REMOTE SENSING AND GIS APPLICATION IN RAINFALL RUNOFF STUDIES

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Runoff is one of the most important hydrologic variables used in most of the water resources applications. Reliable prediction of quantity and rate of runoff from land surface into streams and rivers are difficult and time consuming to obtain for ungauged watersheds. Conventional models for prediction of river discharge require considerable data for several hydro-meteorological parameters. Collection of these data is expensive, time consuming and a difficult process.

The Remote Sensing of natural resources and Geographical Information can be utilized to evolve a system for monitoring, assessment and management of natural resources for generation of data base for hydrologic modelling. Although very few remotely sensed data can be directly applied in hydrological modelling, such information is of great value since many hydrologically relevant data can be derived from remote sensing information. One of the greatest advantage of using remote sensing data for hydrological modeling and monitoring is its ability to generate information in spatial and temporal domain, which is very crucial for successful model analysis, prediction and validation. However, the use of remote sensing technology involves large amount of spatial data management and requires an efficient system to handle such data. The GIS technology provides suitable alternatives for efficient management of large and complex databases.

Geographic Information System (GIS) a technology to store, manipulate and display spatial and non-spatial data, has gained much attention in many areas that requires spatial description and manipulation of information. The GIS technology provides suitable alternatives for efficient management of large and complex data base. Spatial statistics and grid design capabilities of GIS can improve the modelling effort and aid in reliability assessment. The GIS data base for watershed modelling will include details on landuse, water use, soils, hydrological characteristics, drainage network and digital elevation model. These type of data related to catchment characteristics can be accurately and more easily handled in

GIS. Further these type of data being in digital form can be easily updated and modified. 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 tool. 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.

Geographic information systems link land cover data to topographic data and to other information concerning processes and properties related to geographic location. When applied to hydrologic systems, nontopographic information can include description of soils, land use, ground cover, ground water conditions, as well as man-made systems and their characteristics on or below the land surface. Description of topography is called terrain modeling, and because of the tendency of surface water to flow downhill, the hydrologic importance of terrain modeling is clear. While maps have been the most common historical form of representing topography, the advent of digital maps in GIS provides an alternate method of storing and retrieving this information. The amount of digital data required to accurately describe the topography of even small geographic regions make GIS a memory intensive and computationally intensive system. Even so, there is adequate GIS software available for mainframe, mini, and microcomputers.

1.0 GIS Data Types

Topographic Data

One of the capabilities of a GIS most important to hydrologic applications is the description of the topography of a region. Techniques used in the computer description of topography are called digital elevation models (DEM's). Some spatial information is not directly described by elevation, and can be described as topologic data. Topologic data define how the various pieces of the region are connected. Topology can be described as the spatial distribution of terrain attributes. DEM and GIS representations of topologic data are part of the general grouping of digital terrain models (DTM's). An example of hydrologic topology is the collection of lines describing a stream network. Another is the collection of points delineating subregions of a watershed. Both forms of information are related to topography, but may be defined in a topological sense based on the topographic portion of the GIS data base.

Topologic Data

While topographic data fit within the general classification of topologic data, there are significant hydrological attributes not related to land surface elevation. The more obvious of these are catchment areas, flow lengths, land slope, surface roughness, soil types, and land cover. These attributes help to describe the ability of a region to store and transmit water. Some topologic attributes are tied to the concept of a watershed unit. The most basic of these is the description of the watershed boundary. Given a drainage point, the topography alone can be used to define those areas that should drain to the point. Average slope and drainage path networks are related, topographically derived, topologic attributes. These attributes are useful in determining watershed attributes such as time of concentration, flow potential energies, and flow attenuation. The sorting and manipulation capabilities of a GIS are well suited to extracting such attributes.

2.0 GIS Data Handling Approaches

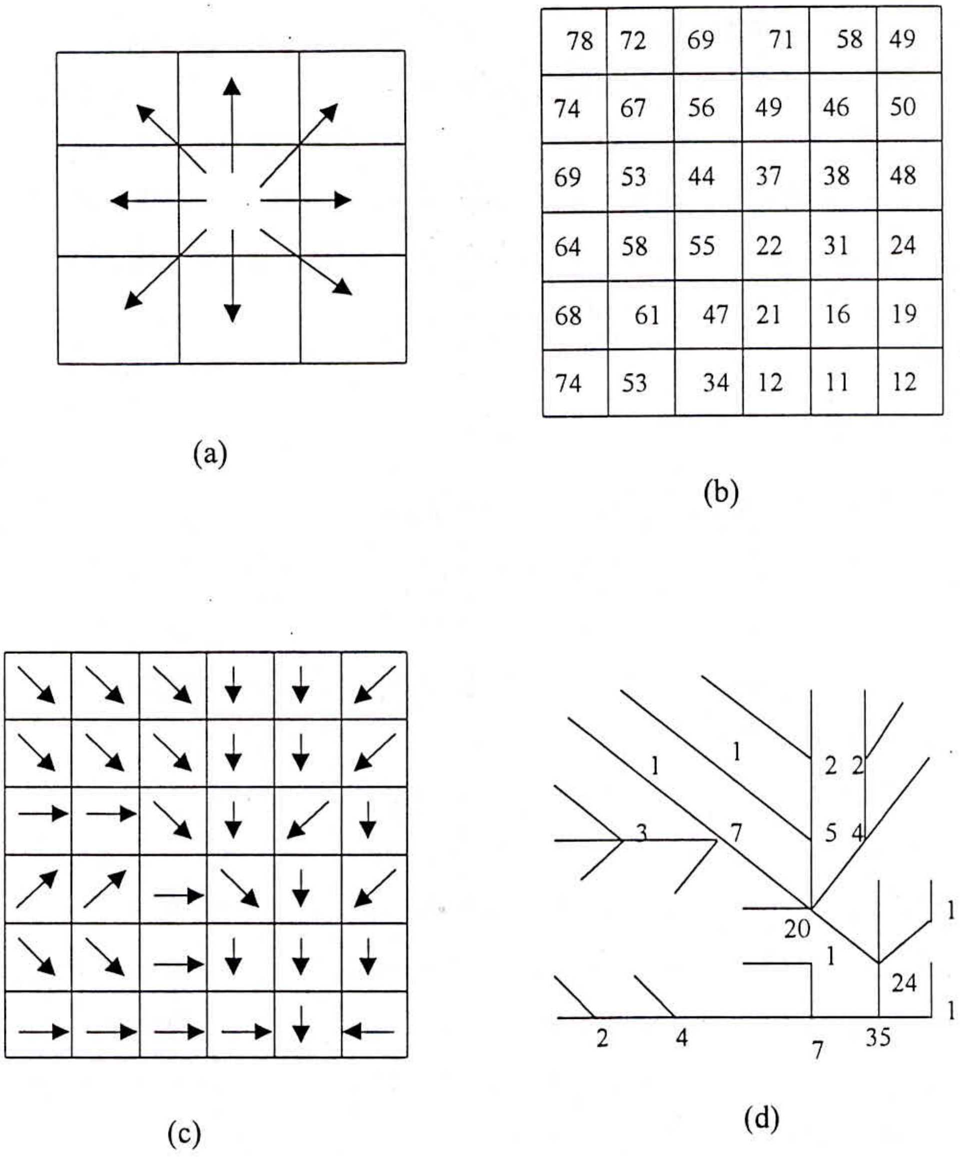
Raster or Grid-Based Data

The first applications of GIS in hydrologic modeling utilized grid cell or raster storage of information. The grid is made up of regularly spaced lines, and the enclosed area of each rectangle is described in terms of its center coordinates. It is important to note that there may be different grid scales for different attributes of the terrain, although following the scale of the available data is the obvious first choice. For attributes that are largely homogeneous, the use of the rigid resolution necessary for a DEM would require the storage of large amounts of redundant data. The reduction in data storage from the use of several grid scales comes at the cost of the complexity of translation between the scales to relate the data.

An inherent problem in hydrologic modeling with grid DEM data is the production of nonphysical depressions due to noise in the elevation data affecting interpolation schemes used to describe variation in elevation between raster points. The result is an unwanted termination of drainage paths in pits. The problem is particularly acute for relatively flat areas. The situation is complicated however by the existence of naturally pitted topography, sometimes called pothole regions. The methods are sufficiently flexible to allow accurate flow path delineation even with filling of real depressions.

Grid-based Flow Pattern

Most of the raster based GIS systems contain routines which determine the flow direction over land surface terrain using pour point model. Water on grid cell is permitted to flow to one of its eight neighboring cells. By taking a grid of terrain elevations, determine the slope of the line joining each cell with each of its neighboring cells, a grid of flow directions is created with one direction for each cell which represents the direction of steepest descent among the eight permitted choices. The concept of grid based flow pattern is represented in Figs. 1(a), 1(b), 1(c) and 1(d). The grid in figure 1(c) is shown as a set of arrows but infect is stored in GIS as a grid of numbers where each flow direction has a unique identifying number. By assigning water flow to one of its eight neighboring cells, equivalent one dimensional flow network is constructed by connecting the cell centers in the direction of flow as shown in Fig. 1(d). There is thus a duality between the grid and equivalent flow network and one might call the network so created a hybrid grid-network.



78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	16	19
74	53	34	12	11	12

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Fig. 1 Watershed terrain analysis using grid GIS method: (a) the eight direction pour point model; (b) a grid of terrain elevations; (c) the corresponding grid of flow directions; (d) the equivalent network showing flow accumulation.

3.0 Hydrologic Modeling Approaches in GIS Context

Prediction of surface runoff is one of the most useful hydrologic capabilities of a GIS system. The prediction may be used to assess or predict aspects of flooding, aid in reservoir operation, or be used to aid in the prediction of the transport of water-borne contaminants. The types of models that have been applied with a GIS will be classified as lumped parameter, physics based (implying full spatial distribution and modeling for runoff related attributes), or some combination of the two.

Lumped Parameter Models

The basic unit of a lumped parameter model is normally taken to be a sub-basin of the total watershed being considered. Each sub-basin is taken as a hydrologic response unit, so that all attributes must be averaged or consolidated into unit-level parameters. The distinction between lumped parameter and distributed models is not as clear as might be desired, because the sub-basin may be taken to be arbitrarily small. Furthermore, the point-by-point descriptions of processes such as infiltration, inter-flow, and overland flow are sometimes modeled as separately contributing processes in a sub-basin. In this way, processes in complex terrain are modeled physically as simple plane (or square bin) processes occurring separately from each other. The U.S. Army Corps of Engineers hydrologic model HEC-1 is an example of a model classified here as a lumped parameter model, but can effectively operate as a distributed model through small sub-basins and/or kinematic wave routing options. Several authors have cited GIS applications of HEC-1. SCS runoff curve number estimation from raster data describing land use and soil type also fall under this category.

Physics Based Models

The lumped parameter model use empirical approaches to describe the runoff phenomenon. In comparison, a physics-based model uses some form of balance equation defined at all points to model runoff flows. The most common approach is the application of the Saint-Venant equations of shallow water flow, which conserve water momentum and volume. When interflow is considered, Darcy's law of porous medium flow is used. When applied to a two-dimensional surface, these balance equations are second order partial differential equations in time and space which must be solved by approximation methods. The solution approach is generally dictated by the form in which the data is stored. For example, grid data lends itself to application of finite difference methods, while TIN data is better suited to finite element methods.

General Indices

In some cases complete rainfall/runoff response need not be described to provide the necessary hydrologic engineering information. General indices of the tendency to produce runoff may be sufficient. Decision making can be based on simple maps of terrain properties. It is in these applications that GIS methods can be most quickly and efficiently applied. Further, the map data produced can be saved for future use in actual rainfall runoff prediction if they are stored in a form appropriate to the model to be used. Two such indices are given below:

- Imperviousness
- Natural Land Cover

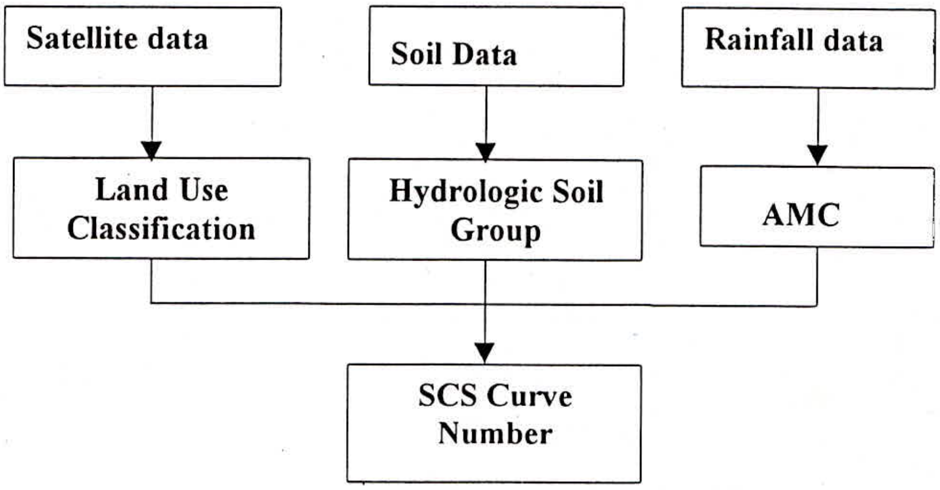
4.0 GIS and Hydrologic Modelling

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 sustantially 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. Currently the structure of soil erosion models and GIS systems are quite different preventing their complete integration. 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.

5.0 Rainfall-Runoff Studies (SCS Model)

The United States Soil Conservation Service, SCS runoff Curve Number model computes direct runoff through an empirical equation that requires rainfall and a basin coefficient as inputs. The basin coefficient, know as the runoff curve number (CN), represents the runoff potential of the land cover complex.


Satellite data
Soil Data
Rainfall data
Land Use Classification
Hydrologic Soil Group
AMC
SCS Curve Number