristics of dryland areas are the factors, which limit availability of adequate soil moisture for plant growth. These include high temperatures, low humidity, intense sunlight and high winds. These factors cause very high rates of potential evapotranspiration. The region often witnesses dry spell which occurs during the growing season. Because of large spatial and temporal variability in rainfall distribution, rainfed agriculture is very susceptible to water shortage. In general total annual rainfall is sufficient for crop production, but highly variable distribution in time and space frequently threatens crop production and contributes to food insecurity (Jennie Barron, 2009).

In the western semi-arid region of India, there is a rich cultural practice to collect water in village ponds as runoff from the adjacent village common land/grassland locally known as gochar or oran land and use it for domestic requirements, which include drinking water. With the increase in population and shrinkage in the runoff generating area, amount of water collected is not sufficient and also it is highly contaminated due to various reasons and hence a large number of people are affected by water borne diseases in these areas. On the agricultural front, though farmers are fully dependent on monsoon rain for crops, there is no practice of collecting and storing water individually or collectively for agricultural use/irrigation purpose (Sharma *et al.*, 2011). Hence in-field rainwater harvesting can have an important impact and is a technique through which farmers can easily collect and store about 8-10% of the rainwater in their own field for

later use. The technology is low cost, very effective for communities to manage their water (Critchley and Siegert, 1991). Rainwater harvesting is a viable adaptation strategy for people living with high rainfall variability, both for domestic supply and to enhance crop, livestock and other forms of agriculture (Prinz *et al.*, 1998; WRC, 2008).

Advances in space based Earth Observation (EO) technology and its applications have potential for transforming the quality of human life. High resolution spatial and temporal satellite data from Indian satellites like RESOURCESAT-1 and CARTOSAT-1 are available for use and creating various resource layers on 1:10,000 scale and possible for creating a GIS database on various resources. This scale suffices the requirement of decentralized planning at grass root level and along with overlay of cadastral boundaries will help in generating information in greater detail. Earth observations play an important role in understanding the terrain and micro-hydrology of the region along with natural resource status. This technique provides accurate, up to date and time series information that can be used for site selection of suitable rainwater harvesting (RWH) sites at micro scales for operational decision making. The location suitability for RWH depends on amount of rainfall, soil characteristics (including texture, infiltration and runoff rates) terrain features (including topography and slope), current land use/land cover, and hydrological features. Earth observation is also useful for monitoring the status of RWH implementation and regional impacts of harvested water.

Materials and Methods

Study area

Study area covers an area of 584.58 sq. km having 50 villages in Jodhpur and Barmer districts of Rajasthan state (Fig. 1). It lies between 25° 56' 45"N to 26° 12' 41"N latitude and 72° 34' 38"E to 72° 53' 10"E longitude. Land utilization pattern includes mixture of moderately cultivated land (mostly rainfed agriculture), open scrub, dense scrub, water bodies and settlement areas. The mean annual rainfall in this region is 275 mm. Soils are loamy sand in texture followed by loam, sandy loam and fine sand. According to distribution size 2.51% area are under 0-1 ha and 22.96%,

18.97%, 47.1% are of area 1-3 ha, 3-5 ha and >5 ha respectively.

Data

Cartosat stereo data have been used to generate high resolution Digital Elevation Model (DEM) for the study area. Potential drains have been derived from Carto DEM. Land use/land cover map of the study area has been prepared based on interpretation of ISS-IV-Carto merged product. Indian Meteorological Department (IMD) daily grid data (1901-2004) has been used to analyze the rainfall pattern of the study area (Rajeevan *et al.*, 2008). Soil texture map from Natural Resource Database (NRDB) of Indian Space Research Organization has been used. Cadastral boundaries and other ancillary data have been collected from Department of Land and Settlement, Government of Rajasthan.

Methodology

Identification of the potential sites/fields for rainwater harvesting

The major steps involved in the process of identifying RWH sites are as follows:

- Baseline survey and creation of a geo-spatial database using GIS and Earth Observation data sets at cadastral level for current land use, soil resources and rainfall for the cluster of villages.
- Generation of high resolution DEM from Cartosat stereo data
- Generation of slope map from DEM
- Delineation of potential drains from DEM

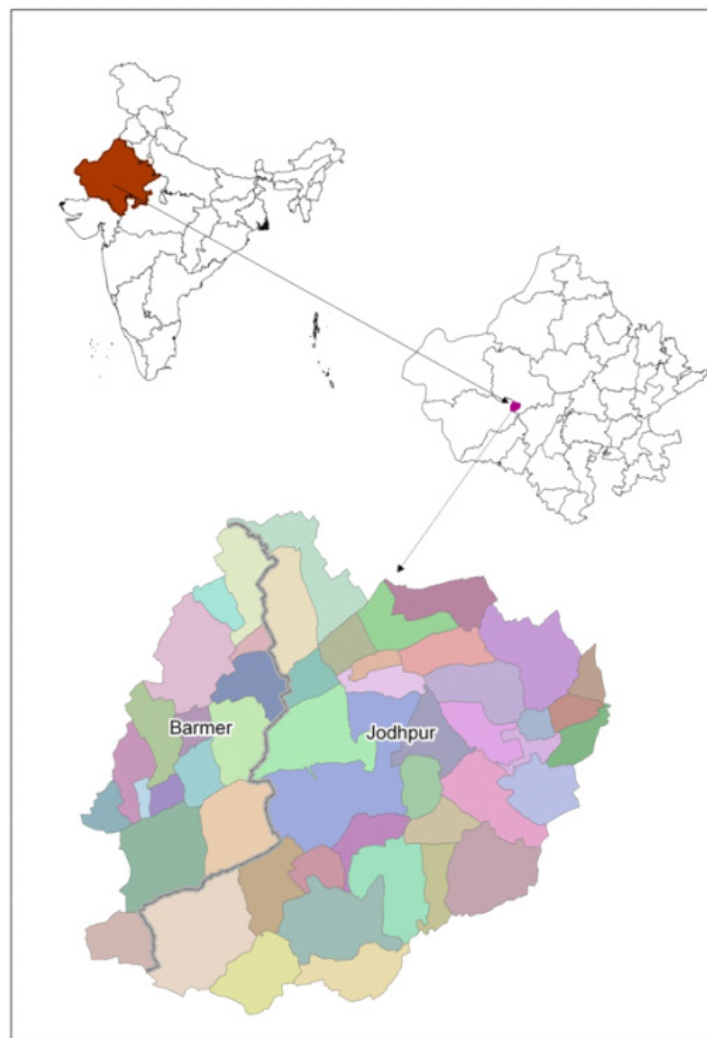


Fig. 1. Location map of the study area.

RWH sites identification analysis has been based on potential drains and its stream order and multi-criteria analysis using various parameters.

Using potential drains and its order

Cadastral/agriculture fields are identified on the basis of potential drains passing through it or nearby. In this case it has been assumed that the entire study area receives more or less similar rainfall and soil texture remains nearly same in the area.

Multi-criteria analysis

Multi-Criteria Evaluation (MCE) is used to identify the suitability of each grid cell for water harvesting and storage. To generate multi-criteria based rankings, weighted Overlay process feature of GIS is used. From the literature review and information obtained from field survey supported by expert judgment, five criteria were selected for the identification of potential areas for in-field RWH viz., soil texture (clay percentage), rainfall, slope, land use/cover (LULC) and flow accumulation. Since not all the criteria are equally important for the identification of potential RWH areas, different

weights (rainfall and flow accumulation (35%), LULC (15%), texture (10%) and slope (5%)) were assigned to the criteria. Also high suitability rank was given for areas with large rainfall surplus as it ensures the availability of runoff to be harvested. High suitability rank has been given to low slope areas. Among the land use category, higher rank has been given to open lands, agriculture lands and dense scrubs. In the case of soil texture, ranks are assigned in such a way that areas with higher clay percentage are having higher rating as the run off is more for clay sand. Block diagram showing the detailed methodology is given in Fig. 2.

Assessment of volume of harvestable rainwater

To assess the volume of water that can be harvested in a given field, a methodology has been developed. The criteria considered different factors like soil texture, LULC, slope and rainfall of the area. Two methods have been proposed based on annual rainfall and event rainfall.

Based on annual rainfall: In this method annual rainfall of the study area has been considered. During the rainfall in the initial phase some of the water percolate with soil

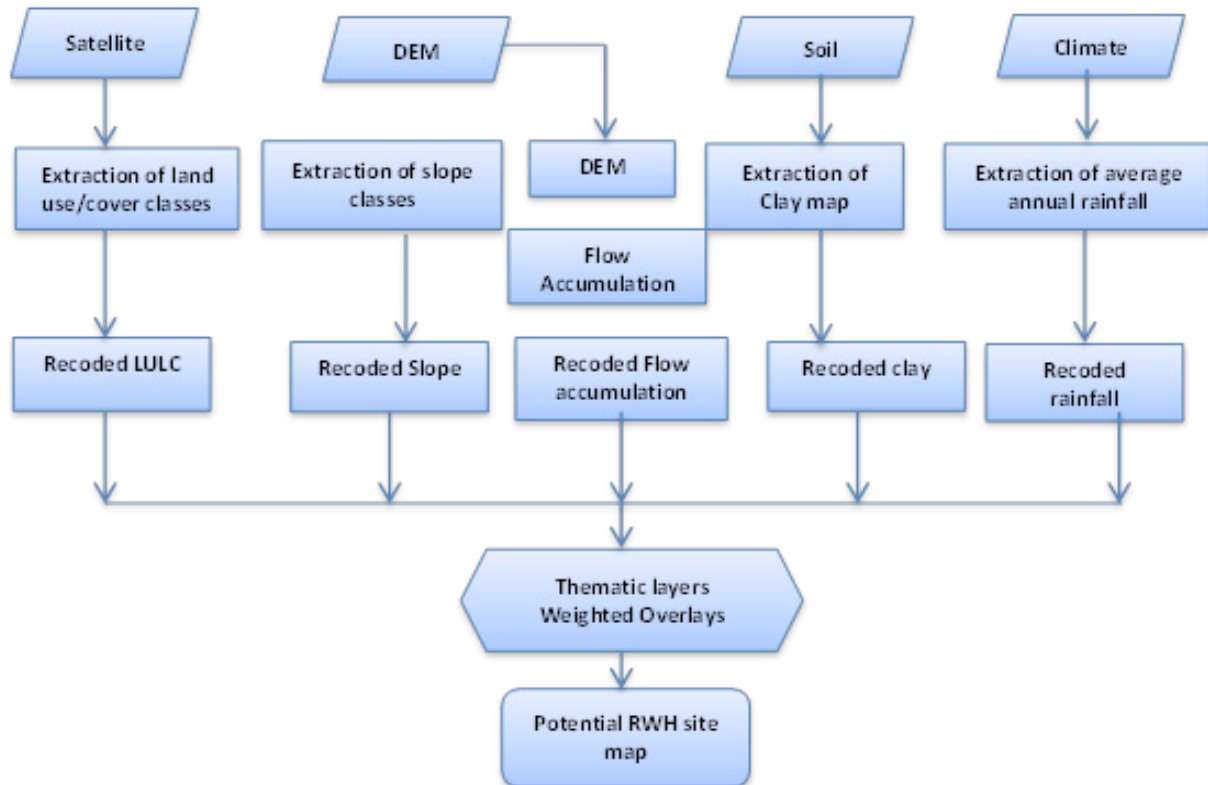


Fig. 2. Block diagram of multi-criteria analysis for RWH site.

Table 1. Values of runoff coefficient factor for different soils, slopes and vegetation

Type of vegetation	Slope range (%)	Runoff coefficient		
		Coarse (Sand, loamy sand, sandy loam)	Medium (Silty loam, loam, silt, sandy clay loam, clay loam, silty clay loam)	Fine (Sandy clay, silty clay, clay)
Dense scrub	0-2	0.1	0.3	0.4
	2-5	0.1	0.3	0.4
	5-10	0.16	0.35	0.50
Open scrub/ open land	0-2	0.10	0.30	0.40
	2-5	0.10	0.30	0.40
	5-10	0.25	0.36	0.55
Agricultural land (no crop)	0-2	0.28	0.47	0.58
	2-5	0.30	0.50	0.60
	5-10	0.40	0.60	0.70
Agricultural Land (early crop stage)	0-2	0.17	0.31	0.33
	2-5	0.20	0.33	0.37
	5-10	0.30	0.39	0.40
Agricultural land (late crop stage)	0-2	0.24	0.38	0.40
	2-5	0.25	0.42	0.45
	5-10	0.35	0.48	0.50

and after that runoff begins depending upon intensity of rain. This runoff factor depends on various parameters like the type and size of catchment, slope, land use, texture and depth of soil and its depth etc. Based on these factors runoff coefficient is decided as per field observations in an area. This runoff coefficient is a dimensionless figure and can be estimated from the individual field data (Murthy, 2003; CGWB, 2007). These coefficients have been adjusted for the agricultural land (no crop, early crop and late crop) and considering the soil factors like soil compaction, moisture retention and infiltration rate.

This coefficient is multiplied with the annual rainfall (mm) and the drainage area (sq. m), which gives the estimate of the amount of water (L) that can be harvested in that particular area. It is assumed that around 20% of the water losses are due to factors like evaporation, seepage, etc. The runoff coefficient depends on factors like type of vegetation, slope and soil texture. Runoff coefficients were derived based

on two years' experience at the pilot site, the intensity of rain observed and last ten years daily rainfall data of the area (Table 1).

The formula to calculate of total amount of rainwater available that can be harvested is:

Rainwater Harvested (L) = Annual rainfall (mm) $\times$ 0.8 $\times$ Area (sq. m) $\times$ Runoff coefficient

Based on event rainfall: This concept takes the last 48 hrs rainfall intensity of particular day. Table 2 describes R factor of amount of rainfall occurrence.

The amount of water that can be harvested in a particular day is:

Rainwater harvested (L) = Rainfall (mm) $\times$ R factor $\times$ Area (sq. m) $\times$ Runoff coefficient

Results and Discussion

Natural resource characterization of the study area including rainfall, land use/land cover, soil texture has been carried out. Annual

Table 2. Amount of rainfall and R factor

Rainfall (mm)	R factor	
	No wetness (Last 48 hrs < 20 mm rainfall)	Wetness (Last 48 hrs > 20 mm rainfall)
<20	0.10	0.20
20-30	0.40	0.60
>30	0.50	0.80

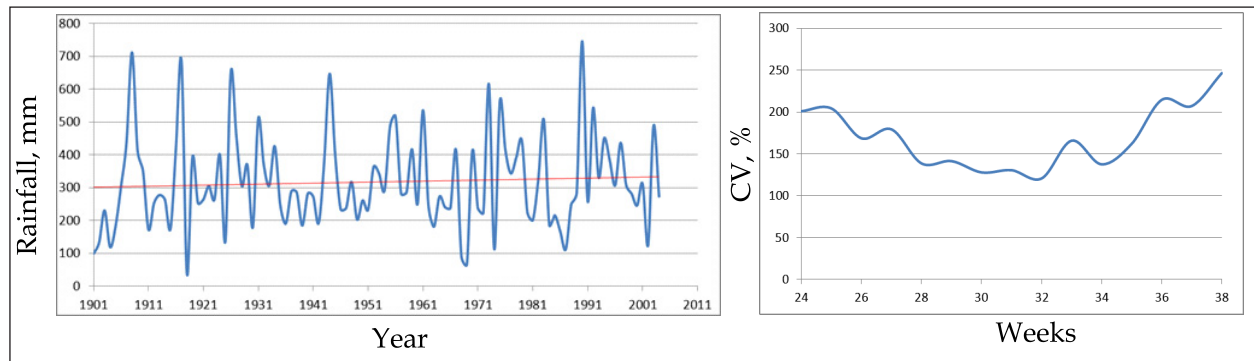


Fig. 3. Annual rainfall and coefficient of variation of the study area.

rainfall of the study area for the period from 1901-2004 has been analyzed. Also the coefficient of variation of weekly rainfall during crop growing season over 104 years (Fig. 3) shows large variation and imply a high uncertainty in crop yields. The mean annual rainfall in the region is 275.16 mm. About 86.14% of annual rainfall is received during south west monsoon (24-38th Meteorological week) when west-southwesterly moving depressions are the main sources of water for kharif crops. The average annual, monthly and weekly rainfall variation over 104 years has been studied. The trend observed in annual rainfall variation in this area showed no significant change during 1901 to 2004. There exists a wide variability in rainfall received between week to week

as well as between months within a year. The interannual and decadal variability also showed positive and negative trends. Because of high variability of rainfall within monsoon season, the proper storage and management of rainwater is essential. In this scenario the study was extended to identify potential rainwater harvesting sites using remote sensing and GIS.

Land use/land cover map of the study area is given in Fig. 4. Land use pattern is predominantly agriculture (91%), followed by open scrub (5.6%), dense scrub (1.2%), settlement (1.92%) and water body (0.28%). The soil texture variation includes mostly loamy sand soils followed by loam, sandy loam and fine sand (Fig. 5). Coarse texture indicates low

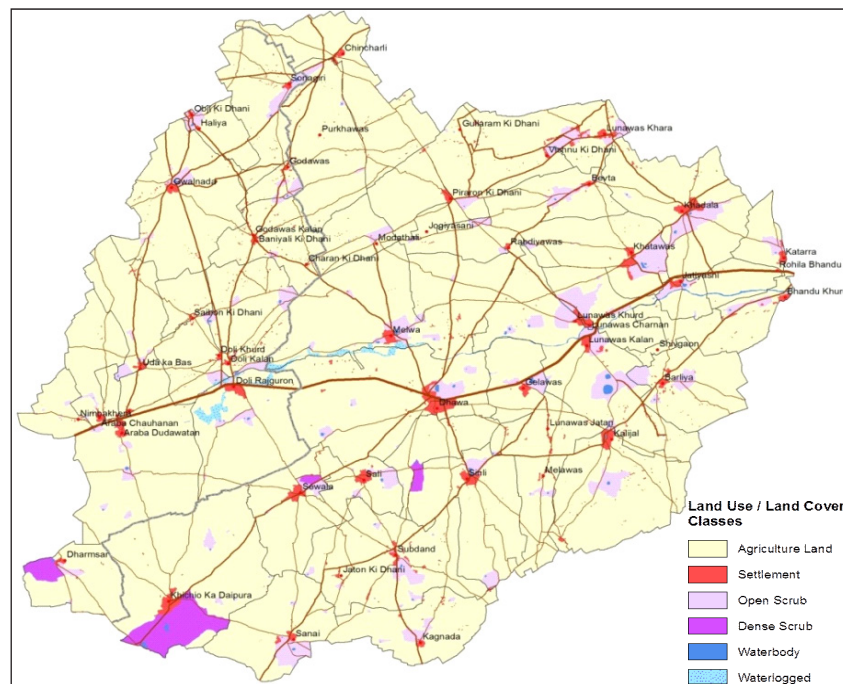


Fig. 4. Land use/land cover map.

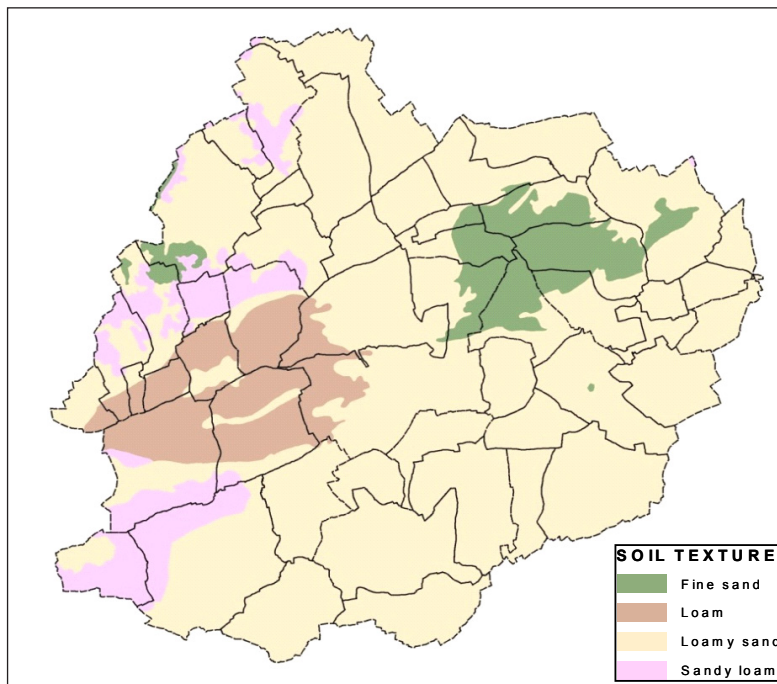


Fig. 5. Soil texture map.

water accumulation and fine texture indicates high water accumulation. Soils are low in organic matter and poor in nutrients (available N is low, available P and K status is medium). Micronutrients such as Mn and Cu contents are adequate, whereas Zn and Fe are deficient. As soils have low clay and silt content therefore nutrient adsorption and retention by these soils

are very low. Because of low fertility status of the soil, crop production is limited.

Identification of RWH sites and rainwater harvesting calculator

The existence of potential drains on agriculture fields gives high weightage for considering that field for RWH. Analysis

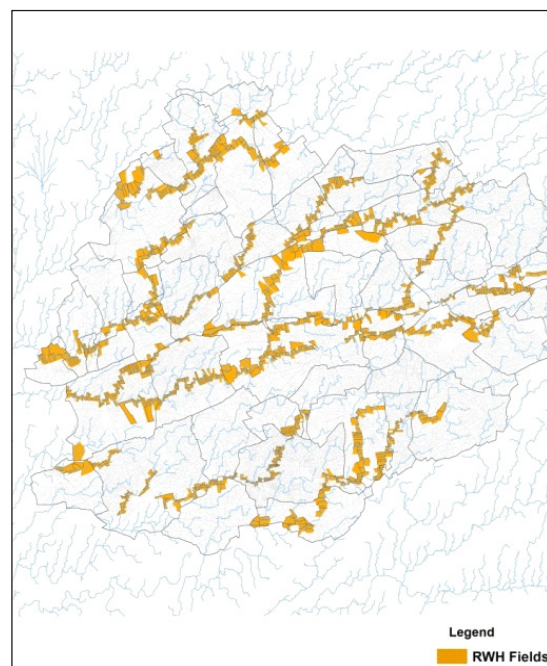


Fig. 6. Identified potential RWH sites.

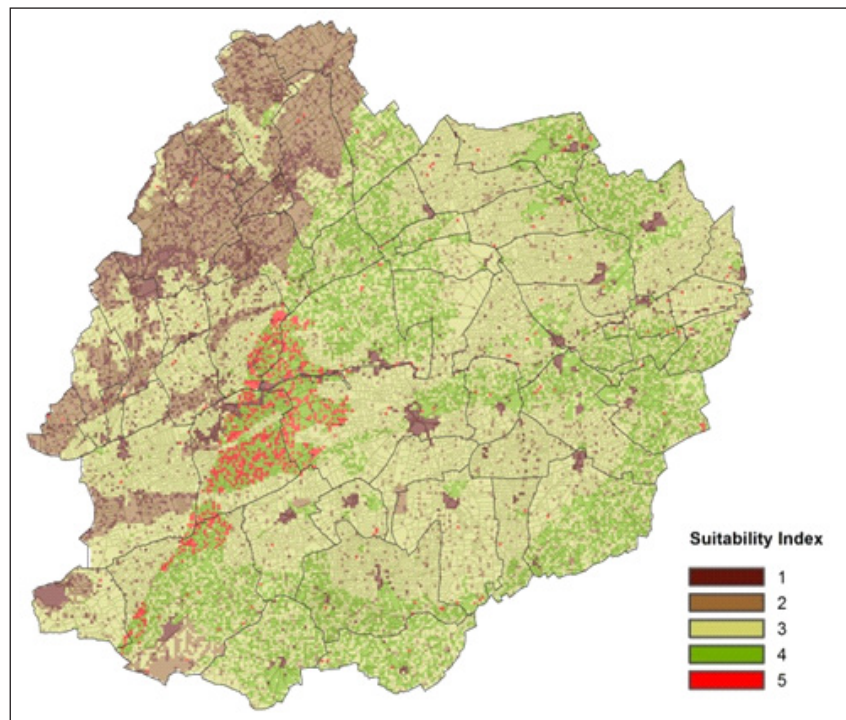


Fig. 7. RWH site suitability based on multi-criteria analysis.

carried out by overlaying the potential drains on cadastral fields shows that 1480 fields (9.7%) having maximum potential to harvest rainwater (Fig. 6). Existence of potential drains during rainy season has been verified in the test field.

Multi-criteria analysis has been carried out based on layers viz. rainfall, land use, soil texture, flow accumulation and slope. Areas with good rainfall, higher slope and flow accumulation are having high suitability (Fig. 7).

Fig. 8. In field smart rainwater harvesting calculator.

A rainwater harvesting calculator has been developed to calculate the volume of harvestable rainwater in any field based on annual and event based rainfall (Fig. 8). The tool will help the farmer to identify his field and calculate the volume of water that can be harvested and also to decide on the dimension of the water harvesting structures.

Conclusion

EO data can play a vital role in identifying RWH sites in semi-arid regions. A technology demonstration study was carried out for a cluster of villages. The results obtained were validated in a test plot. The study underlines the convergence of science and technology with traditional wisdom. The studies point to the importance of smart rainwater harvesting in semi-arid regions for ensuring food security, safe drinking water, promoting agrohorticulture, agroforestry practices and cultivation of high value crops towards achieving long term sustainable livelihood for local populations.

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