TRAINING COURSE
ON

APPLICATIONS OF REMOTE SENSING AND GIS IN WATER RESOURCES MANAGEMENT

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LECTURE NOTE
ON

URBAN RUNOFF MODELLING USING REMOTE SENSING AND GIS

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URBAN RUNOFF MODELING USING REMOTE SENSING AND GIS

INTRODUCTION

Hydrology is the scientific study of water, its measurement on the surface of the Earth and its effects. Water and changes in the hydrologic cycle have important economic effects for water delivery and drainage to agriculture and urban areas and for flood control. It includes economic and social aspects as well as the hydrologic aspects, and is generally studied as water resources management. There are a number of areas in water resources that can benefit from remotely sensed data. For example, estimating runoff, flood damage and monitoring changes in lake and reservoir volumes can be studied using remotely sensed data. Delineation of floodplains, basin morphology, waterlogging and soil erosion are other applications of remote sensing. The temporal nature of satellite images make the information very useful for monitoring changes in a watershed.

The use of remote sensing images for water resources is basically for mapping, monitoring and management. The very low reflectance of water in the near-infrared region of the spectrum makes this waveband the obvious choice for identifying and measuring the surface water. GIS has been extensively used as a tool for integrating the information obtained from satellite images, field and other sources. This lecture will describe some aspects of urban runoff modeling using remote sensing and GIS.

URBANISATION AND ITS IMPACT

Urbanisation is defined as the process of modernization of villages and elimination of disparities, between such villages and the towns and cities where desired facilities, amenities and basic needs of life, such as houses to live in, power, water, hospitals, schools, transport, communication, recreation, roads and such other social infrastructure are made available and where there is a density of population of not less than 1000 per square mile and total population of not less than 5000 and where the most of the people adopt a non-agricultural way of life (Baji,1981). Urban growth have direct influence on the land system and which in turn influences the air and water system. The impact of urban growth on environment are shown in Table 1.

REMOTE SENSING AND GIS

Remote sensing images are not only used for monitoring of hydrological state variables but also as the basis for parameter estimation of hydrological models. Remote sensing, particularly from various satellites in various spectral bands, can provide information on catchment characteristics (e.g. landcover, landuse, slope, vegetation), from which the parameters of hydrological models can be gathered. Particularly in combination with other spatial information, such as digital elevation models, digital terrain models, soil maps, remote sensing will allow spatial estimation of hydrological model parameters, e.g. the maximum soil water storage capacity in a watershed. Remote sensing images can be acquired for remote areas, where no measurements are feasible or can be carried out only under very difficult circumstances which cause high costs. Furthermore, satellite remote sensing allows repetitive coverage of an area, which is highly relevant in the development of hydrological models requiring dynamic components.

Table 1: Various Impacts of Urbanisation

Environment	Degradation through careless planning and urban poverty
Air	Increase in sulfur oxides, hydrocarbons, carbon monoxide, photochemical oxidants, odors and nitrogen oxides
Water	Withdrawal of water, construction of hard stands, roads, roof tops etc. accelerates erosion.
Hydrology	Influenced by the spatial and temporal characteristics of the inputs exerted by the land surface, because of urbanisation.
Erosion	Changes in cross-sectional area of streams due to land clearing, road building etc.
Land	Increase in housing demand will have economic effects
Agriculture	Reduction in agricultural land creates the imbalance in food production
Deforestation	Increase in temperature, more runoff in the area etc.
Ecology	Increases the danger of fluctuations in populations of economically important species.
Noise	Affects the health of people
Education & Health	Absence of spatial management information system related to densities and infrastructure causes delays and wrong decision for planning.
Runoff	As the area covered by urbanisation approaches 100%, the amount of vegetation, natural surface and infiltration will all approach zero. Excessive run off will create the problem of water logging and flooding. Runoff will also affect the stream water quality.

A GIS is an information system that is designed to work with the data referenced by spatial on geographic coordinates. It is both a database system with specific capabilities for spatially referenced data. as well as set of operations for working with data. GIS consists of chain of operations that helps us from planning the observation and collection of data to storage and. analysis of data, to the use of the derived information in some decision making process. GIS has played an extremely important role in watershed management, environment monitoring, land use and planning activities.

Development of an accurate and up-to-date watershed database is the first and an important stage of a hydrological study. Information on hydro-meteorological variables and watershed characteristics are stored as thematic geo-registered layers. Typically, these data layers include raw data such as digital elevation data, multi-spectral satellite imagery, soils map, watershed boundary etc. The database may also includes derived data layers such as terrain slope and aspect, up slope area, land cover classification, soil erodibility, evapotranspiration etc.

Information derived from remote sensing images can be used in conjunction with other ancillary data (e.g., soils, elevation, slope, aspect, depth-to-ground-water) in a GIS. Therefore, the ideal integrated system performs both digital image processing and GIS spatial modelling. The GIS analytical capabilities are based on 'map algebra' logic that can easily perform linear combinations of GIS operations to model the desired process. There are many areas in water resources management and development where remote sensing images in GIS environment play an important role.

Multi-spectral satellite image data are processed to generate thematic maps. IRS and SPOT stereoscopic data are suitable for digital topographic, thematic map production at scales of 50,000 and better. Elevation contours from topographic maps can also be used to generate DEM which can produce slope map. Elevation and slope maps are essentially required in any water resources management study. DEM can be superimposed on other thematic information to view the watershed in 3D.

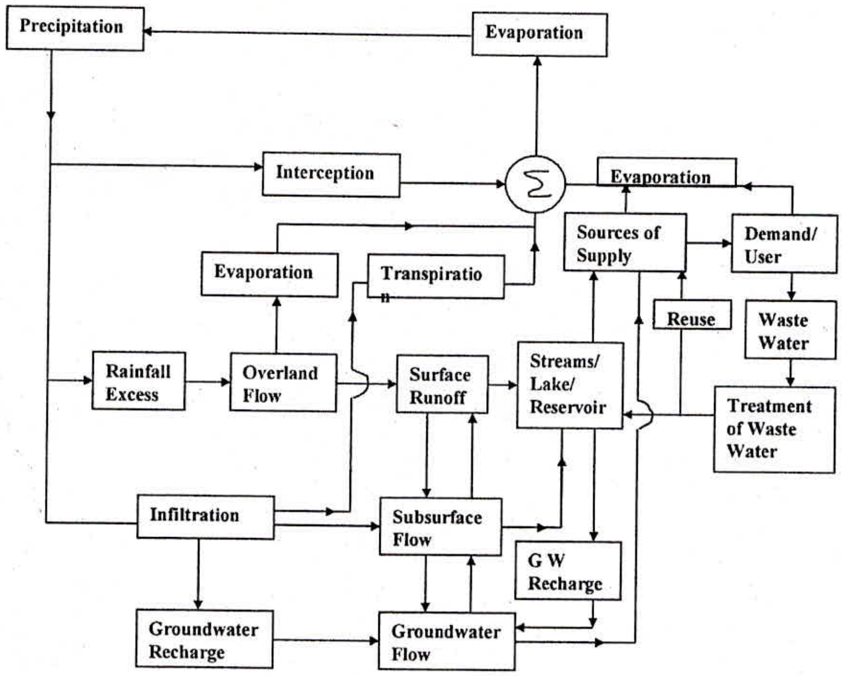
URBAN RUNOFF MODELLING

In the early days GIS were mainly used as hydrological mapping tools. Nowadays, they play a more important role in hydrological model studies. Their applications span a wide range from sophisticated analyses and modelling of spatial data to simple inventories and management tools, and can be found in many fields, such as land planning, natural resource management, environmental assessment and planning, ecological research etc. Distributed rainfall runoff modelling requires a large number of parameters to describe local topography, soil type, land use, and can be substantially facilitated by the use of GIS. The application of GIS has enhanced the capacity of models in data management, parameter estimation and presentation of model results, but GIS can not replace hydrological models in solving hydrological problems.

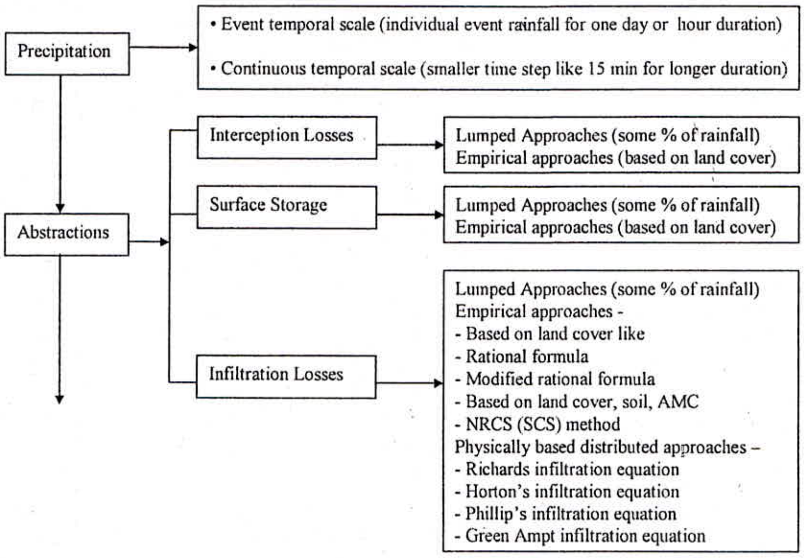
Due to its data handling and manipulation capabilities, GIS is increasingly being used as an interface and data manager for hydrologic models. There are four levels of linkage of hydrological model with GIS. These levels vary from essentially considering GIS and the model as separate systems to fully integrating the model and GIS. The lowest level of integration consists of using GIS as an aid in developing the input data file for the model. A user then takes the preliminary files and modifies them to produce a complete input file in the format required by the model. A similar procedure in the opposite direction can be applied to the outputs of the model in order to present and store them in GIS. This approach enables one to use an existing GIS and an existing model without modification to either but requires the most of user's effort. The next level of integration is to use an interfacing program specifically written to communicate between the GIS and the model. The interface program may serve as a control program issuing commands to the GIS and the model. Output from the GIS is converted into the proper input format for the model and then read by the model. Output from the model may likewise be converted to a GIS format and then displayed by the GIS. All these operations are carried out under the control of the interface program. A third level of integration occurs when the interface program is incorporated into the model. This requires modification to the input/output routines of existing models or developing special input/output routines for new models. Some programming may also have to be done within the GIS to alter its input/output structure to make it more compatible with that of the model. If one is making extensive changes to a model or developing a new model, this level of integration would be appropriate. The highest level of integration occurs when the model and GIS are essentially a single, integrated unit. One way of achieving this is by programming the model using the programming language appropriate to the GIS being employed. This makes GIS a master module, which controls the model runs.

In case of rainfall runoff modelling, various models such as SCS model, TOPMODEL, HEC model and GIUH based model can be applied in GIS environment. Also for soil erosion modelling various models such as USLE, WEPP, ANSWERS, AGNPS and SWAT models have been applied using GIS.

URBAN HYDROLOGY



RAINFALL-RUNOFF PROCESSES



Various Approaches Used for the Estimation of Different Processes Involved in Rainfall Runoff Process

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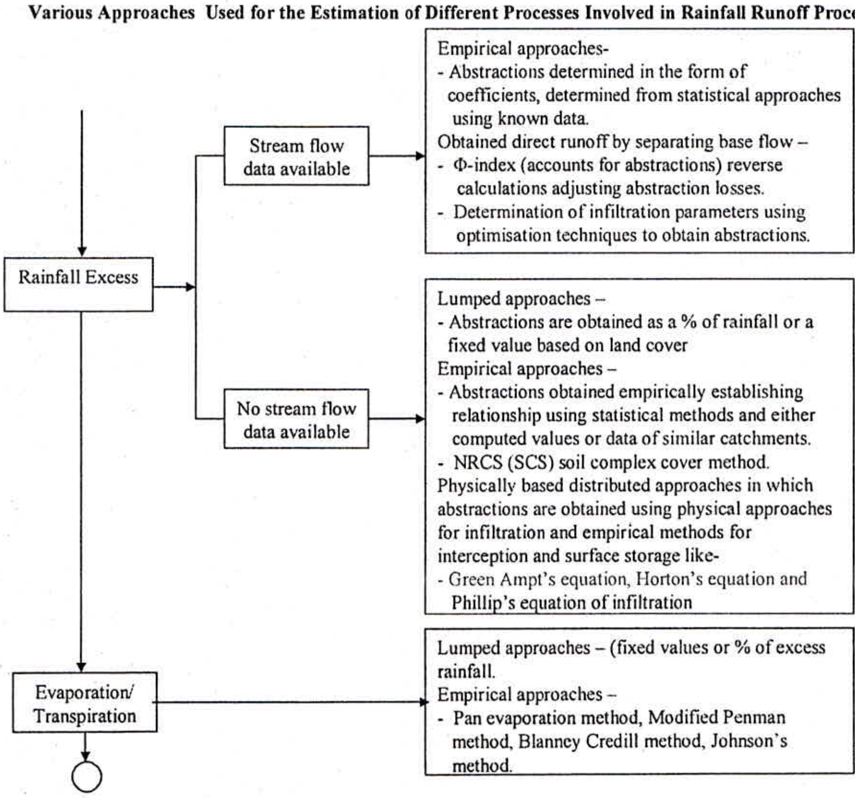
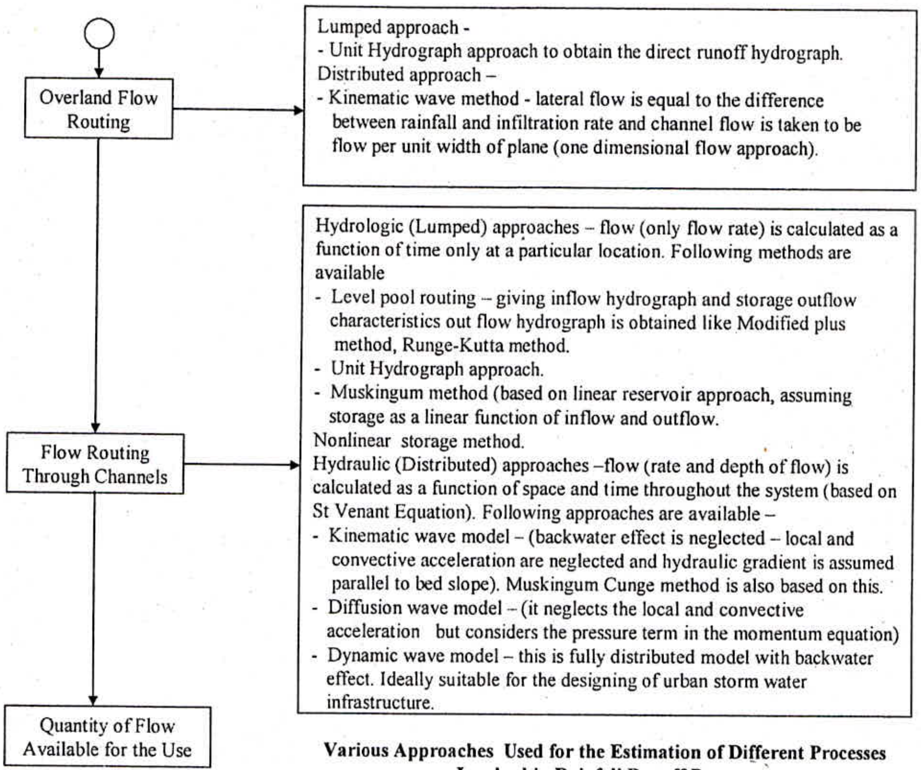


RAINFALL-RUNOFF PROCESSES



Various Approaches Used for the Estimation of Different Processes Involved in Rainfall Runoff Process

ASSESSMENT OF URBAN RUNOFF

FOR PLANNING & MANAGEMNT OF WATER RESOURCES

- It requires, estimation of volume of runoff not peak runoff alone
- It requires forecasting of runoff available in near future
- We require simple methods at this stage, which are physically sound and less data intensive
- Urban dynamics should be considered while forecasting the runoff, which in turn requires establishment of relationship between demographic and land use/ cover characteristics of an urban area.

FOR DESIGN OF STORM WATER INFRASTUCTURE

- It Requires Very Accurate Quantitative Assessment of Urban Runoff
- It Requires Estimation of Runoff as a Function of Space and Time
- So We Require Physically Based Distributed Models
- Such Models are Data Intensive, Requires Lot of Data for The Model Calibration and Validation
- Detailed Data are Not Available in Sufficient for the Indian Conditions, Even We don't have Infrastructure to Collect Such Data in Urban Areas.

FOR OPERATION OF THE URBAN DRAINAGE SYSTEM

- It Requires Real Time Estimation of Runoff
- It Should be Capable in Simulating Effect of Different Regulatory Components of Storm Water System Like, Treatment Plants, Detention Ponds etc.
- So We Require Physically Based Distributed Models
- Such Models are Again Data Intensive, Which are not Available for the Indian Conditions

AVILABLE URBAN STORM MODELS & PACKAGES

classification of models

Type of Model	Model Characteristics
Simple Model	• Simple representation of the urban watershed • Produces long term averages (e.g. annual runoff/ peak flow). • Uses empirical and statistical methods such as coefficient and rational methods. • No flow routing. • Includes SWMM - Level I; NRCS (SCS) soil-complex-cover method etc.
Simple Routing Models	• Routes flows through a rudimentary model of the drainage network, or accounts for delaying effect of routing. • Typically used to produce hydrographs over several years at a limited number of locations. • Uses statistical and deterministic approaches, principally bases on unit hydrograph methods. • Includes STORM model, HSPF model, WASSP model, WALLRUS model
Complex Routing Models	• Routes flows through an extensive model of the drainage network. • Can perform continuous simulation of hydrologic catchment system. • Typically used to produce hydrographs over the short term (e.g. hours/days) at a few or many locations for flood analysis. • Uses deterministic methods to describe processes. • Includes SWMM model, QQS model, KINEROS etc.

RAINFALL-RUNOFF MODELLING FOR URBAN AREAS

present status in Indian context

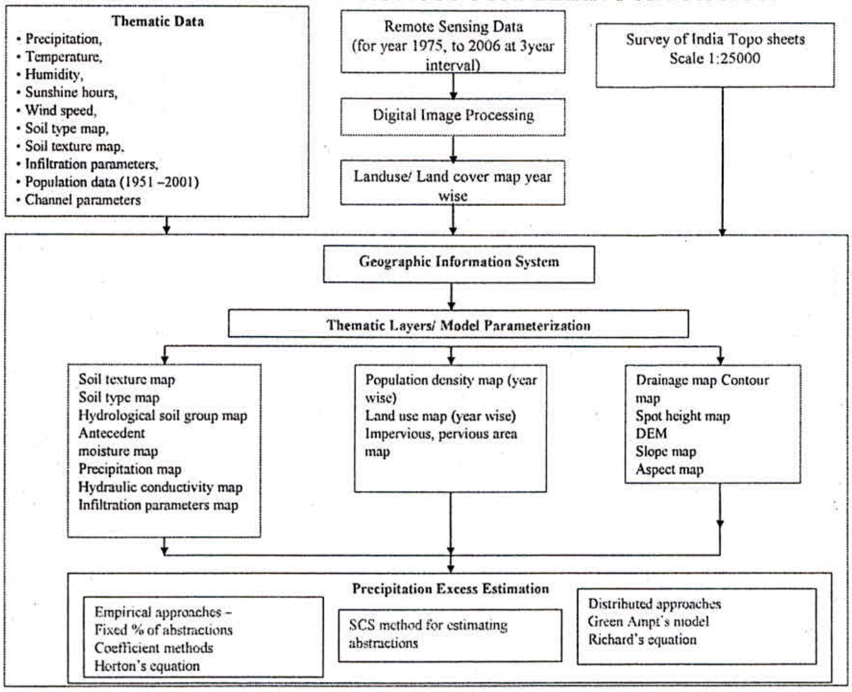
- No measured runoff data are available to calibrate the existing foreign models.
- No calibrated models are available for the Indian conditions.
- In most of the cases only *Rational formula* or Modified *Rational Formulas* and has been used in the India for the estimation of peak floods for the urban storm infrastructure design.
- In some cases SCS/ TR-55 (now NRCS) models are used to estimate the runoff but not calibrated.
- No model is available to estimate the urban runoff volume for the planning and management of water resources.

RAINFALL-RUNOFF MODELLING FOR PLANNING LEVEL STUDIES

some issues

- **For the planning and management of water resources, we can use the simple methods, which are physically sound.**
- **Various modelling options available for the estimation of runoff in absence of the observed runoff data are,** ***but these are not calibrated for Indian conditions.***
  - SCS curve method
  - Empirical approaches like-
  - Rational formulae
  - Simple method
  - SWMM-Level 1 method
  - Wallingford procedure
- **Distributed routing models are essential for the storm water infrastructure design.**
- **Accurate estimation of land use / cover information is very necessary for the estimation of urban runoff, which is dynamic in nature.**
- **For water management planning studies we need to forecast the available runoff in the near future along with other hydrological parameters and water demands, which in turn required relationship between runoff, population and land use.**
- **These relationships can be obtained using RS & GIS and statistical techniques.**

PROPOSED RAINFALL-RUNOFF MODELLING APPROACH



FUTURE PERSPECTIVE

Remotely sensed data provide an extremely valuable source of information for many water resource management and monitoring tasks. Remote sensing is more immediately applicable to hydrology and water resources, as compared to other areas. This is primarily because the analysis procedures have been quite well developed and the images are available frequently at a relatively large scale with good resolution which allow specific water resource problems to be monitored through various seasons and even from year to year. Such monitoring is highly cost effective, especially for large and inaccessible areas.

The use of remote sensing and GIS for water management includes the application of hydrological models, the parameters of which are based on remote sensing information. One of the main advantages of remote sensing images for water management lies, however, in the fact, that relevant data can be gathered over large areas with high resolution in time and space. Furthermore, this information containing large quantities of spatial and temporal data can be acquired in near real-time. It allows the use of high quality information in GIS for management decisions in real-time. This is of great value for decisions on e.g. releases from dams for water supply purposes, for irrigation scheduling, and for water quality control and improvement. The benefits of such data are invaluable for real-time flood management in river systems as well as in urban drainage systems.

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