

**MODULE – 8 LECTURE NOTES – 1****REMOTE SENSING APPLICATIONS IN WATERSHED MANAGEMENT****1. Introduction**

Scientific planning and management is essential for the conservation of land and water resources for optimum productivity. Watersheds being the natural hydrologic units, such studies are generally carried out at watershed scale and are broadly referred under the term watershed management. It involves assessment of current resources status, complex modeling to assess the relationship between various hydrologic components, planning and implementation of land and water conservation measures etc.

Remote sensing via aerial and space-borne platforms acts as a potential tool to supply the essential inputs to the land and water resources analysis at different stages in watershed planning and management. Water resource mapping, land cover classification, estimation of water yield and soil erosion, estimation of physiographic parameters for land prioritization and water harvesting are a few areas where remote sensing techniques have been used.

This lecture covers the remote sensing applications in water resources management under the following five classes:

- Water resources mapping
- Estimation of watershed physiographic parameters
- Estimation of hydrological and meteorological variables
- Watershed prioritization
- Water conservation

**2. Water resources mapping**

Identification and mapping of the surface water boundaries has been one of the simplest and direct applications of remote sensing in water resources studies. Water resources mapping using remote sensing data require fine spatial resolution so as to achieve accurate delineation of the boundaries of the water bodies.

Optical remote sensing techniques, with their capability to provide very fine spatial resolution have been widely used for water resources mapping. Water absorbs most of the energy in

NIR and MIR wavelengths giving darker tones in the bands, and can be easily differentiated from the land and vegetation.

Fig. 1 shows images of a part of the Krishna river basin in different bands of the Landsat ETM+. In the VIS bands (bands 1, 2 and 3) the contrast between water and other features are not very significant. On the other hand, the IR bands (bands 4 and 5) show a sharp contrast between them due to the poor reflectance of water in the IR region of the EMR spectrum.

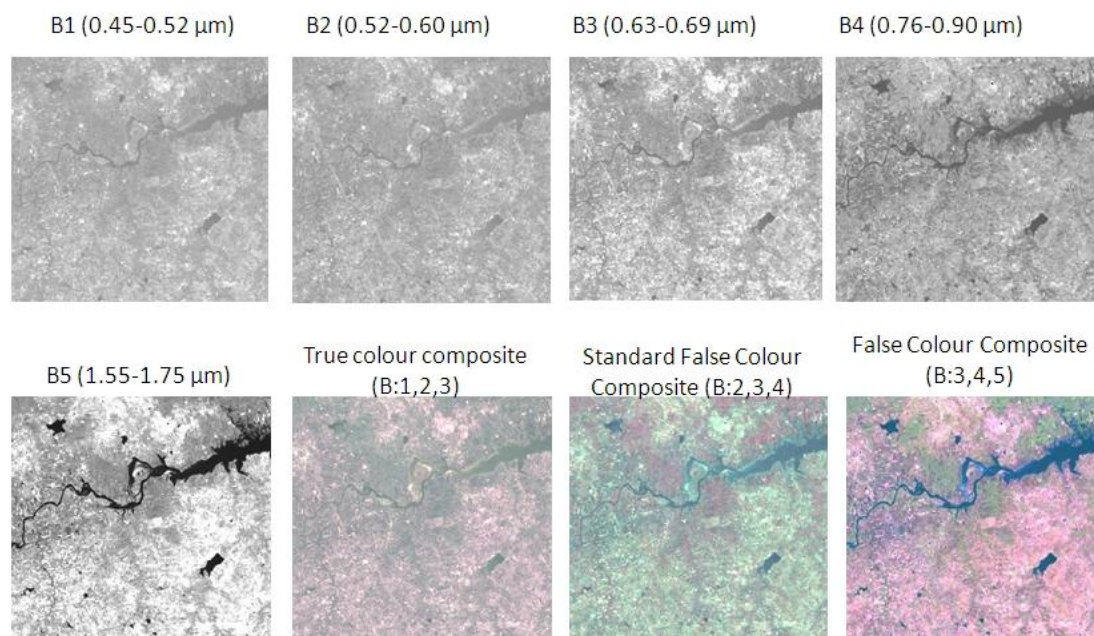


Fig. 1 Landsat ETM+ images of a part of the Krishna river basin in different spectral bands

(Nagesh Kumar and Reshmidevi, 2013)

Poor cloud penetration capacity and poor capability to map water resources under thick vegetation cover are the major drawbacks of the optical remote sensing techniques.

Use of active microwave sensor helps to overcome these limitations as the radar waves can penetrate the clouds and the vegetation cover to some extent. In microwave remote sensing, water surface provides specular reflection of the microwave radiation, and hence very little energy is scattered back compared to the other land features. The difference in the energy received back at the radar sensor is used for differentiating, and to mark the boundaries of the water bodies.

### **3. Estimation of watershed physiographic parameters**

This section covers the remote sensing applications in estimating watershed physiographic parameters and the land use / land cover information.

#### **3.1 Watershed physiographic parameters**

Various watershed physiographic parameters that can be obtained from remotely sensed data include watershed area, size and shape, topography, drainage pattern and landforms.

Stereoscopic attribute of aerial photographs or satellite images permit quantitative assessment of landforms and evaluation of basin topography, which can be used to develop or update the topographic maps. With the help of satellite remote sensing, global scale digital elevation models (DEMs) are available today at fine spatial resolution and reasonable vertical accuracy. DEM from the Shuttle Radar Topographic Mission (SRTM) and ASTER GDEM are examples. SRTM DEM provides near-global DEM at 90m spatial resolution and 16m vertical accuracy. Airborne laser altimeters also provide quick and accurate measurements for evaluating changes in land surface features and are effective tools to ascertain watershed properties.

Fine resolution DEMs have been used to extract the drainage network/ pattern using the flow tracing algorithms. The drainage information can also be extracted from the optical images using digital image processing techniques.

The drainage information may be further used to generate secondary information such as structure of the basin, basin boundary, stream orders, stream length, stream frequency, bifurcation ratio, stream sinuosity, drainage density and linear aspects of channel systems etc.

Fig. 2 shows the ASTER GDEM for a small region in the Krishna Basin in North Karnataka and the drainage network delineated from it using the flow tracing algorithm included in the 'spatial analyst' tool box of ArcGIS. Fig. 2(b) also shows the stream orders assigned to each of the delineated streams.

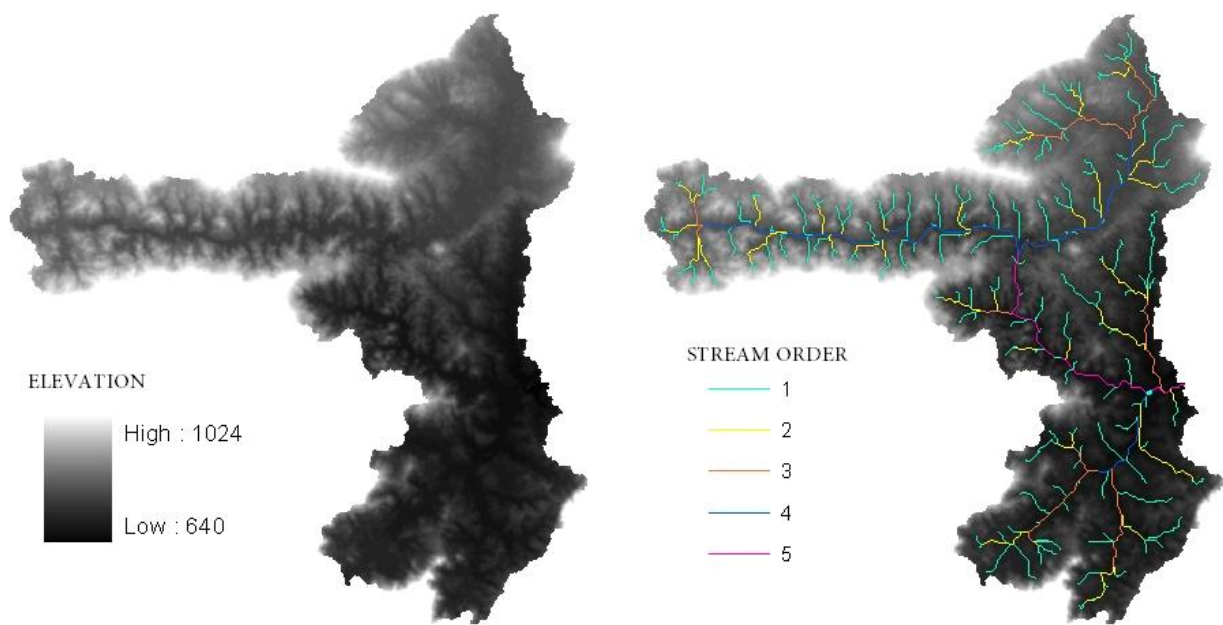


Fig.2 (a) ASTER GDEM of a small region in the Krishna Basin (b) and the stream network delineated from the DEM

### 3.2 Land use / land cover classification

Detailed land use / land cover map is another important input that remote sensing can yield for hydrologic analysis.

Land cover classification using multispectral remote sensing data is one of the earliest, and well established remote sensing applications in water resources studies. With the capability of the remote sensing systems to provide frequent temporal sampling and the fine spatial resolution, it is possible to analyze the dynamics of land use / land cover pattern, and also its impact on the hydrologic processes.

Use of hyper-spectral imageries helps to achieve further improvement in the land use / land cover classification, wherein the spectral reflectance values recorded in the narrow contiguous bands are used to differentiate different land use classes which show close resemblance with each other. Identification of crop types using hyper-spectral data is an example.

With the help of satellite remote sensing, land use land cover maps at near global scale are available today for hydrological applications. European Space Agency (ESA) has released a

global land cover map of 300 m resolution, with 22 land cover classes at 73% accuracy (Fig. 3).

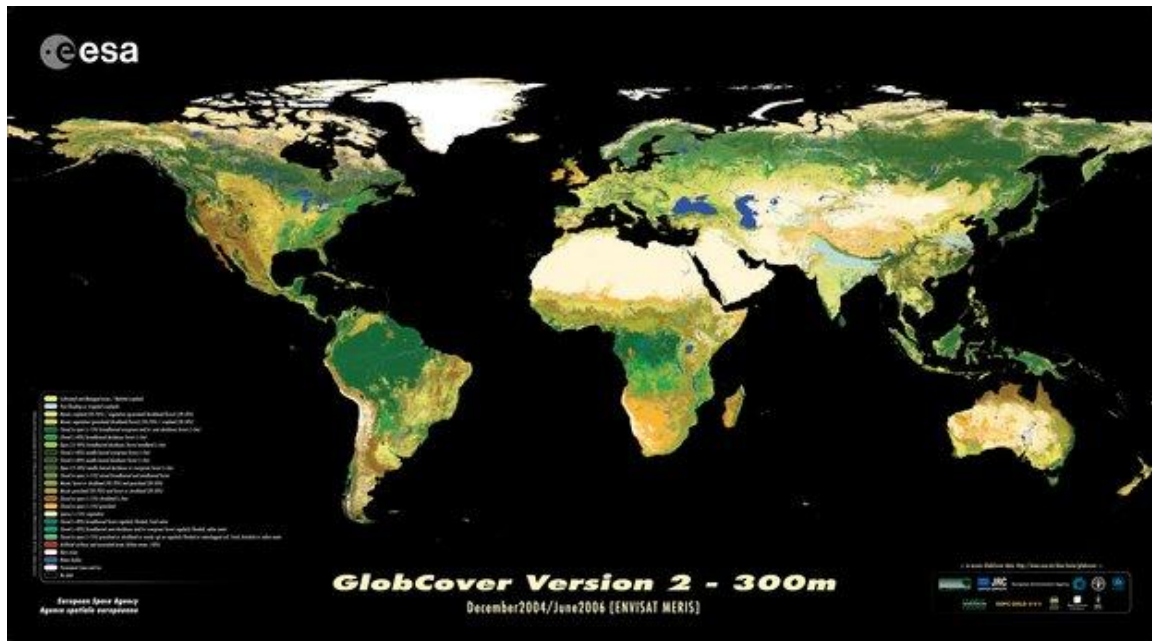


Fig. 3. Global 300 m land cover classification from the European Space Agency (Source: [http://www.esa.int/Our\\_Activities/Observing\\_the\\_Earth/ESA\\_global\\_land\\_cover\\_map\\_available\\_online](http://www.esa.int/Our_Activities/Observing_the_Earth/ESA_global_land_cover_map_available_online))

#### 4. Estimation of hydrological and meteorological variables

Hydrological processes such as precipitation and evapotranspiration are generally used as inputs to the hydrological models to simulate other processes such as runoff (surface and sub-surface), storage change in the unsaturated zone, and ground water flow. This section covers the remote sensing applications in estimating precipitation, evapotranspiration and soil moisture.

##### 4.1 Precipitation

Remote sensing techniques have been used to provide information about the occurrence of rainfall and its intensity. Basic concept behind the satellite rainfall estimation is the differentiation of precipitating clouds from the non-precipitating clouds (Gibson and Power, 2000) by relating the brightness of the cloud observed in the imagery to the rainfall intensities.

Satellite remote sensing uses both optical and microwave remote sensing (both passive and active) techniques.

Table 1 lists some of the important satellite rainfall data sets, satellites used for the data collection and the organizations that control the generation and distribution of the data.

Table 1. Details of some of the important satellite rainfall products (Nagesh Kumar and Reshmidevi, 2013)

Program	Organization	Spectral bands used	Characteristics and source of data
World Weather Watch	WMO	VIS, IR	1-4 km spatial, and 30 min. temporal resolution ( <a href="http://www.wmo.int/pages/prog/www/index_en.html">http://www.wmo.int/pages/prog/www/index_en.html</a> )
TRMM	NASA JAXA	VIS, IR Passive & active microwave	Sub-daily 0.25° (~27 km) spatial resolution ( <a href="ftp://trmmopen.gsfc.nasa.gov/pub/merged">ftp://trmmopen.gsfc.nasa.gov/pub/merged</a> )
PERSIANN	CHRS	IR	0.25° spatial resolution Temporal resolution: 30 min. aggregated to 6 hrs. ( <a href="http://chrs.web.uci.edu/persiann/">http://chrs.web.uci.edu/persiann/</a> )
CMORPH	NOAA	Microwave	0.08 deg (8 km) spatial and 30 min. temporal resolution ( <a href="http://www.cpc.ncep.noaa.gov/products/janowiak/cmorph_description.html">http://www.cpc.ncep.noaa.gov/products/janowiak/cmorph_description.html</a> )

Acronyms

CHRS: Center for Hydrometeorology and Remote Sensing, University of California, USA  
 CMORPH: Climate Prediction Center (CPC) MORPHing technique  
 NASA: National Aeronautics and Space Administration, USA  
 NOAA: National Oceanic and Atmospheric Administration, USA  
 PERSIANN: Precipitation Estimation from Remotely Sensed Information using Artificial Neural Network  
 TRMM: Tropical Rainfall Measuring Mission  
 WMO: World Meteorological Organization

## 4.2. Evapotranspiration

Evapotranspiration (ET) represents the water and energy flux between the land surface and the lower atmosphere. ET fluxes are controlled by the feedback mechanism between the atmosphere and the land surface, soil and vegetation characteristics, and the hydro-meteorological conditions.

There are no direct methods available to estimate the actual ET by means of remote sensing techniques. Remote sensing application in the ET estimation is limited to the estimation of the surface conditions like albedo, soil moisture, surface temperature, and vegetation characteristics like normalized differential vegetation index (NDVI) and leaf area index (LAI). The data obtained from remote sensing are used in different models to simulate the actual ET.

Courault et al. (2005) grouped the remote sensing data-based ET models into four different classes:

- Empirical direct methods: Use the empirical equations to relate the difference in the surface air temperature to the ET.
- Residual methods of the energy budget: Use both empirical and physical parameterization. Example: SEBAL (Bastiaanssen et al., 1998), FAO-56 method (Allen et al., 1998)
- Deterministic models: Simulate the physical process between the soil, vegetation and atmosphere making use of remote sensing data such as Leaf Area Index (LAI) and soil moisture. SVAT (Soil-Vegetation-Atmosphere-Transfer) model is an example (Olioso et al., 1999).
- Vegetation index methods: Use the ground observation of the potential or reference ET. Actual ET is estimated from the reference ET by using the crop coefficients obtained from the remote sensing data (Allen et al., 2005; Neale et al., 2005).

Optical remote sensing using the VIS and NIR bands have been commonly used to estimate the input data required for the ET estimation algorithms.

As a part of the NASA / EOS project to estimate global terrestrial ET from earth's land surface by using satellite remote sensing data, MODIS Global Terrestrial Evapotranspiration

Project (MOD16) provides global ET data sets at regular grids of 1 sq.km for the land surface at 8-day, monthly and annual intervals for the period 2000-2010.

### 4.3 Soil moisture estimation

Remote sensing techniques of soil moisture estimation are advantageous over the conventional *in-situ* measurement approaches owing to the capability of the sensors to capture spatial variation over a large aerial extent. Moreover, depending upon the revisit time of the satellites, frequent sampling of an area and hence more frequent soil moisture measurements are feasible.

Fig. 4 shows the global average monthly soil moisture in May extracted from the integrated soil moisture database of the European Space Agency- Climate Change Initiative (ESA-CCI).

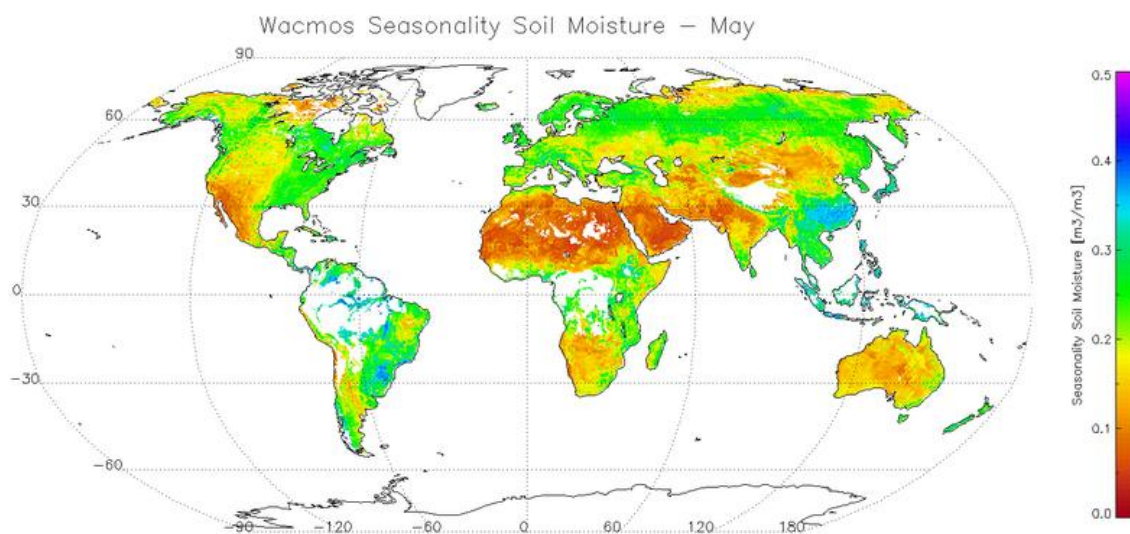


Fig 4. Global monthly average soil moisture in May from the CCI data

(Source: <http://www.esa-soilmoisture-cci.org/>)

Remote sensing of the soil moisture requires information below the ground surface and therefore mostly confined to the use of thermal and microwave bands of the EMR spectrum.

Remote sensing of the soil moisture is based on the variation in the soil properties caused due to the presence of water. Soil properties generally monitored for soil moisture estimation include soil dielectric constant, brightness temperature, and thermal inertia.

Though the remote sensing techniques are giving reasonably good estimation of the soil moisture, due to the poor surface penetration capacity of the microwave signals, it is

considered to be effective in retrieving the moisture content of the surface soil layer of maximum 10 cm thickness. In the recent years, attempts have been made to extract the soil moisture of the entire root zone with the help of remote sensing data. Such methods assimilate the remote sensing derived surface soil moisture data with physically based distributed models to simulate the root zone soil moisture. For example, Das et al. (2008) used the Soil-Water-Atmosphere-Plant (SWAP) model for simulating the root zone soil moisture by assimilating the aircraft-based remotely sensed soil moisture into the model.

Some of the satellite based sensors that have been used for retrieving the soil moisture information are the following.

- Passive microwave sensors: SMMR, AMSR-E and SSM/I
- Active microwave sensors (radar): Advanced SCATterometer (ASCAT) aboard the EUMETSAT MetOp satellite
- Thermal sensors: Data from the thermal bands of the MODIS sensor onboard Terra satellite have also been used for retrieving soil moisture data.

Use of hyper-spectral remote sensing technique has been recently employed to improve the soil moisture simulation. Hyper-spectral monitoring of the soil moisture uses reflectivity in the VIS and the NIR bands to identify the changes in the spectral reflectance curves due to the presence of soil moisture (Yanmin et al., 2010). Spectral reflectance measured in multiple narrow bands in the hyperspectral image helps to extract most appropriate bands for the soil moisture estimation, and to identify the changes in the spectral reflectance curves due to the presence of soil moisture.

## **5. Watershed characterization and prioritization**

Watershed characterization involves the measurement and analysis of various hydro-geological and geo-morphological parameters, soil and land use characteristics etc. (Rao and Raju, 2010).

Watershed prioritization is the ranking of different watersheds or sub-watersheds within a watershed for any specific application based on the watershed characteristics.

Examples:

- Watershed prioritization considering the erosion risk, using parameters such as relief ratio, drainage density, drainage texture and bifurcation ratio (Chaudhary and Sharma, 1984).
- Watershed prioritization based on the sediment yield index (Khan et al., 2001)
- Watershed characterization and land suitability evaluation using land use/ land cover, soil data, slope, and soil degradation status (Saxena et al., 2000)
- Prioritization of micro-catchments based on morphological parameters (Raju and Nagesh Kumar, 2012)

Fig. 5 shows a sample watershed characterization map of the Northern United States for water quality risks

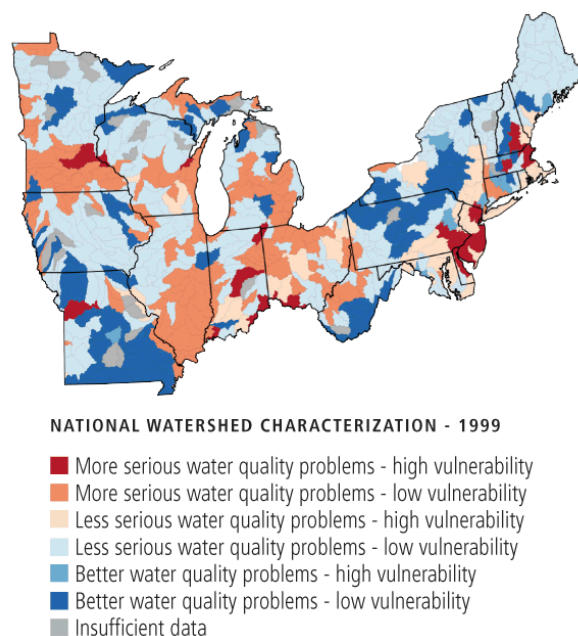


Fig.5 Watershed characterization of the Northern United States for water quality risk

Source: [http://www.nrs.fs.fed.us/futures/current\\_conditions/soil\\_water\\_conservation/](http://www.nrs.fs.fed.us/futures/current_conditions/soil_water_conservation/)

Remote sensing techniques have been effectively used for watershed characterization and prioritization to identify the water potential, erosion risk, management requirements etc.

Remote sensing helps in obtaining the database essential for such analyses. Input data that have been generated using remote sensing techniques for such studies includes physiographic and morphometric parameters, land use / land cover information and hydrological parameters as mentioned in the previous section.

#### 4.4.1 Case study: Prioritization of micro-catchments in the Kherthal catchment in Rajasthan based on morphology (Source: Raju and Nagesh Kumar, 2012)

Kherthal catchment in Rajasthan lies between latitudes  $24^{\circ}51'$  and  $25^{\circ}58'$  N and longitudes  $73^{\circ}8'$  and  $73^{\circ}19'$  E. The catchment consists of 25 micro-catchments and spreads over approximately  $159 \text{ km}^2$  area.

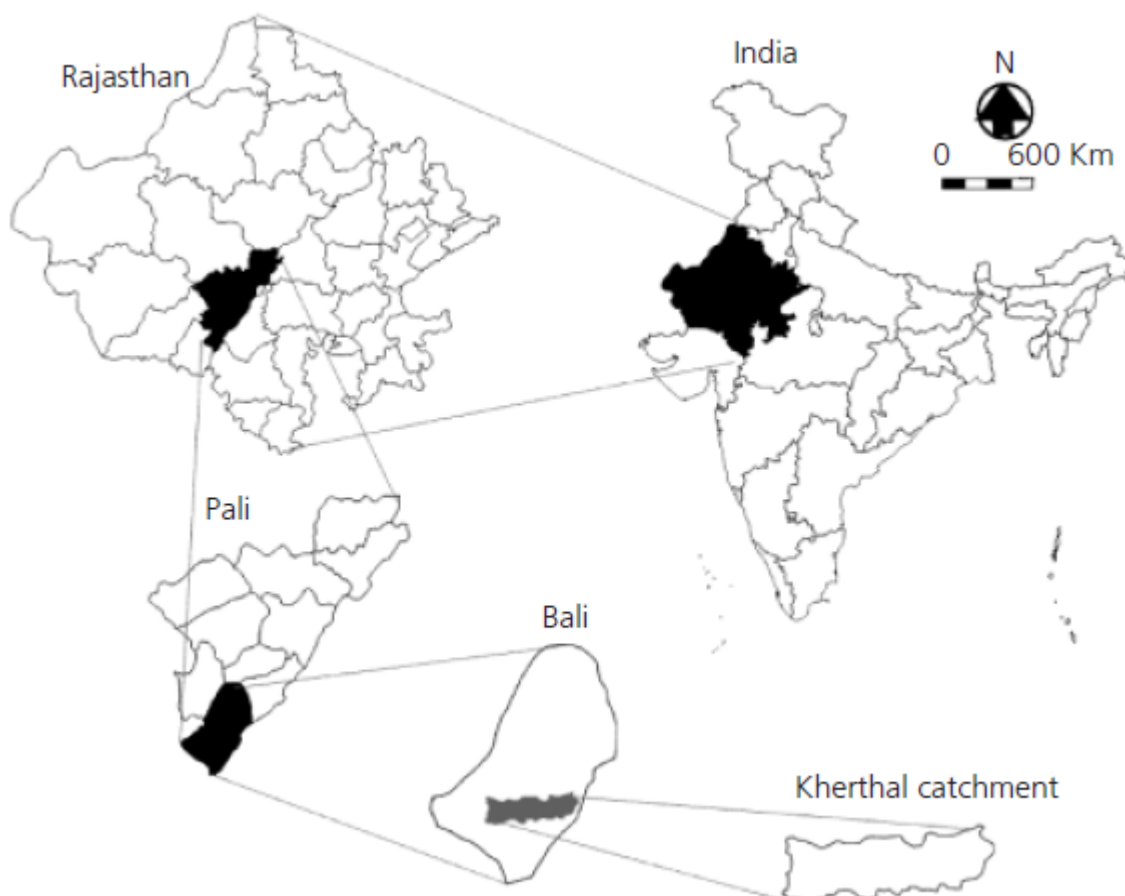


Fig.6 Location map of the Kherthal catchment

Raju and Nagesh Kumar (2012) considered a set of seven geomorphologic parameters to prioritize the micro-catchments in the Kherthal catchment for the watershed conservation and management practices.

Morphologic parameters considered are the following.

- Drainage density ( $D_d$ )
- Bifurcation ratio ( $R_b$ )
- Stream frequency ( $F_u$ )
- Texture ratio ( $T$ )
- Form factor ( $R_f$ )
- Elongation ratio ( $R_e$ )
- Circulatory ratio ( $R_c$ )

Details of these parameters are shown in Table 2.

Table 2. Description of the morphologic parameters used in the study

Parameter	Definition	Mathematical expression
Basin length	Length of basin	$L_b = 1.312A^{0.568}$
Drainage density	Ratio of total length of stream segments of all orders per unit area ( $\text{km}^{-1}$ ) and represents closeness of channel spacing	$D_d = \frac{L}{A}$
Bifurcation ratio	Ratio of number of streams of a given order to number of streams of next higher order. Index of hydrograph shape of basins	$R_b = \frac{N_u}{N_{u+1}}$
Stream frequency	Total number of stream segments of all orders per unit area ( $\text{km}^{-2}$ )	$F_u = \frac{N'}{A}$
Texture ratio	Ratio of number of stream segments of first order and perimeter of that catchment ( $\text{km}^{-1}$ ). Index of underlying geology, infiltration rates of rocks and relief characteristics of the catchment	$T = \frac{N_1}{P}$
Form factor	Ratio of basin area to square of basin length (no units) Relates shape of the basin, peak flow and duration	$R_f = \frac{A}{L_b^2}$
Elongation ratio	Ratio of diameter of circle of the same area as the drainage basin and maximum length of basin. Index of basin shape and hydrological character	$R_e = 1.128 \frac{A^{0.5}}{L_b}$
Circulatory ratio	Ratio of area of basin to area of circle having its circumference equal to perimeter of the basin. Influenced by length and frequency of streams, geological structures, land use, climate, slope of catchment	$R_c = 12.57 \frac{A}{P^2}$

These morphologic parameters were interpreted / calculated for all the micro-catchments by using IRS LISS-III images and Survey of India topographic sheets of 1:50,000 scale.

22 out of the 25 micro-catchments were considered for the analysis. Values of the geomorphologic parameters for these 22 micro-catchments are given in Table 3.

Table 3. Morphologic parameters for the micro-catchments in the Kherthal catchment

Alternative	Parameter								
	MWS in the field	Area: km <sup>2</sup>	$D_d$ : km/km <sup>2</sup>	$R_b$	$F_u$ : No. of streams/km <sup>2</sup>	$T$ : km <sup>-1</sup>	$R_f$	$R_e$	$R_c$
A1	2	50-500	3-392	1-701	6-337	4-152	-0-341	-0-658	-0-422
A2	3	12-500	3-834	3-764	8-480	3-223	-0-412	-0-724	-0-539
A3	4	6-750	5-126	1-898	15-556	4-330	-0-448	-0-755	-0-490
A4	5	3-000	4-577	1-839	14-667	3-118	-0-500	-0-798	-0-587
A5	6	4-250	2-696	3-060	9-647	2-587	-0-477	-0-779	-0-621
A6	7	4-000	7-985	2-473	22-250	4-086	-0-481	-0-782	-0-350
A7	9	2-000	4-477	2-938	12-500	2-304	-0-529	-0-820	-0-593
A8	10	0-750	4-436	2-750	13-333	1-612	-0-604	-0-877	-0-500
A9	11	1-750	3-969	2-200	9-143	1-010	-0-538	-0-828	-0-185
A10	12	10-500	4-700	1-993	13-238	3-783	-0-422	-0-733	-0-274
A11	13	3-200	3-974	2-292	10-625	1-952	-0-496	-0-794	-0-347
A12	14	1-300	3-464	2-667	8-462	1-300	-0-561	-0-845	-0-432
A13	15	2-500	4-464	1-843	11-200	2-303	-0-513	-0-808	-0-651
A14	16	1-500	2-798	2-333	6-667	1-056	-0-550	-0-836	-0-429
A15	17	4-250	4-303	1-720	9-176	1-760	-0-477	-0-779	-0-414
A16	18	14-000	4-071	2-224	8-929	3-507	-0-406	-0-719	-0-482
A17	19	2-500	4-870	2-150	12-800	2-460	-0-513	-0-808	-0-587
A18	20	6-750	3-520	1-775	6-074	1-447	-0-448	-0-755	-0-336
A19	21	2-250	3-385	1-000	5-333	0-840	-0-520	-0-814	-0-554
A20	23	4-500	1-979	3-400	3-333	0-556	-0-473	-0-776	-0-216
A21	24	13-550	2-814	2-567	4-576	1-841	-0-408	-0-720	-0-446
A22	25	2-250	3-829	2-167	8-444	1-643	-0-520	-0-814	-0-452

For the prioritization, the maximum values for the first 4 parameters and the minimum values for the remaining 3 parameters were considered as the evaluation criteria. These criteria were evaluated using three methods: compromise programming, technique for order preference by similarity to an ideal solution (TOPSIS) and compound parameter approach (CPAP) (More details can be found in Raju and Nagesh Kumar, 2012).

In the CPAP, micro-catchments were ranked for the seven parameters individually and the average of the seven ranks was used as the compound parameter, which was then used to rank the micro-catchments. Table 4 shows the individual ranks of the parameters, compound parameter and the corresponding ranks of the micro-catchments.

Table 4. Ranking of the micro-catchments by compound ranking

Alternative	$D_d$	$R_b$	$F_u$	$T$	$R_f$	$R_e$	$R_c$	Equal weight	
								Ave	Rank
A1	17	20	18	2	1	1	1	8.57	5
A2	13	1	14	6	4	4	16	8.29	4
A3	2	15	2	1	6	6	21	7.57	3
A4	5	17	3	7	13	13	2	8.57	6
A5	21	3	10	8	9	9	10	10.00	8
A6	1	8	1	3	11	11	3	5.43	1
A7	6	4	7	10	18	18	18	11.57	12
A8	8	5	4	16	22	22	20	13.86	16
A9	12	12	12	20	19	19	5	14.14	18
A10	4	14	5	4	5	5	15	7.43	2
A11	11	10	9	12	12	12	6	10.29	9
A12	16	6	15	18	21	21	11	15.43	19
A13	7	16	8	11	14	14	4	10.57	10
A14	20	9	17	19	20	20	13	16.86	21
A15	9	19	11	14	10	10	17	12.86	14
A16	10	11	13	5	2	2	19	8.86	7
A17	3	13	6	9	15	15	22	11.86	13
A18	15	18	19	17	7	7	7	12.86	15
A19	18	21	20	21	16	16	9	17.29	22
A20	22	2	22	22	8	8	14	14.00	17
A21	19	7	21	13	3	3	12	11.14	11
A22	14	22	16	15	17	17	8	15.57	20

Sub catchments A6, A3 and A10 were identified as the highest priority micro-catchments in the Kherthal watershed.

From the study, analysis of the geomorphologic parameters was found to be very effective in assessing the geo-morphological and hydrological characteristics of the micro-catchments.

#### 4.5 Water conservation and rainwater harvesting

Rainwater harvesting, wherein water from the rainfall is stored for future usage, is an effective water conservation measure particularly in the arid and semi-arid regions.

Rainwater harvesting techniques are highly location specific. Selection of appropriate water harvesting technique requires extensive field analysis to identify the rainwater harvesting potential of the area, and the physiographic and terrain characteristics of the locations. It depends on the amount of rainfall and its distribution, land topography, soil type and depth, and local socio-economic factors (Rao and Raju, 2010).

Rao and Raju (2010) had listed a set of parameters which need to be analyzed to fix appropriate locations for the water harvesting structures. These are

- Rainfall
- Land use or vegetation cover
- Topography and terrain profile
- Soil type & soil depth
- Hydrology and water resources
- Socio-economic and infrastructure conditions
- Environmental and ecological impacts

Remote sensing techniques had been identified as potential tools to generate the basic information required for arriving at the most appropriate methods for each area.

In remote sensing aided analysis, various data layers were prepared and brought into a common GIS framework. Further, multi-criteria evaluation algorithms were used to aggregate the information from the basic data layers. Various decision rules were evaluated to arrive at the most appropriate solution as shown in Fig. 6.

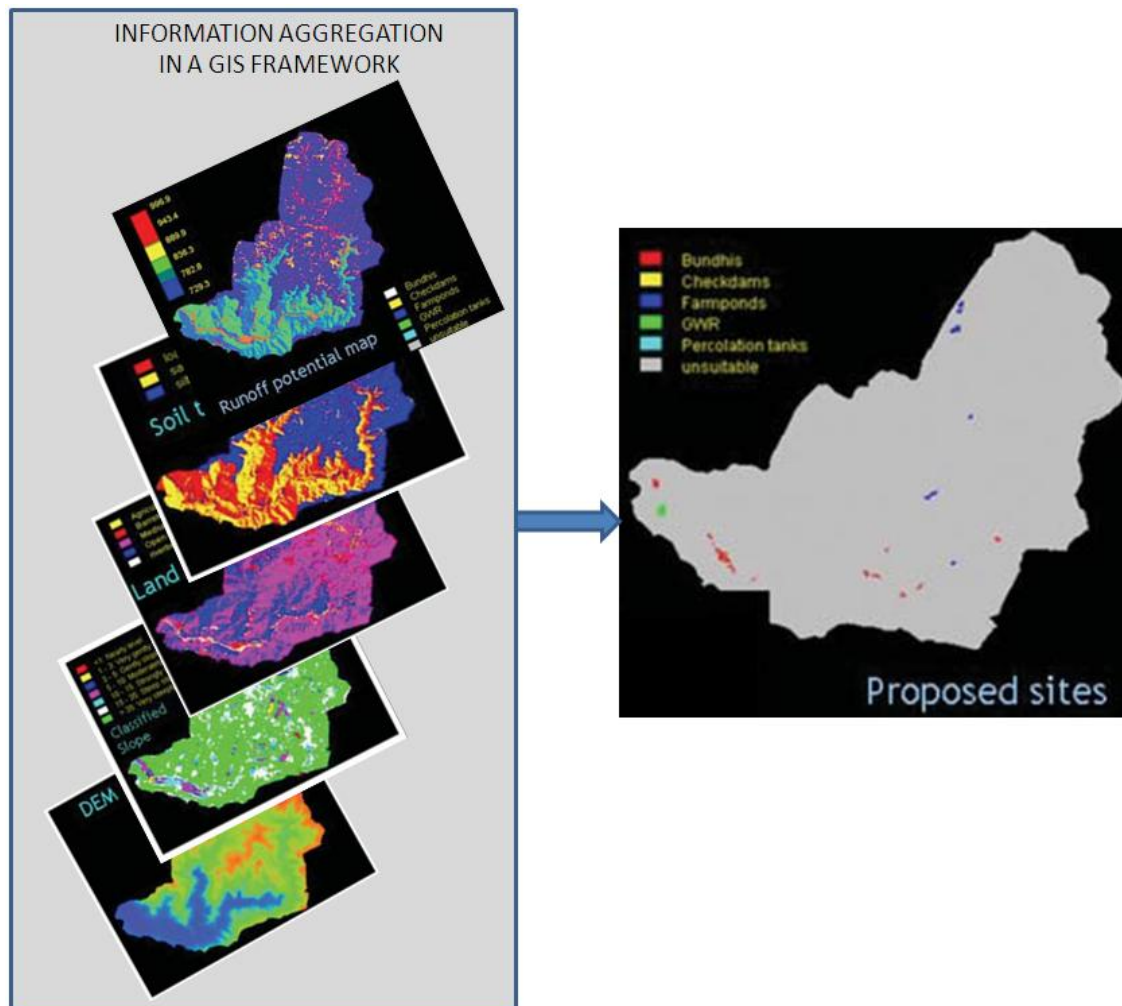


Fig.6. Schematic representation showing the remote sensing data aggregation in evaluating the suitability of various water harvesting techniques

(Images are taken from Rao and Raju 2010 and aggregated here)

The capability to provide large areal coverage at a fine spatial resolution makes remote sensing techniques highly advantageous over the conventional field-based surveys.

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