Module 6 – (L22 – L26): “Use of Modern Techniques in Watershed Management”

Applications of Geographical Information System and Remote Sensing in Watershed Management, Role of Decision Support System in Watershed Management

WATERSHED MANAGEMENT

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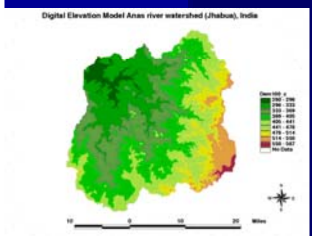
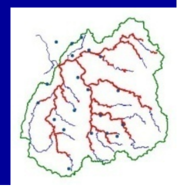
Lecture No - 22

GIS & Applications in Watershed Management

L22– GIS & Applications in Watershed Management

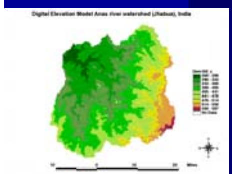
- **Topics Covered**
- Geographical Information System, GIS implementation, GIS Spatial data model, Advantages of GIS, GIS dimensionality, Applications in Watershed Management.
- Keywords: Geographical Information System, Spatial data model, Dimensionality, ArcGIS.

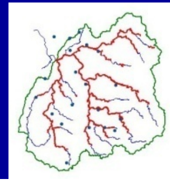




Geographic Information System (GIS)

- **Geographic Information System (GIS)** is a Computer based decision making tool to plan, implement and govern the objects in space.
- GIS accept large volumes of spatial data derived from different sources, retrieve, manipulate, analyze & display according to user-defined specifications.
- Components of GIS: Data input; Data output; Storage and management; Manipulation and analysis
- **Data Handling**
- Raster or grid-based data
- Vector data – uses points & coordinates (points, lines & areas)
- Digital Elevation Models (DEM)
- Triangular Irregular Networks (TIN)





Geographic Information System (GIS)..

- **GIS** transforms data into information on spatial locations of entities that occupy space in natural & built Environment.
- **Spatial Data**
- 80% of all information held in databases anywhere in the world contains some kind of geographic element. Information that has:

  1) A location (spatial data); 2) Values (attribute data).
- Additional information includes – 1) Connectivity; 2) Contiguity.
- Any entity that has location and can be shown on map. E.g. Maps of state of India.
- Conventional Data: Attributes of the Spatial entity. E.g. State wise per capita income.
- **Results Interpretation**

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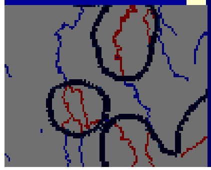
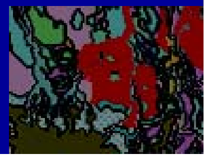
- Analysis presented in form of map
- Visualization- supplemented by spatial & aspatial queries of model results





Geographic Information System (GIS)..

- Application of GIS :- GIS is capable to capture, store, manipulate, analyze & visualize diverse set of spatial data.
- Spatial perspective is very useful in the establishment of linkage between various types of process i.e. hydrological process, soil erosion, vegetation cover , human activities etc., and also interaction between them.

- **Various GIS packages**
- ArcInfo, ArcView (ESRI); AutoCAD Map (Autodesk Inc.); GRASS (Baylor Uni., Texas); IDRISI (Clark Labs); ILWIS (Int. Inst. For Aero. Survey & Earth Sciences, Netherlands); MapInfo (Mapinfo Cor.); MFworks (Think Space Inc.); GeoMedia (Intergraph Cor.); Microstation (Bentley Systems Inc); PAMAP (PCI Geomatics); SPANS (Tydac Inc.); GRAM++ (IIT Bombay) etc.

Representing Surfaces and sub-surfaces

- DEMs, TINs and contours available for surface representation
- Cross section shown by fencing, stacked surfaces and true 3D volumes beyond the scope
- Wire-frame models capable of displaying geologic cross sections and borehole geophysical data
- Selection of particular spatial data source
- Data structure, file format, quantization and error propagation
- GIS offers efficient algorithms for dealing with most of data
- Surface Generation
- Spatial Resolution and Information content
- Drainage networks and resolution
- Spatially variable precipitation

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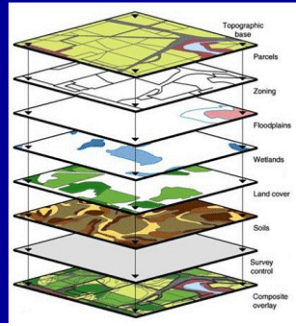


GIS Implementation Stages

Major stages of GIS Implementation:

- 1. GIS awareness – what is possible with GIS?; Projects to be used?.
- 2. Defining needs – Feasibility studies, Functional requirement study; Budget; Proposal
- 3. GIS selection – suitable – specific needs; market survey - purchase
- 4. GIS implementation – Installation; Training, database design/ development, case study/ Implementation
- 5. Man power development
- 6. Field applications – for specific studies
- 7. Operation & Maintenance.

Advantages of GIS applications

- Interactive visualization/ analysis
- Planning and management
- Spatial data management and access
- Environmental risk assessment
- Multi-dimensional planning
- Customs applications development for decision support
- Web accessible spatial information

GIS for Watershed Management

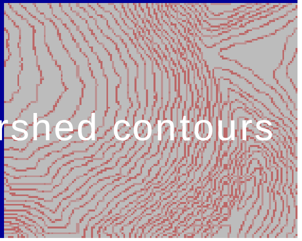
- Vital components of watershed management:
  - ✓ Soil and land resource data for planning at micro level.
  - ✓ Creation of a Multi-temporal database for natural resources
  - ✓ People's participation
  - ✓ Awareness for farmers, policy makers , users, soil conservationist & scientists.
- People's participation at micro-level
- Technological integration:
  - ✓ GIS along with conventional database
  - ✓ Hydrological and socio economic analysis
  - ✓ Technological adoption and conventional practices

GIS for Watershed Management

- **Basic Steps in Typical GIS application for watershed**
  - ✓ Acquisition of DEM data from satellite image/toposheet.
  - ✓ Conduct DEM processing to derive stream, catchment and drainage point features.
  - ✓ Populate data with required attributes.
  - ✓ Use network analysis and archydro tools to derive desired matrices.
- GIS have become an **integral part of Hydrology**
- **GIS Maps**: topography, land use and cover, soils, rainfall and meteorological variables

GIS – Data Sources & Structures

- **Variety of data sources and structure for a single hydrological parameter**
- For example **topography** can be represented by a series of point elevations, contour lines, Triangular Irregular Network (TIN), elevations in a gridded or rectangular coordinated systems
- **Rainfall** – Time series at a point, array of rainfall rates derived from radar, gridded array of rainfall rates, isohyetal contours
- **Infiltration rates –** Soil maps
- **Evapotranspiration rates or hydraulic roughness:** Raster array of remotely sensed surrogate measures



Watershed contours

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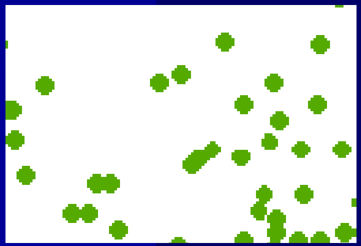
GIS Spatial Data Model

- Spatial data are referred to as **layers**, **coverages**, or **layers**
- **Vector** data represent features as discrete points, lines, and polygons

Examples:

- ArcInfo Coverages
- ArcGIS Shape Files (Point, Line, Polygon)
- CAD (AutoCAD DXF & DWG, or MicroStation DGN files)
- ASCII coordinate data



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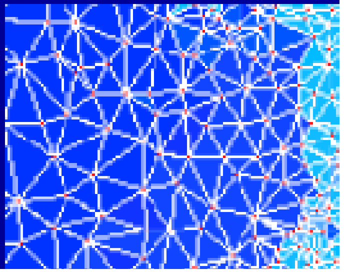
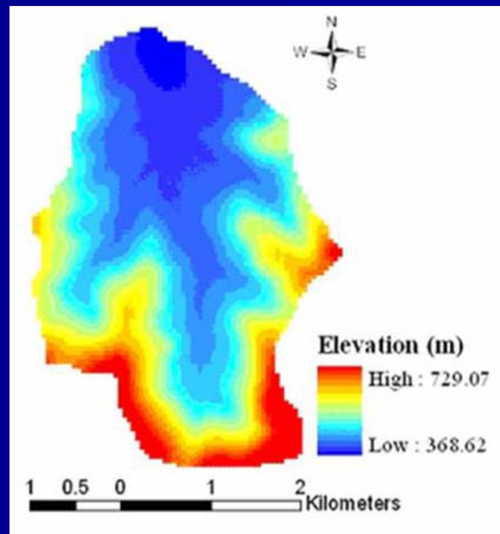


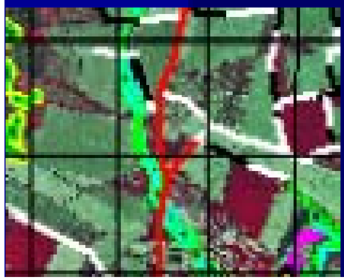
GIS Spatial Data Model

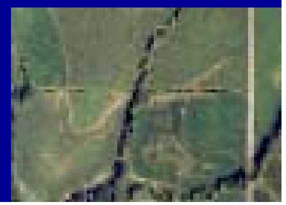
- **Raster** data represent the landscape as a rectangular matrix of square cells

Examples:

- ArcInfo Grids
- Images
- Digital Elevation Models (DEMs)
- Generic raster datasets



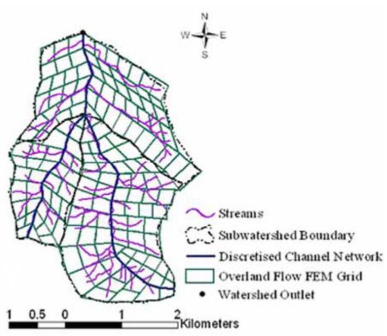


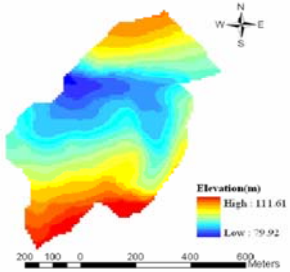


GIS - Dimensionality

- Does not follow precise Euclidean notions of 1,2 and 3-Dimensional data
- Ex: Generally stream net work composed of vectors in 2D but here nodes and various points along the stream may be represented by 1-D point data
- Complexity of data representations offers many possibilities for analyzing hydrological data
- Distance along the stream is different from simply specifying x,y-point
- Point data: measured quantities are often represented at a single point in 2D space

  Ex: Rain gauge Station





Map Scale and Spatial Details

- Map of topography can be shown at any scale in GIS
- Resolution of DEM may be altered by resampling to a coarser or finer resolution
- Hydrologist must be decide what scale will best represent the impact of topography on the hydrological processes
- Selection of Datum
- Geographic Coordination System
- Map Projection System
- DEM: An ordered array of numbers representing the spatial distribution of elevations above some arbitrary datum in a landscape
- Consist of elevations sampled at discrete points
- DEM – Subset of DTM
- DTM: Spatial distribution of terrain attributes like slope, soil depth, soil drainability, soil fertility
- Choice of particular method of representation of surface depends on end use

Application of GIS for Watershed Management

GIS has been exploited by the hydrology and watershed management community in different ways:

- ✓ Watershed delineation
- ✓ Watershed Characterization and Assessment
- ✓ Management Planning
- ✓ Watershed Restoration (Analysis of Alternative Management Strategies)
- ✓ Watershed Policy Analysis and Decision Support

Watershed Delineation Using GIS

- The major steps involved in delineating a watershed are:
  - Geo-registering the scanned topo sheets
  - Creating shape files
  - Contour digitization
  - Preparation of DEM
  - Filling of DEM
  - Flow Direction Raster generation
  - Flow Accumulation Raster
  - Determining Pour Points
  - Watershed Delineation

Watershed Characterization & Assessment

- GIS has been widely used in characterization and assessment studies which require a watershed-based approach.
- Basic physical characteristics of a watershed such as the drainage network and flow paths can be derived from readily available Digital Elevation Models (DEMs).
- This, in conjunction with precipitation and other water quality monitoring data, enhances development of a watershed action plan and identification of existing and potential pollution problems in the watershed .
- Data gathered from GPS surveys and from environmental remote sensing systems can be fused within a GIS for a successful characterization and assessment of watershed functions and conditions.

WM - Management Planning

- Information obtained from characterization and assessment studies - in the form of charts and maps can be combined with other data sets to improve understanding of the complex relationships between natural and human systems.
- GIS provides a common framework – spatial location – for watershed management data obtained from various sources.
- GIS can be a powerful tool for understanding these processes and for managing potential impacts of human activities.
- Modelling & visualization capabilities of modern GIS, coupled with Internet & World Wide Web, offer new tools to understand the processes & dynamics that shape the physical, biological and chemical environment of watersheds.
- Linkage between GIS, Internet, & environmental databases is especially helpful in planning studies where information exchange and feedback on a timely basis is very crucial.

Watershed Restoration (Analysis of Alternative Management Strategies)

- Watershed restoration studies generally involve evaluation of various alternatives.
- GIS has been used for restoration studies ranging from relatively small rural watersheds to heavily urbanized landscapes.
- Coupled with hydrodynamic and spatially explicit hydrologic/water quality modelling, GIS can assist in unified source water assessment programs including the total maximum daily load (TMDL) program.
- GIS can also provide a platform for collaboration among researchers, watershed stakeholders, and policy makers.
- Integrating capabilities of GIS provide an interface to translate & emulate complexities of a real world system within confines of digital world accurately & efficiently.

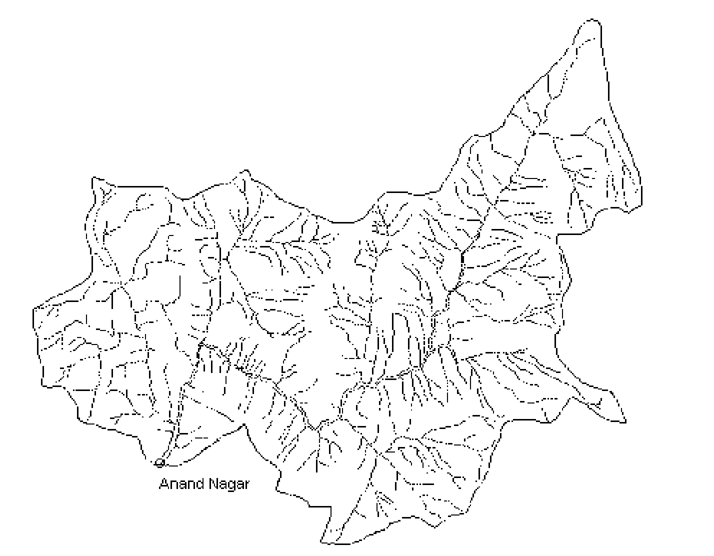
Case Study: Amba Watershed

- Study Area
- Lies in the Khalapur taluka near Khopoli in Western Ghats of Raigad district in Maharashtra
- East Longitudes 73°15' and 73º25'; North Latitudes 18º40' and 18º 50'
- Topographical maps number 47F/5 and 47 F/6
- Part of the catchment Numbered as 5B2A6 by Watershed Atlas of India

Case study: Data

- Survey of India toposheet number 47 F/5 and 47 F/6 of scale 1:50000 with contour interval of 20m.
- Hourly rainfall data measured at Tukasai meteorological station situated at Anand nagar adjacent to Amba River.
- IRS-1D LISS-III MSS digital data for the watershed acquired on 13th November 2001.
- Pixel size as 23.50m; Window size is kept as 360 lines by 405 pixels.

Drainage map



Case study: Methodology

- Thematic maps are compiled from the source data products like Survey of India topo sheets, IRS-ID LISSIII MSS digital data.
- The thematic maps were digitized and rasterized in the GIS environment and these raster data is registered with the other thematic information.
- SCS-CN method is applied to estimate the rainfall excess of each pixel at various time intervals.
- Time of concentration of all the pixels based on the actual flow length is calculated to estimate the hydrograph at the outlet of the watershed.

Methodology..

- Algorithm to find rainfall excess per pixel
- Input: Rainfall (mm),CN based on Soil Type, Landuse class and AMC-III, Initial Abstraction.
- For every pixel, the themes considered for the runoff estimation are land use, HSG (Hydrological Soil Group) and AMC-III.
- Base flow of 2cu.m/sec (CWC Report, 1992)
- Output: Runoff volume for each pixel (ASCII file)

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

$$CN = \frac{25400}{254 + S}$$

Q= runoff (mm)

P= rainfall (mm)

S=potential maximum retention

I_a= Initial abstractions

CN= Curve Number

Algorithm to find actual flow length and time of concentration

Input: DEM ASCII file (Elevation of each pixel)

Process: 3X3 grid, Minimum among the 8 adjacent cells.

Flow length=23.50m (Hori. And Vert. direction)

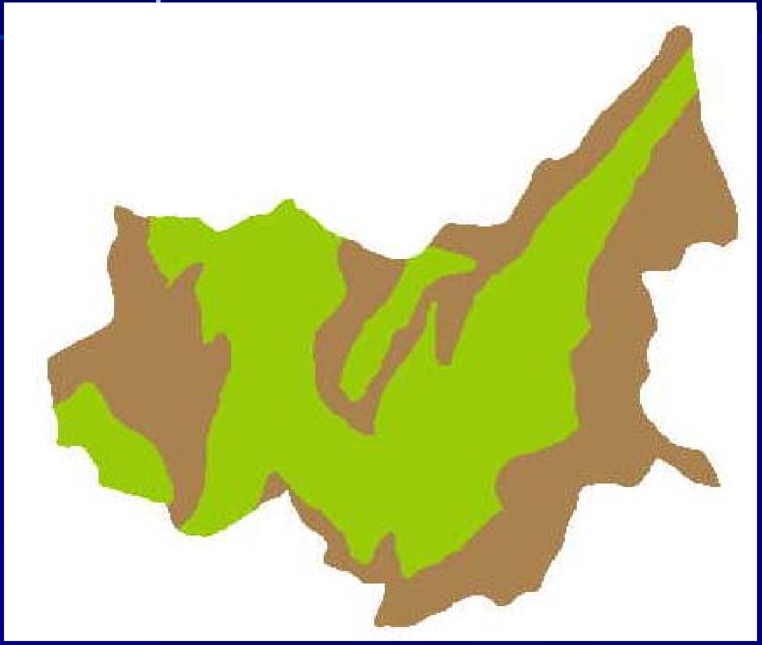
Flow length=1.414*23.50m (Diagonal Direction)

Removal of pits.

Minimum distance from the pixel of lowest elevation.

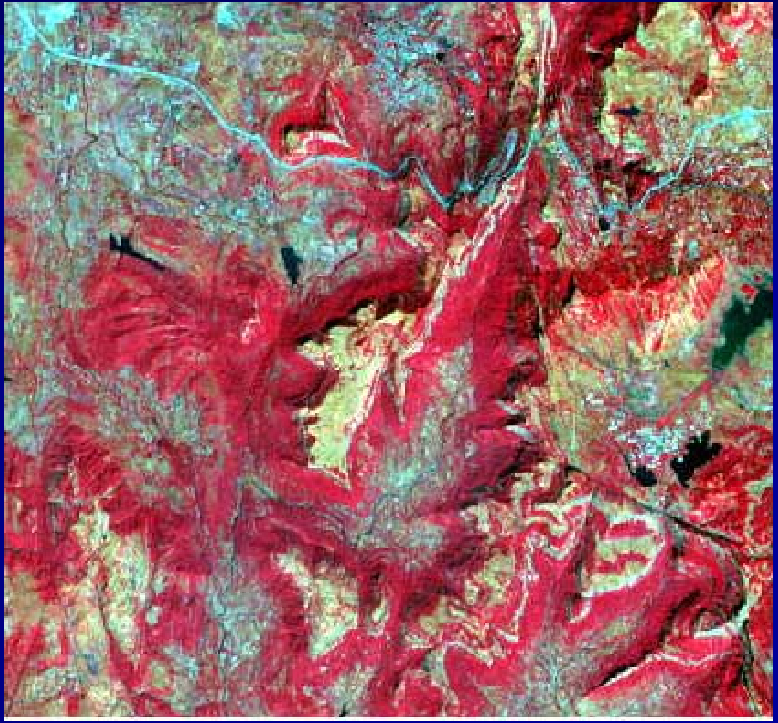
Output: Lag time based on hydraulic length, slope and surface retention, time of concentration by Lag Method.

Case study: Results



Hydrologic Soil Groups

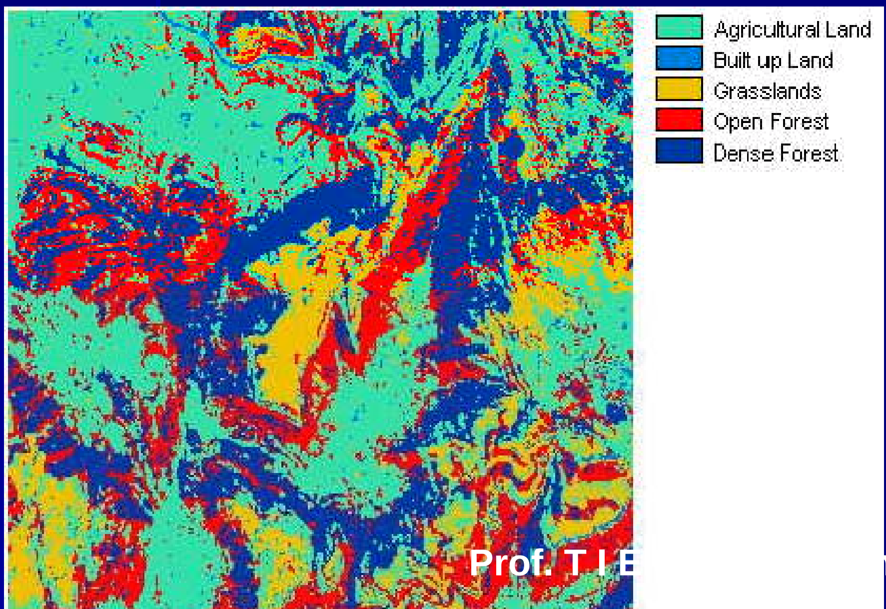
of Amba Watershed

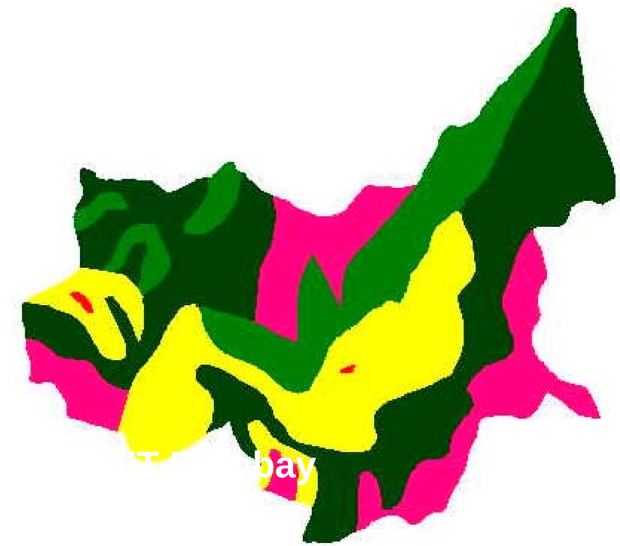


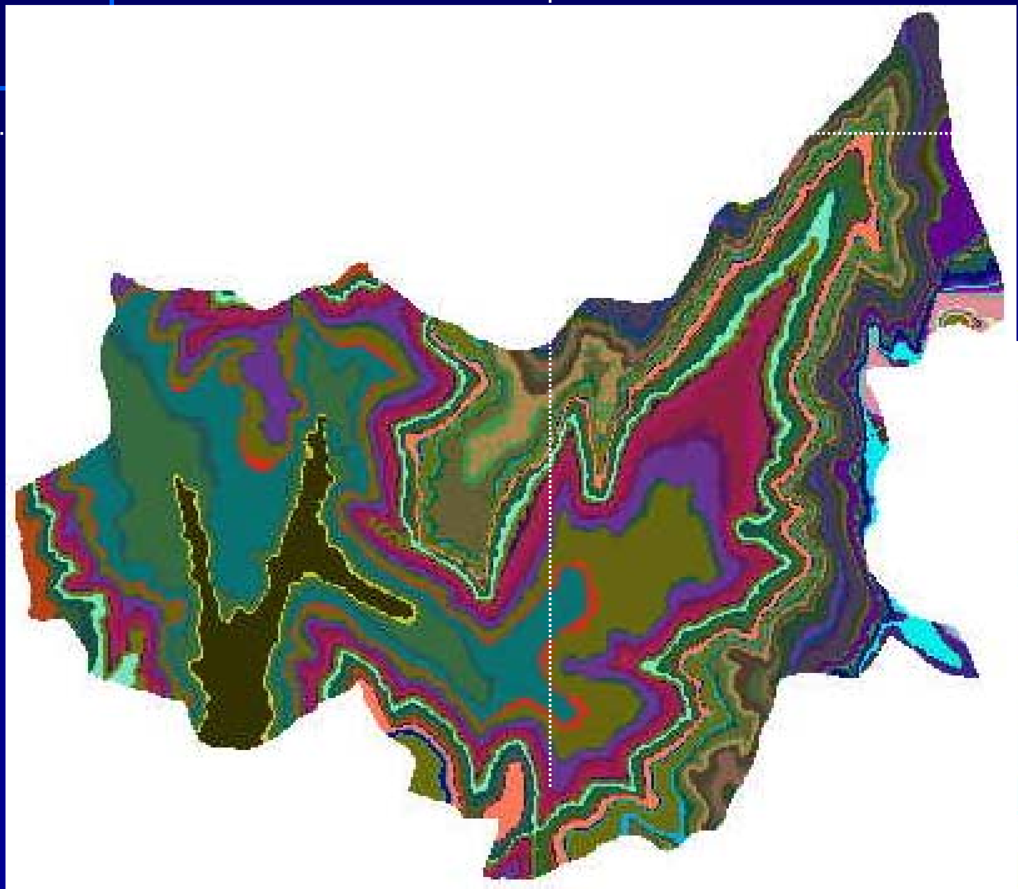
Standard FCC of Amba Watershed

- Digital analysis of the IRS-ID LISS-III band 2, band 3 and band 4.
- Classes identified are agricultural land, built up land, grassland, open forest and dense forest.

Land use Map of Amba Watershed







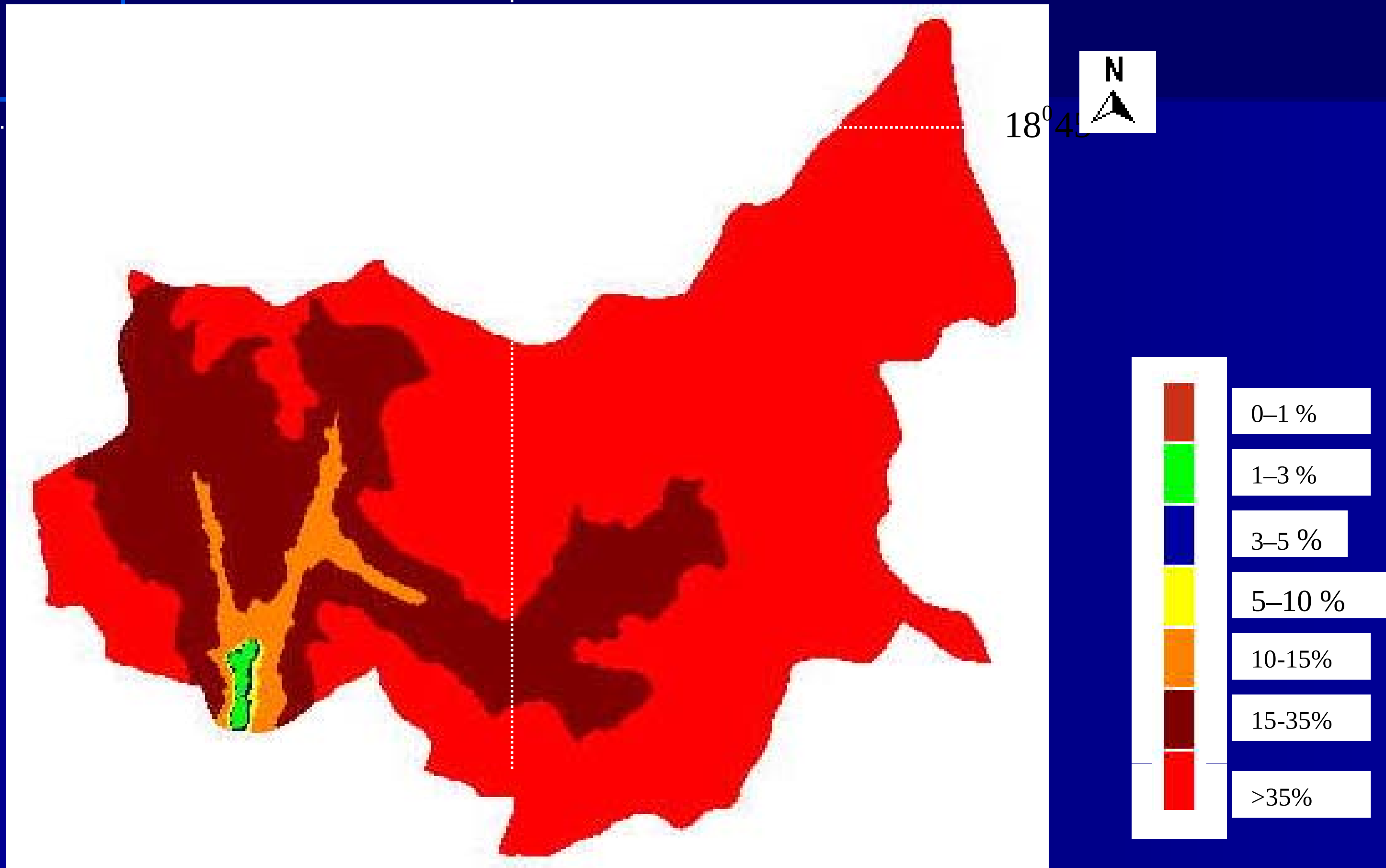
N

18°45'

Elevation values in meters

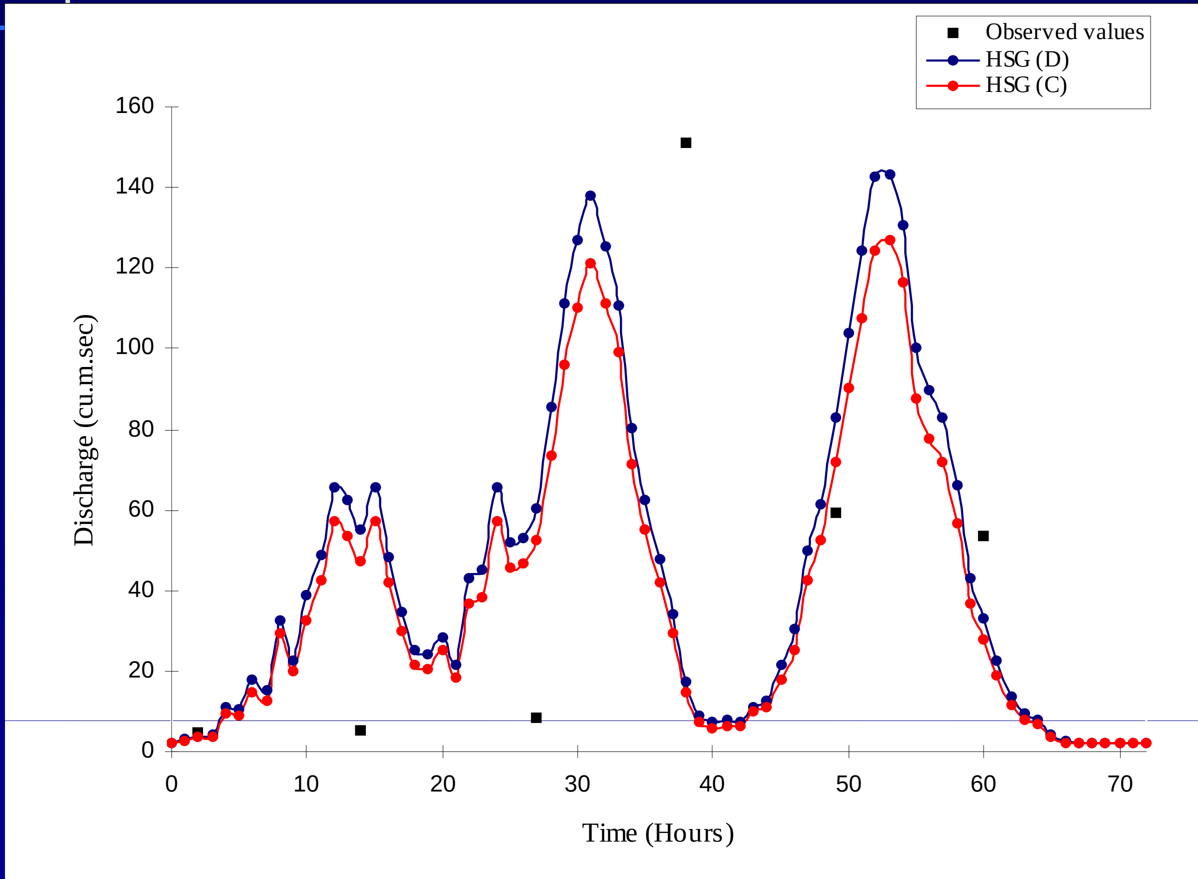
52.6316	210.526	368.421	526.316	684.211
63.1579	221.053	378.947	536.842	694.737
73.6842	231.579	389.474	547.368	705.263
84.2105	242.105	400.	557.895	715.789
94.7368	252.632	410.526	568.421	726.316
105.263	263.158	421.053	578.947	736.842
115.789	273.684	431.579	589.474	747.368
126.316	284.211	442.105	600.	757.895
136.842	294.737	452.632	610.526	768.421
147.368	305.263	463.158	621.053	778.947
157.895	315.789	473.684	631.579	789.474
168.421	326.316	484.211	642.105	800.
178.947	336.842	494.737	652.632	
189.474	347.368	505.263	663.158	
200.	357.895	515.789	673.684	

Digital Elevation Model (DEM)



Slope Map of Amba Watershed

Simulation of Storm- with HSG (D)



Runoff hydrographs for storm

Infiltration rate of 0.35mm/hr

Runoff volume

42.85%

References

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- Leipnik, Mark R., Karen K. Kemp, and Hugo A. Loaiciga, Implementation Of GIS For Water Resources Planning And Management, *Journal of Water Resources Planning and Management,* Vol. 119, No.2, 1993.
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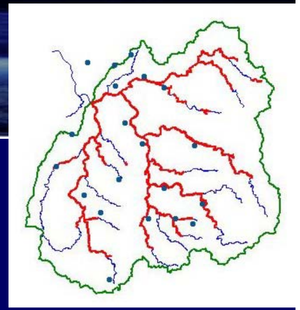
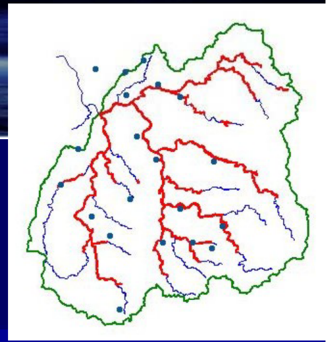


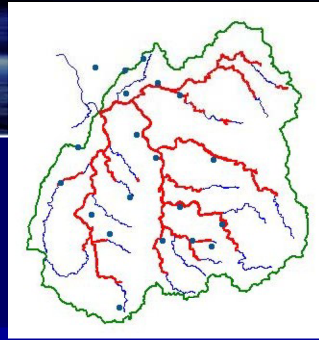
Tutorials - Question!.?.

- Critically study various GIS packages available for watershed based studies.
- Evaluate the capabilities of each package.
- Explore how effectively the GIS packages can be used for development of watershed management plans.



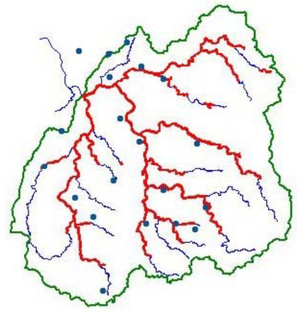
Self Evaluation - Questions!.

- Illustrate the working of GIS with details of various components.
- Discuss the various stages of GIS implementations.
- Describe basic steps in typical GIS applications for watershed management.
- Illustrate GIS based spatial data modeling.



Assignment- Questions?.

- How we represent surfaces & sub-surfaces in GIS?.
- What are the advantages of GIS applications for various problems?.
- Illustrate GIS data sources & data structures.
- Describe GIS dimensionality issues.
- Describe various applications of GIS in water management.



Unsolved Problem!.

- Using ArcGIS tools, develop GIS database for your watershed area.
- Based on Topo sheet and other available data, generate DEM, LU/LC map, slope map, soil map etc.
- Explore how effectively GIS can be used for watershed management plans.

THANK YOU

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