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# 3 Geospatial Techniques for Conservation of Himalayan Water Resources

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## Introduction

Water is key driver of economic and social development and one of the fundamental elements in sustaining the integrity of the natural environment. It is the major renewable resource amongst the various natural resources. Water being an indispensable constituent for all life supporting processes, its assessment, conservation, development and management is of great concern for all those who manage, facilitate and utilize (Gupta *et al*., 2013).

Issues related to water resources development and management are not in isolation but are inter-related with other human activities. The issues involved range from those of basic human well-being (food security and health), economic development (industry and energy) and preservation of natural ecosystems on which ultimately we all exist and sustain. The combination of lower precipitation and higher evaporation in many regions is diminishing water quantities in rivers, lakes, and ground water storage, while increased pollution is damaging ecosystems and the health, lives and livelihoods of those without access to adequate, safe drinking water and basic sanitation (UN, 2005). The increase in frequency of occurrences of extreme events is probably firm conservation and optimal utilization of this scarce resource is extremely important for sustainable development. The water management in the coming years is likely to have profound impact on human society with regard to its quality of life and its very existence.

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***Water Resources of Himalayan Region***

The Indian Himalayan Region (IHR) with geographical coverage of over 5.3. lakh Km$^2$ comprises of the vast mountain range extending over 2500 km in length between the Indus and the Brahmaputra river systems and raising from low-lying plains to over 8000 m above sea level, it is around 300 Km at its widest part with an average width of 80 Km. Ganges, Brahmaputra, Yamuna, and other major river systems originate in the Himalayas. The Himalayan mountain system is the source of one of the world's largest supplies of fresh water. Any changes in the Himalayan glacier dynamics and melting are expected to severely affect about 1.3 billions of people. Not only rivers but also the Himalayan region is dotted with hundreds of lakes from low elevation to the high elevations.The mountain lakes, caused by glacial activity, are termed as tarns by geographers. Many large lakes of Lesser Himalaya are fault basin lakes formed due to tectonic activity resulting in blocking of the streams/rivers during Holocene period (Gupta *et al*., 2013). These have main source of water through precipitation and underground springs. Such lakes are found in Kumaun, Himachal Pradesh and Jammu.

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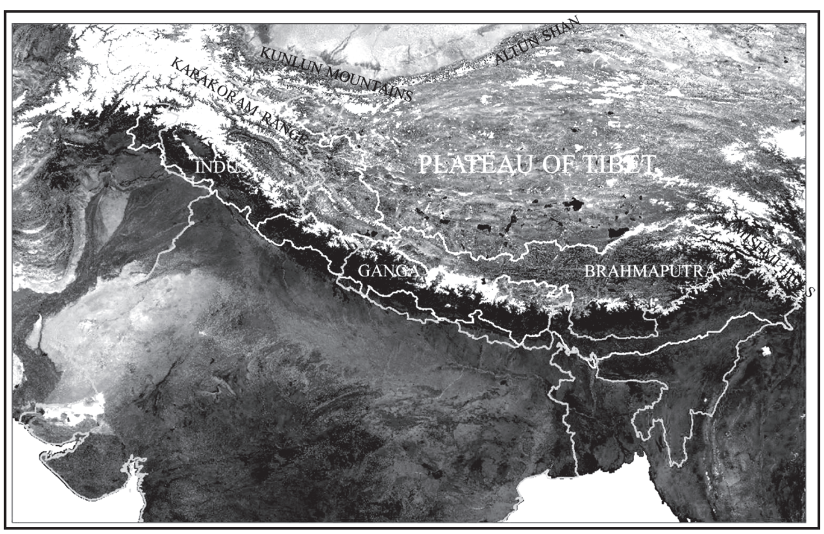


Fig. 3.1: Himalayan River Basin

The principal glaciers in Himalayas can be divided in three groups:

*Punjab Himalaya Group of Glaciers*

Rakhiot Glacier, Kolhai Glacier, Neh-Nar Glacier, Sarbal Glacier, Kangriz Glacier, Brahma Glacier, DrungDrung Glacier, Mulkila Group Glaciers, Barashigri Glacier, DibiBokri Glacier, Gara Glacier and Gorgarang Glacier.

*Garhwal Himalaya Group of Glaciers*

Gangotri Glacier, Santopath Glacier, Kedarnath Glacier, Milam Glacier, Pindari Glacier, Shankulapa Glacier, and Poting Glacier.

*Assam Himalaya Group of Glaciers*

Glaciers adjoining Kanchenjunga peak, Sanlung Glacier and Glaciers adjoining GyaraPari peak.

**Table 3.1: Glaciated areas in the Himalayan region (Source: Qin 1991)**

| Drainage Basin | No. of Glaciers | Total Area ($km^2$) | Total Ice Reserves ($km^3$) |
|---|---|---|---|
| Ganges River | 6,694 | 16,677 | 1971 |
| Brahmaputra River | 4,366 | 6,579 | 600 |
| Indus River | 5,057 | 8,926 | 850 |
| Total | 16,117 | 32,182 | 3,421 |

***Significance of Satellite Remote Sensing for Water Resources Management***

Measurements from satellite remote sensing provide a means of observing and quantifying land and hydrological variables over geographic space and support their temporal description. Remote sensing instruments capture upwelling electromagnetic radiation from earth surface features which is either reflected or emitted. The former is reflected solar radiation and the latter is in thermal infrared and microwave portions of electro-magnetic spectrum. Active microwave radars obtain reflected/returned microwave signals. The reflected solar energy is used for mapping land and water resources like landuse, land cover, forests snow & glaciers, water features, geologic & geomorphic features, water quality, etc. The thermal emission in the infrared is used for surface temperature, energy fluxes and microwave for soil moisture, snow & glacier, flood, etc.

Remote sensing has several advantages over field measurements. First measurements derived from remote sensing are objective; they are not based on options. Second, the information is collected in a systematic way which allows time series and comparison between schemes. Third, remote sensing covers a wide area such as entire river basin. Ground studies are often confined to a small pilot area because of the expense and logistical constraints. Fourth, information can be aggregated to give a bulk representation, or disaggregated to very fine scales to provide more detailed and explanatory information related to spatial uniformity. Fifth, information can be spatially represented through geographic information systems, revelling information that is often not apparent when information is provided in tabular form.

Toward evolving and supporting comprehensive water management strategies space technology plays a crucial role. Systematic approaches involving judicious combination of conventional group measurements and remote sensing techniques pave way for achieving optimum planning and operations of water resource projects. Remote sensing has shown enormous promise for providing wealth of data and information that were deficient with the in-situ observations. It has also been a valuable tool in many hydrologic modelling applications due to its capability of providing unrestricted collection of information with wide spatial coverage and temporal revisit. Earth Observation Satellite (EOS) data has been extensively used to map surface water bodies, monitor their spread and estimate the volume of water. The SWIR band of AWIFS sensor in IRS-P6 was found to be useful in better discrimination of snow and cloud, besides delineating the transition and patch in snow covered areas. Snow-melt runoff forecasts are being made using IRS-WiFS/AWiFS and NOAA/AVHRR data. These forecasts enable better planning of water resources by the respective water management boards. Monitoring reservoir spread through seasons has helped to assess the storage loss due to sedimentation, updating ratting curves. Satellite data derived spatial and temporal information on cropping pattern, crop intensity and condition forms basic inputs for developing indicators for agriculture performance of the irrigation system and bench marking of systems. Satellite data derived geological and hydro-geomorphologic features assist in prospecting the ground water resource to plan aquifer recharging, water harvesting and drinking water sources. High resolution satellite data remarkably augmented the remote sensing services extending it to infrastructure planning & management. Table 3.2 depicts the Sensors/Satellite data suitable for Water Resources Management.

**Table 3.2: Sensors/Satellite data suitable for Water Resources Management**

| Application | Satellite and Sensor |
|---|---|
| • Field/Plot boundaries<br>• Irrigation network/infrastructure<br>• Cartographic information<br>• Micro-scale features | Cartosat-1 & 2 (PAN),<br>Iknos, Quickbird,<br>SPIN,SPOT (PAN) |
| • Land use/Land Cover<br>• Surface Water Resources<br>• Water logging | IRS, Landsat, SPOT, ASTER, CBERS |
| • Evapotranspiration<br>• Soil Moisture | NOAA, Aqua, Terra, Landsat, ASTER, CBERS |
| • Surface roughness<br>• Soil Moisture | ERS, Radarsat, RISAT |

(Table Contd…)

| Application | Satellite and Sensor |
|---|---|
| • Flood Inundation<br>• River bank erosion<br>• River control works | IRS, Landsat, SPOT, ERS, Radarsat, JERS, RISAT<br>IRS, Landsat, SPOT, Cartosat-1 & 2<br>Cartosat-1 & 2, Iknos, Quickbird |
| • Surface water<br>• Snow cover<br>• Glaciers | IRS, Landsat, SPOT, ASTER, NOAA, Aqua, Terra |
| • Snow depth<br>• Snow water equivalent | ERS, Radarsat, JERS, RISAT |
| • Water quality | IRS, Landsat, SPOT |
| • Precipitation | TRMM, METROSAT |

The overall applications of RS & GIS in water resources sector can be broadly categorized into the following:

- Water Resources Assessment
- Water Resources Management
- Water Resources Development
- Watershed Management
- Flood Disaster Support
- Environmental Impact Assessment & Management
- Water Resources Information & Decision Support Systems

Satellite remote sensing data is being put into use to provide quantitative and reliable information, there by facilitating improved water resources management.

- Snow & Glacier
  - Snow cover mapping & monitoring
  - Snow melt runoff forecasting
  - Glacier mapping & monitoring
  - Glacial lake monitoring
  - Glacier mass balance
- Surface water resources
  - Water bodies
  - Wetlands
- Irrigation water management
  - Inventory of irrigated agriculture
  - Performance evaluation & bench marking
  - Monitoring intervention schemes
  - Near real time monitoring
  - Surface water logging
  - Soil salinity/Alkalinity
  - Irrigation infrastructure mapping
  - Assessment of irrigation potential creation

  - Pre-feasibility study
  - Actual evapotranspiration estimation
  - Irrigation information system
- Reservoir Sedimentation
  - Assessment of sedimentation
  - Updation of elevation-area-capacity curve
  - Estimation of reservoir capacity
  - Assessment of rate of siltation
  - Estimation of life of reservoir
  - Reservoir catchment analysis
  - Impact of foreshore cultivation
- Hydro-power Generation
  - Submergence area analysis
  - Inputs for pre-feasibility analysis
  - Input for ranking studies
  - EIA studies
- Interlinking of Rivers
  - Pre-feasibility studies
  - Canal alignment studies
  - Submergence area analysis
- Flood Disaster Monitoring and Management
  - Flood inundation mapping
  - Flood hazard zonation
  - Flood forecasting
  - Flood inundation simulation
  - Disaster management & support
- Watershed Management
  - Water harvesting
  - Sustainable action plans
  - Soil erosion & catchment's area treatment
  - Morphometric analysis
- River Engineering
  - River Migration
  - River control works mapping & monitoring
- Ground Water Prospecting
- Environmental Impact Assessment and Management

**Water Resources Assessment**

Surface water occurs in the form of liquid water in lakes, reservoirs, rivers, and in its solid form as snow, glacier and lake ice. Remote sensing platforms are amenable to detect and map the spatial extent of both forms of water. Accurate information on surface water, its existence, spatial extent, temporal changes is essential to manage this resource judiciously. Fig. 3.2 shows Drainage Map of Mandakini Valley of Uttarakhand.

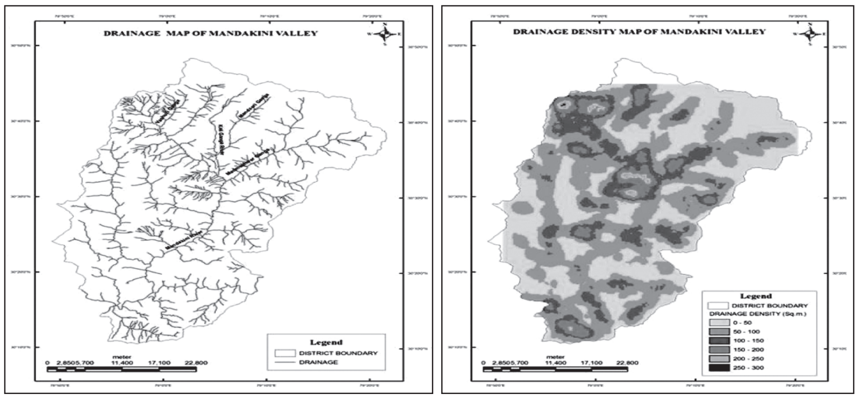


Fig. 3.2: Drainage Map of Mandakini Valley of Uttarakhand

***Snow and Glacier Studies***

Snow cover and the equivalent amount of volume stored supplies at least one-third of the water. The vast difference in spectral properties of snow and other natural land cover supports its identification on satellite data. The relatively high albedo of snow reflects much higher percentage of incoming solar shortwave radiation than snow free surface (80% for relatively new snow whereas roughly 15% for snow free vegetation). The snow cover can be detected and monitored from a variety of remote sensing platform. Both reflective and thermal remote sensing is being extensively used for mapping snow cover area; it's built up during winter and depleting during summer season. Microwave instruments are providing parameterization of snow cover physical properties such as snow water equivalent, density, grain size, depth, state (wet/dry) and age. Remote sensing images provide accurate information on the glaciers and their spatial extent. The glacier lakes are easily identifiable on multi spectral satellite data of medium resolution (24-30 m) to fine resolution (6 m).

***Snow Cover Mapping***

Snow-cover mapping is a prerequisite for deriving the main input variable for a deterministic snowmelt runoff model (SRM). Since the direct run off measurements cannot be possible only on the basis of remote sensing data so it is necessary to determine runoff values indirectly with the aid of hydrological models. In many areas of world, the majority of freshwater available for consumption, irrigation is due to the snowmelt run off so in order to make its efficient use, total flow prediction would be quite useful. Like using geospatial technique not only run off but also extent of the snow, its depth could be determined. Fig. 3.3 shows Snow cover area- NOAA-AVHRR Images (2004)

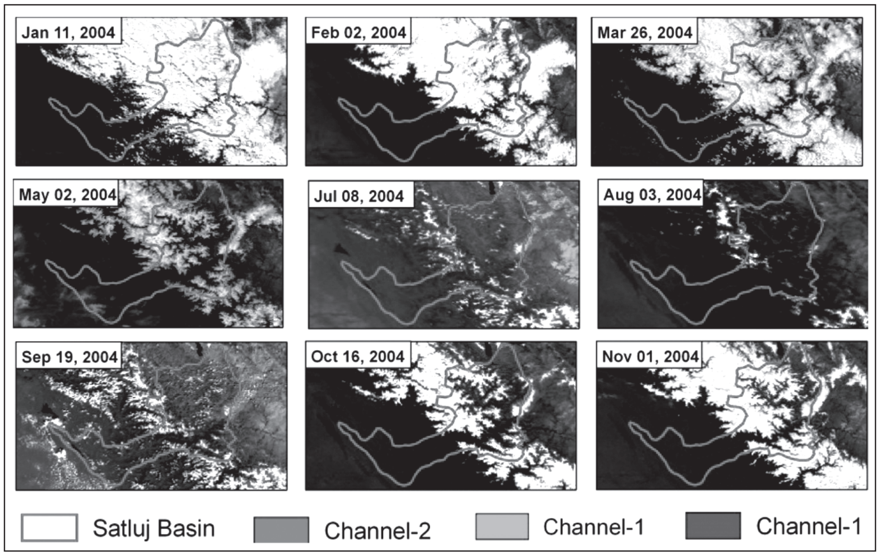


Fig. 3.3: Snow Cover Area-NOAA-AVHRR Images (2004)

Snow extent may be mapped from most satellite with sensors in the visible band including the NOAA series, Landsat, SPOT and GOES. Snow cover extent can be used as a input in hydrological models so as to use for different applications as per need.

High snow cover indicates higher water contents and hence more snowmelt run off generation is there. In order to predict this, Remote sensing provides the privilege for measuring the extent of snow cover and also for monitoring the water content of the snow cover, e.g. from the air with laser sensors. Table 3.3 depicts Sensors use for snow cover mapping.

**Table 3.3: Sensors use for snow cover mapping**

| Satellite-Sensor | Snow Cover Mapping Status |
|---|---|
| NOAA-AVHRRMODIS-Aqua/Terra | Region level snow cover area mapping on daily basis |
| Resoucesat 1 (AWiFS) | Regional to basin level snow cover area mapping and monitoring on five daily basis |
| Resourcesat 1 (LISS III), LANDSAT (ETM), ASTER, SPOT | Basin to sub basin level snow cover area mapping and monitoring |

***Snowmelt Runoff Forecasting***

The Snowmelt Runoff Model (Rango, 1996) makes use of satellite data for snow extent to develop snow cover depletion curves by elevation zone. The model then simulates streamflow from each elevation zone. SRM and HBV are the most widely used models for snowmelt runoff modelling.The greatest similarity between the two models is that each uses a temperature index method to predict melt rate whereas the greatest difference lies in the way snow cover is handled. Glaciers has a major contribution in hydrological regime so in order to resolve the issues related to glacier fed rivers, it is necessary to have the detail understanding of the hydrology and ecology of the snow and ice phenomenon.

In many regions of the world river runoff occurring in spring and summer originates from snowmelt in mountainous regions. Thus the hydropower production during spring and Summer depends to a great extent on the quantity of snow which fell in the mountains during winter and early spring. If therefore the quantity of snow and its water equivalent is known early during the year it is possible to make forecasts of the expected runoff in the following months. If the reservoirs feeding the hydropower plants are large enough, it is possible to optimize hydropower production by scheduling the releases from the reservoirs to the power plants accordingly (Schultz, 1993).

The extent of snow cover, which represents the stored amount of water and the state of the snow are both important for river flow forecasting. This information is necessary for water power generation, irrigation, domestic water supply, flood control and planning by water management generally. If a multiple purpose reservoir is to maintain a specified storage capacity to leave room for flood control, and at the same time keep a minimum water volume stored in order to improve the low flows, its successful operation depends on short-term and seasonal forecasts of inflow.

In general, snowmelt models can be divided into two types of models, namely energy balance models and index models. Energy balance models require information on radiant energy, sensible and latent heat, energy transferred through the rainfall over the snow and heat conduction from ground to the snowpack. Index models use one or more variables in an empirical expression to estimate snow cover exchange. Air temperature is the most commonly used index.

***Inventory of Glaciers, Glacial Mass Balance and Glacial Retreat***

Retreat of glaciers is the cause of great concern for the perennially fed Himalayan river system. The Ganges, the Brahmaputra and the Indus rivers rely on the glacier resources like snow and ice from the Himalayas. Remote sensing images provide ample information on the status of the glaciers and dynamic changes over time. The glaciers lakes are easily identifiable on multi spectral satellite data and their spatial extent can also be measured with reasonable accuracy. Satellite data of medium resolution (24-30 m) and fine resolution (6 m) is found suitable to map these frozen entities. Fig. 3.4 shows Snow and Glacier studies over Uttarakhand. Fig. 3.5 shows Comparison of SCA estimated from different sensor data.

***Wetlands Mapping***

Reflective and thermal infrared images are extensively used to map and monitor these bodies.

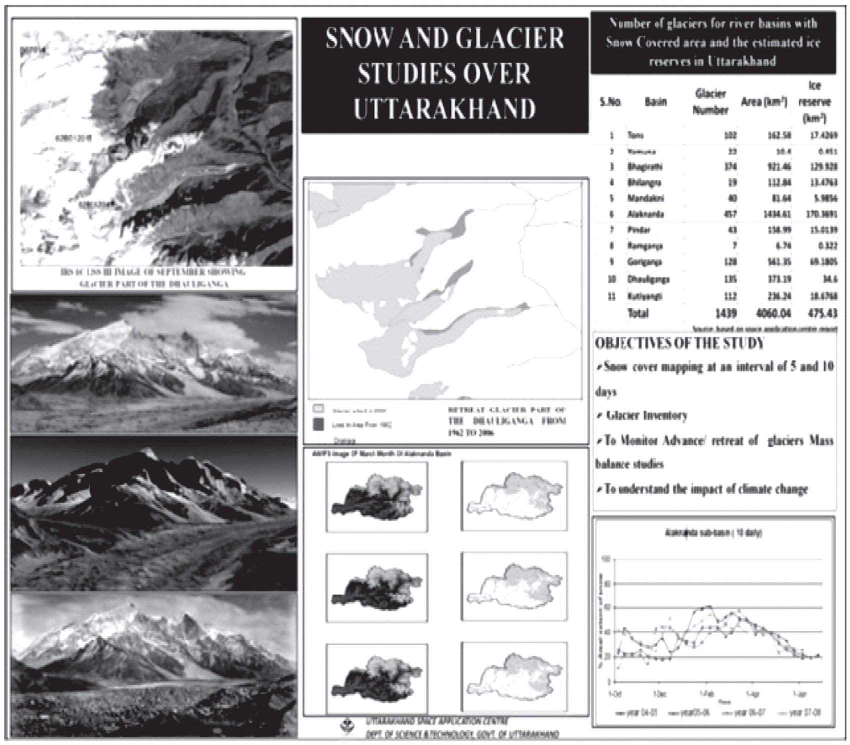


Fig. 3.4: Snow and Glacier Studies over Uttarakhand

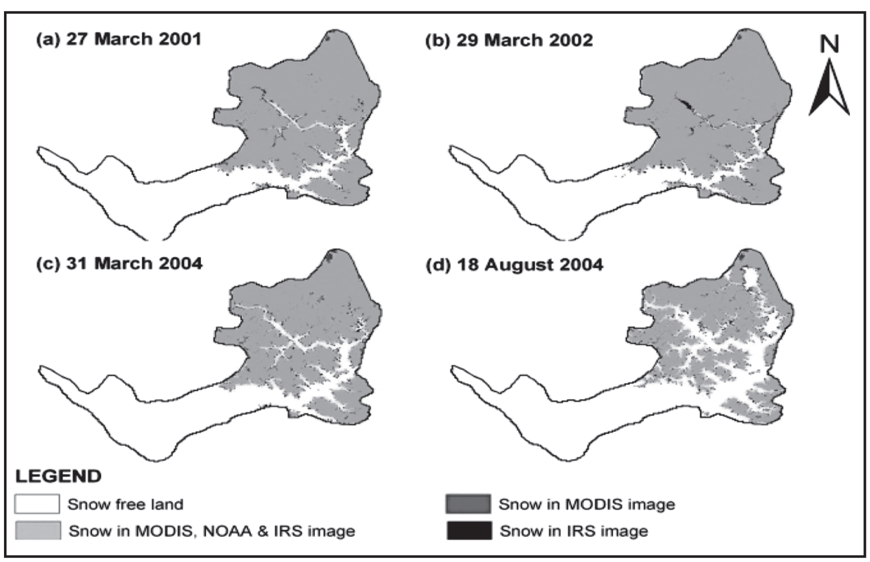


Fig. 3.5: Comparison of SCA Estimated from Different Sensor Data

### *Snow Avalanches*

Snow and avalanche study establishment used satellite data for avalanche hazard zonation in parts of Jammu & Kashmir, Uttarakhand and Himachal Pradesh. Fig. 3.6 shows Glacier Features in Satellite Image (Thornthwaite *et.al*, 1957).

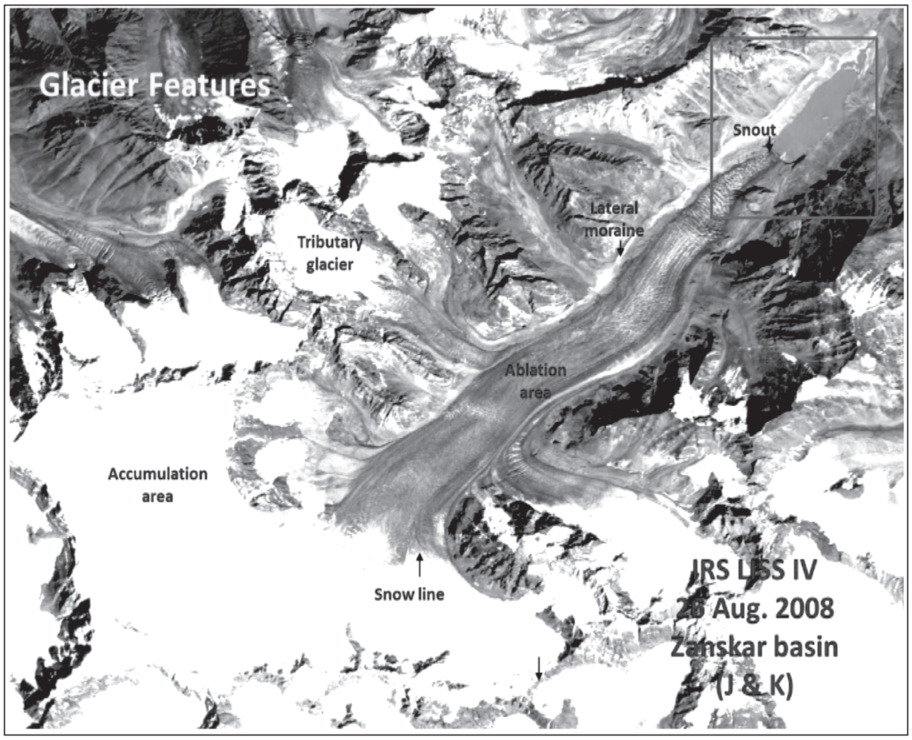


Fig. 3.6: Glacier Features in Satellite Image

### *Runoff and Hydrological Modeling*

The status of water availability, particularly spatial and temporal pattern at the basin level is essential for regional planning and decision making on water management. Runoff is an indication of water availability. Since conventional technique does not prove to be reliable everywhere, hence rainfall-runoff models are commonly used for computing runoff.

Basic components of rainfall run off modelling are:

- Precipitation-(Point, spatial extension)
- Runoff components(evapotranspiration, accumulation in depressions, infiltration, percolation)
- Channel flow
- Runoff concentration

Though remote sensing technique cannot be directly measure the quantity or volume of water flowing through a hydrological basin, river yet there are areas where Remote sensing can be used in hydrologic and run off modelling:

- Data used as an input such as Land use/land cover classes, soil moisture; and
- Determining watershed geometry, drainage network and other map-type information for annual runoff or low flow equations.

Remote sensing can provide quantitative information of suitable spatial resolution to be extremely valuable for model inputs. For example, stereo pair Cartosat-1, LIDAR data, SAR interferometric, ALTM can be used to generate the Digital Elevation Model (DEM) with the h accuracy of horizontal and vertical resolution in centimetres.

Many applications of remote sensing data in hydrologic models were developed to quantify surface runoff. The GIS allows for combining other spatial forms of data such as topography, soils maps s hydrologic variables such as rainfall distributions or soil moisture (Kouwen *et al*., 1993). The Soil and Water Assessment Tool (SWAT) (Arnold and Fohrer, 2005) has proven to be an effective tool for assessing water resource and non-point source pollution problems for a wide range of scales and environmental conditions.

Zade *et al*., (2005) estimated runoff for all major basins of India using satellite data using Soil conservation service (SCS) approach.

Chormanski *et al*., (2008) examined the impact of different methods for estimating impervious surface cover on the prediction of peak discharges, as determined by a fully distributed rainfall-runoff model (WetSpa).

**SCS Method**

The run off curve number method for the estimation of direct runoff from storm rainfall is well established in hydrologic engineering and environmental impact analyses. This model is developed by the United States Department of Agriculture (USDA) Soil Conservation Society (SCS) known as curve number (CN) is popular among all rainfall-run off models because of its simple mathematical relationships and low data requirement. The CN represents the watershed coefficient, which is the combined hydrological effect of soil, land use, agricultural land treatment class, hydrological condition and antecedent soil moisture condition (AMC). Generally, the model is well suited for small watersheds of less than 4000ha, as it requires details of soil physical properties; land use, conservation treatment and vegetation condition. The CN method is based on the assumption of proportionality between retention and runoff. The mathematical relation for runoff is given by:

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)}$$

Q is the actual runoff, P is the Precipitation, $I_a$ the initial abstraction which includes interception, surface storage and infiltration into soil and S id the potential retention.

Since $I_a$ = 0.2, S (based on the analysis performed by SCS for the development of the rainfall-runoff relation for average condition, i.e. AMC II), AMC is determined by the sum of the last five consecutive days' rainfall.

### *Water Balance Studies*

Human interventions impacts on hydrologic cycle could be determined by water balance study. SCS curve number model, Thornthawaite and Mather model, Green Amptmodel, Soil Moisture Accounting Model etc. are very popular models for computing runoff. All these models take the information derived from the Remote sensing data.

Shrestha *et al*, (1999) have used Landsat TM satellite data to identify uniform land cover areas and GOES data for input insolation for a monthly water balance model.

## Reservoir Management

### *Reservoir Sedimentation*

Reservoirs lose their storage capacity due to sedimentation. The analysis of sedimentation data of Indian reservoirs show that the annual siltation rate has been generally 1.5 to 3 times more than the designed rate and the reservoirs are generally losing capacity at the rate of 0.30 to 0.92 % annually. The consequence of loss in storage due to sedimentation is precluding the intended usages such as flood protection/moderation, irrigation, hydro-power generation etc. Sedimentation in reservoirs occurs not only in dead storage but also in live storage region simultaneously, which reduces the useful storage and affects the water utilization pattern of the project. Fig. 3.7 is showing the process ofsedimentation in reservoir.

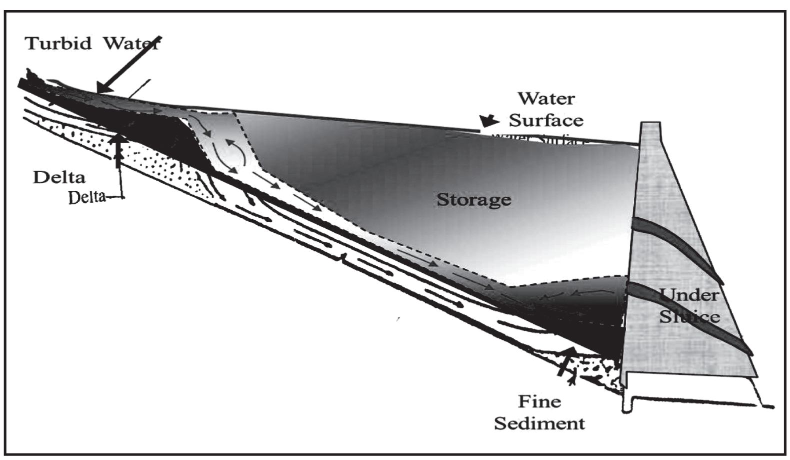


Fig. 3.7: Reservoir Sedimentation

Capturing the water spread at various reservoir operating levels would help in estimating the current reservoir storage and a comparison with previous or original storages would provide the loss in storage due to sedimentation. In this context, satellite remote sensing plays a very useful role due to its synoptic and repetitive coverage. Multi-spectral satellite data facilitates distinction between water bodies and the surrounding land use/land cover. The water spread boundary captured by the satellite data provides water spread contour at that particular reservoir water level. Multi-temporal satellite data have been used as an aid to capacity survey of many reservoirs in a cost and time effective manner.

***Catchment Area Treatment***

The catchment's behaviour and its resource capability especially in regions of soil erosion is one of the major threats to water resources storage and management. The catchment behaviour is mainly affected by vegetation cover, topographic features, climatic variables and soil characteristics. Assessing the soil erosion rate is essential for the development of adequate erosion prevention measures for sustainable management of land and water resources. While soil erosion models only calculate the amount of soil erosion based on the relationships between various erosion factors, RS and GIS integrated erosion prediction models do not only estimate soil loss but also provide the spatial distributions of the erosion. Especially, generating accurate erosion risk maps in GIS environment is very important to locate the areas with high erosion risks and to develop adequate catchment area treatment plans and strategies. Some the models integrating with RS and GIs are Revised Universal Soil Loss Equation (RUSLE) and Coordination of Information on the Environment (CORINE). Gupta *et al*., 2012 depicted that Remote Sensing (RS) and Geographic Information System (GIS)-based soil erosion risk assessment models continue to play an important role for soil conservation planning. Gupta *et al*., (2013) says that Sediment Yield Index (SYI), used for the mapping and quantification of potential soil erosion, provided a comparative erodibilty criteria of watersheds (low, moderate, high etc.) and do not provide the absolute sediment yield. Using medium to high resolution satellite imagery, image classification techniques have been used to generate accurate and reliable land use/land cover data and spatial inputs for erosion modeling.

***Watershed Management***

For sustainable integrated management of the Land and water resources, watershed, a natural hydrologic unit is considered to be the most appropriate basis. Watershed characterization involves measurement of related parameters, such as geological, hydrogeological, geomorphological, hydrological, LULC, soil etc. Remote sensing using aerial and space borne sensors can be effectively used for watershed characterization and assessing watershed priority, evaluating problems, potentials, management requirements and periodic monitoring. Watershed development requires delineation, characterization, prioritization, generation of development plans, monitoring their implementation and impact assessment. An essential component for preparation of watershed development plans is the database of natural resources (Boulet et.al, 2000). Generation of database by conventional means is quite tedious and time consuming, hence the satellite data based generation namely soil, geomorphology, geology, LULC, slope is preferred because it is highly efficient. Fig. 3.8 is showing watershed which is delineated by DEM.

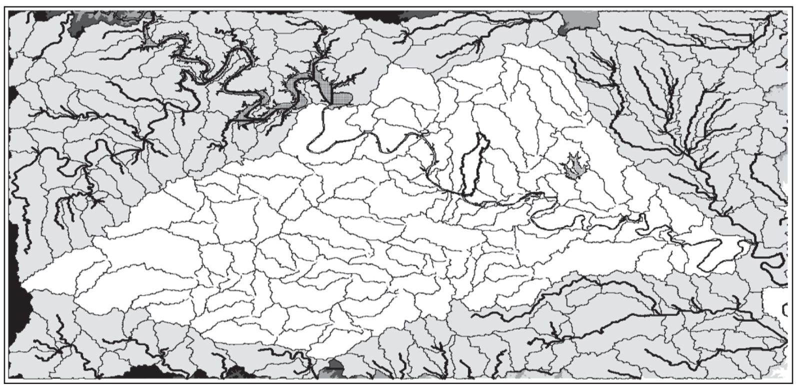

Fig. 3.8: Watershed from DEM

***River Engineering***

River migration and river control works form the major elements in the flood plain management. Satellite data provides accurate delineation of river configuration and the status of flood/river control works.

Most of the flood prone rivers in India change their course frequently after every flood wave attacking strategic locations at different times. Hence, it is necessary to understand the behaviour of the river and its latest configuration so as to plan the flood control measures effectively and additionally, monitoring the existing flood control structures from time to time to avoid breaches in view of the frequent changes in river configuration. Since the flood prone rivers are subjected to erosion, eating away the fertile land so in order to provide bank protection, vulnerable areas subjected to bank erosion along the rivers have to be monitored. In this regard latest and temporal information is required. Further, flood hazard zonation maps at large scale are eventually required for planning non-structural measures. In this regard, collecting the data using conventional technique is quite complex and require extensive efforts hence satellite remote sensing provides an excellent source of information. Remote sensing data couple with Geographic Information System (GIS) tool proves to be capable pf over coming some of the critical limitations that are being faced.

Hydrologic Engineering Center's River Analysis System (HEC RAS) is a common hydraulic model used to study flow depths and total energy loss along a study reach of a river system. HEC-RAS is a 1-D model that performs calculations for steady or unsteady flow in gradually-varied or rapidly-varied flow analysis. Even though HEC-RAS is a 1-D hydraulic model, it is commonly used to model flow patterns where the velocity along the y- or z-coordinate axes issignificant (Gupta *et al*., 2014). Fig. 3.9 showing graph of Cross Section through HEC-RAS Model of Kedarnath Valley, Uttarakhand.

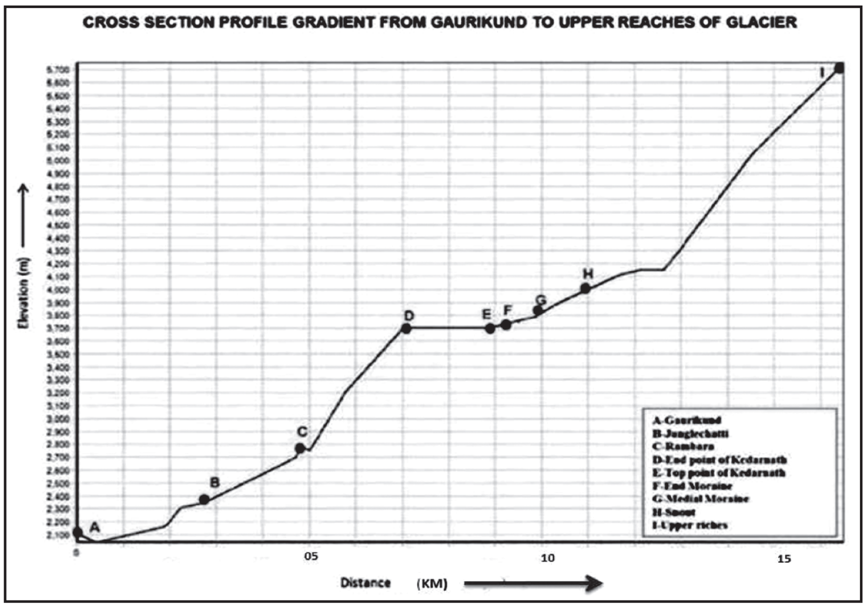

Fig. 3.9: Cross Section through HEC-RAS Model

***Urban Flood Management***

Flooding in urban areas is an inevitable problem for many cities, particularly in cities which are old and have developed according to varying historical needs and visions. One of the typical features of urban flooding is shortening the runoff travel time and making it flash event. The primary causes of urban flooding are:

- Extensive concrete surfaces leading to significant proportions of surface runoff with very little *in situ* percolation.
- Inadequate channelization of natural waterways.
- Surcharge due to blockage of drains and street inlets.

Since urban settlements are undergoing continuous development, data on flow rates, physical and topographical settings require more periodic assessment and monitoring to cope up with storm water flooding.

**Table 3.4: Water Quality parameter Vs Spectral region**

| Water Pollution/Quality Parameter | Spectral Region |
|---|---|
| Total Suspended Solids | Visible spectral region of EMR |
| Temperature | Thermal infrared and passive microwave |
| Agriculture runoff | B & W and colour infrared photography |
| Eutrophication | Colour Infrared |
| Water depth | Blue/Green regions of visible Spectrum, Aerial/Laser profile |

### *Water Quality*

Visible and infrared (reflected) regions of EMR are useful for detecting indicators of water quality. Table 3.4 depicts Water Quality parameter Vs Spectral region Thermal infrared is also used for measuring water quality but it uses a direct measure of emitted energy.

## REFERENCES

Arnold JG and Fohrer N, 2005. SWAT 2000: Current Capabilities and Research Opportunities in Applied Watershed Modeling, Hydrological Processes, 19: 563-572.

Boulet, G., Chehbouni, A., Braud, I., Vauclin, M., Haverkamp, R. and Zammit, C, 2000. A Simple Water and Energy Balance Model Designed for Spatialisation and Remote Sensing Data Utilization. Agric. For. Met. (SALSA Special Issue) 105: 117-132.

Chormanski J, Van de Voorde T, Roeck T D, Batelaan O and Canters F, 2008. Improving Distributed Runoff Prediction in Urbanized Catchments with RS based Estimates of Impervious Surface Cover, Sensors, 8: 910-932.

Gupta, P. Goyal, S. Rawat, M.S. 2014. "Space Based Disaster Management and Slope Profile Generation Using Hec-Ras Model of Himalayan Terrain" Proc. International Society of Photogrammetry and Remote Sensing, TC VIII Mid-Term Symposium, 9-12 Dec. Hyderabad.

Gupta, Peeyush and Uniyal, S. 2012. A Case Study of Ramgad Watershed, Nainital for Soil Erosion Risk Assessment Using CORINE Methodology. International Journal of Engineering Research & Technology (IJERT).1(10): 1-7.

Gupta, Peeyush and Uniyal, S. 2013. Prioritization based on Morphometric Analysis of Bhilnagana Watershed using Spatial Technology. International Journal of Remote Sensing & Geosciences (IJRSG). 2(1): 49-52.

Gupta, Peeyush and Uniyal, S.2013. Watershed Prioritization of Himalayan Terrain, using SYI Model. International Journal of Advancement in Remote Sensing, GIS and Geography (IJARSGG). 1(1): 42-48.

Gupta, Peeyush. Uniyal S. and Goyal S. 2014. Climatic Variability and its Ecological Impacts Using Space Technology. International Journal of Geology, Earth and Environmental (IJGEE). 4 (3): 194-202.

Kouwen N, Soulis ED, Pietroniro A, Donald J and Harrington RA, 1993. Grouped Response Units for Distributed Hydrologic Modelling. Journal of Water Resources Planning and Management, ASCE, 119(3). 289-305.

Rango, A. and Ritchie, J.C. (eds), 1996. Remote Sensing Applications to Hydrology. Special Issue. Journal of Hydrological Science, 41(4): 429-431.

Shrestha, AB; Wake, CP; Mayewski, PA; Dibb JE, 1999. Maximum Temperature Trends in the Himalaya and its Vicinity: An Analysis based on Temperature Records from Nepal for the Period, 1971-94. Journal of Climate, 12: 2775-2787.

Schultz, G.A, 1993. Hydrological Modeling based on Remote Sensing Information. Advances in Space Research. 13(5): 149-166.

Thornthwaite, C.W. & Mather, R.J. 1957. Instructions and Tables for Computing Potential Evapotranspiration and Water Balance. Publication No. 10, Laboratory of Climatology, Centerton, New Jersey, USA.

Zade M, Ray SS, Dutta S and Panigrahy S, 2005. Analysis of Runoff Pattern for all Major Basins of India Derived Using Remote Sensing Data, Current Science, 88(8): 1301-1305.