Soft computing tools for floodplain modelling

Cite as: AIP Conference Proceedings **1324**, 430 (2010); https://doi.org/10.1063/1.3526251
Published Online: 03 December 2010

D. P. Vijayalakshmi, and K. S. Jinesh Babu

Soft computing tools for floodplain modelling

D. P. Vijayalakshmi* **K. S. Jinesh Babu****

* Former Research Scholar, Civil Engineering Department, IIT Madras, Tamil Nadu, India

** Assistant Professor, Civil Engineering Department, Anna University of Technology - Tirunelveli, Tamil Nadu, India

*E-mail: er_dpviji@yahoo.co.in **Email : er_jinesh_babu@yahoo.co.in

Abstract -The most common reason for flooding could be overtopping of river or stream due to heavy downfall. A floodplain is the normally dry land area adjoining river or stream that is inundated during flood events and it carries flow in excess of the river or stream capacity. Flood frequency and flood water-surface elevations are the vital components for the flood hazard mapping. This paper focuses the soft computing methodology that incorporates advanced technologies for hydrologic and hydraulic analyses that are needed to be carried out to predict the flood water-surface elevations for any ungaged watershed.

I. INTRODUCTION

Flooding is considered as the world's most costly type of natural disaster in terms of both human causalities and property damage [7]. The extreme flood events could cause severe damage to property, agricultural productivity, industrial production, communication networks and infrastructure, especially in the downstream parts of catchments. The annual disaster record reveals that flood occurrence has increased about 10 folds during the last 45 years, from 20 events in the year 1960, to 190 events in the year 2005 [6]. As a result, extreme floods are posing a great concern and challenge to design engineers, reinsurance industries, policy makers and to the government.

With increase in settlement of population around floodplain areas, the flood-induced damages are continuously increasing. Activities like land clearing for urbanisation or agriculture, development of infrastructures such as highway and bridges in the floodplain are further aggravating the flood magnitude. The complete flood protection with provision of great flood control structures like flood dams are practically impossible due to its high cost. Also, the behaviour of flood due to flood mitigation project such as river widening and straightening should be thoroughly analysed as this kind of mitigation works may transfer the flood problem form upstream to the downstream part of the river. The literature review manifest that the best way to analyse the flood behaviour is generating the flood-prone or flood hazard map. These maps could show areas likely to be flooded, from readily available information. Flood hazard maps show the extent of inundation, determined from a study of flooding at the given location.

II. INDIAN SCENARIO

India is one of the worst flood-affected countries, being second in the world after Bangladesh and accounts for one fifth of global death count due to floods. About 40 million hectares is flood-prone, which is about 12% of the total geographical area (328 million ha) of the country [7]. The 1986 flood on the Godavari River, with a peak discharge of about 99,300 m^3/s [5], is the largest flood on record in the entire Indian subcontinent till date [4]. The flooding occurs typically during July – September due to the formation of heavy tropical storms, ever decreasing channel capacity due to encroachments on river beds, and sometime due to tidal backwater effects from the sea [3]. Thus, it is of prime importance to minimise the property damage, reduce infrastructure disturbances, and identify zones and building structures having greater flood hazard and flood risk.

Work has continued on mapping of the flood-prone areas in India. Several agencies, such as the Central Water Commission - CWC (Flood Atlas of India), the Building Materials and Technology Promotion Council - BMTPC (Vulnerability Atlas of India), and the National Atlas and Thematic Mapping Organization - NATMO (Natural Hazard Map of India), have been involved in the flood-hazard mapping. These and other studies indicate that the areas that are frequently vulnerable to flooding in the country are:

1. Sub-Himalayan region and the Ganga plains
2. Brahmaputra Valley
3. Punjab plains
4. Mahanadi-Godavari-Krishna-Kaveri Delta plains
5. Lower Narmada-Tapti-Mahi Valleys

III. HYDROLOGIC & HYDRAULIC ANALYSIS

Hydrologic and hydraulic analyses of floods are required for the planning, design, and management of many types of facilities, including hydro-systems within a floodplain or watershed. These analyses are needed for determining potential flood elevations and depths, area of inundation, sizing of channels, levee heights, right of way limits, design of highway crossings and culverts, and many others. The typical requirements include [2]:

1. Floodplain information studies: Development of information on specific flood events such as 10, 100, and 500-year frequency events.
2. Evaluation of future land-use alternatives: Analysis of a range of flood events (with different frequencies) for existing and future land uses to determine flood-hazard potential, flood damage, and environmental impact.
3. Evaluation of flood-loss reduction measures: Analysis of a range of flood events (with different frequencies) to determine flood damage reduction associated with specific design flows.
4. Design studies: Analysis of specific flood events for sizing facilities to assure safety against failure.
5. Operation studies: Evaluation of a system to determine if the demands placed upon it by specific flood events can be met.

The methods used in hydrologic and hydraulic analysis are determined by the purpose and scope of the project and the data availability.

CP1324, *International Conference on Methods and Models in Science and Technology (ICM2ST-10)*
edited by R. B. Patel and B. P. Singh

Hydrological modelling is used to simulate rainfall-runoff, enabling to assess flood risk, improve decision-making about protection measures and mitigate the damage caused by flooding. Hydrologic analysis for floodplains entails either a rainfall-runoff analysis or a flood-flow frequency analysis. If information from an adequate number of historical annual instantaneous peak discharges is available, the flood-flow frequency analysis can be performed to determine peak discharge for various return periods. Otherwise a rainfall-runoff analysis must be performed using a historical storm or design storm for a particular return period to develop a storm runoff hydrograph.

Hydraulic analysis deals with the dynamics of flow in a river or channel and in overbank areas. Hydraulic analysers predict water-surface elevations and flow velocities in time and space using the boundary conditions such as the results of hydrologic models and recorded flood data [1]. For a detailed and rigorous comprehensive analysis, an unsteady-flow analysis based upon a hydraulic-routing model and storm runoff hydrograph can be used to define more accurately maximum water-surface elevation. The unsteady-flow analysis could provide more detailed information such as the routed-discharge hydrographs at various locations throughout a river reach.

IV. SOFT COMPUTING TOOLS

Planning, execution, monitoring and assessment of flood mitigation projects based on the holistic and integrated approach of Integrated Flood Management (IFM) require knowledge of the entire river basin to ensure a more effective output and outcome. Advances in geospatial technologies (Global Positioning System (GPS), Remote Sensing (RS) and Geographic Information System (GIS)) have enabled the acquisition of data and analysis of the river basin for urban flood hazard mapping in a faster and more accurate manner. GIS facilitates integration of spatial and non-spatial geographical data such as rainfall and stream flows, river cross-sections and profiles and river basin characteristics. Other information such as flood maps, infrastructures, land-use and socio-economic information can be inventoried for future use. Flood maps prepared using satellite images of real flood events and information from the ground are useful for flood damage assessment, future flood mitigation planning and validation of hydrologic and hydraulic analysis.

Hydrologic analysis of floods can be carried out using HEC-HMS (developed by U.S Army Corps of Engineers) to derive the storm-runoff hydrograph for a particular return period. HEC-HMS is designed to simulate the rainfall-runoff processes of dendritic watershed systems and it is the successor to HEC-1. Hydrologic elements are arranged in a dendritic network, and computations are performed in an upstream-to-downstream sequence. The physical representation of a watershed is accomplished with a basin model. Basin model in HEC-HMS is set up for each sub-basin using two hydrologic elements: sub-basin and junction. Sub-basin element handles the infiltration loss and base-flow computations, and rainfall-runoff transformation process. Junction element handles the observed flow data and is mainly used for the comparison of the observed flow hydrographs with the simulated flow hydrographs. Meteorologic model in HEC-HMS is the major component that is responsible for the definition of the meteorologic boundary conditions for the sub-basins. It includes precipitation, evapotranspiration and snowmelt methods to be used in simulations.

The time span of a simulation is controlled by control specifications and it include a starting date and time, ending date and time, and a time interval. A simulation run is created by combining a basin model, meteorologic model, and control specifications. Simulation results include information on peak flow and total volume. Analysis tools are also designed to work with simulation runs to provide additional information or processing.. Model calibration need to be carried out to obtain optimal values of parameters of different methods used in sub-basin and junction elements. The calibrated model is then used for runoff generation for different frequency storms. The source of the frequency storms is the Intensity-Duration-Frequency curves which are prepared based on long records of precipitation data.

Hydraulic analysis of floods can be carried out using HEC-RAS (developed by U.S Army Corps of Engineers) and it is a succeeded version of HEC-2. Earlier it could only be used for steady, gradually varied flow modelling. The capability of unsteady flow modelling was added in 2001. HEC-RAS model can perform water surface calculations for gradually varied steady flow for a river reach, or a full network of channels. It is capable of modelling subcritical, supercritical and mixed flow regime water surface profiles. The steady flow component is based on the solution of the one dimensional energy equations. A peak discharge is applied at each cross section to determine the maximum water surface elevation. The unsteady flow component of HEC-RAS simulates one-dimensional unsteady flow through a full network of open channels and is primarily used for subcritical flow regime calculations but may also be applied for supercritical and rapidly varied flows. The unsteady flow module has some additional capabilities like it can model storage area and hydraulic connections between storage areas. The unsteady flow analysis is performed by applying the full equations of motion called St. Venant Equations at a cross-section with upstream and downstream boundary conditions and various other parameters.

The geometric data required to define includes:

- Cross-section data
- Reach lengths (measured between cross sections)
- Stream junction information (Reach lengths across junctions and tributary angles)

For an unsteady flow, hydraulic structures are modeled considering the physical parameters of the structure in the appropriate format in the HEC-RAS data editor. The types of structures that can be modeled in HEC-RAS include bridges, culverts, inline and lateral weirs and gates, spillways and levees. Moreover the unsteady component can model storage areas, hydraulic connections between storage areas, hydraulic connections between stream reaches, pumping stations, flap-gated culverts. Other features include floodplain encroachment analysis, channel modification analysis, scour analysis at bridges, groundwater interflow and contraction and expansion losses.

V. OVERALL METHODOLGY

The evaluation of flood risk is generally based on a two-stage procedure: In the first stage, the statistical probabilities of stage-discharge characteristics of river sections are calculated; thereby the over-bank flow and the river sections at which the flow exceeds the carrying capacity of the river channel are determined. In addition, measurements of critical channel sections are undertaken to assess the hydraulically determined characteristics of the sections of the river course. In the second stage, the inhabited areas falling in the greater or lesser flood risk zone are evaluated based on the relief map. Research on flood hazard mapping reveals that three elements: maximum water level, the velocity of water flow, and the amount of time flood remains in a given land area, are essential to evaluate possible damage. The described requirements are considered to be essential for preparation of urban flood management and risk plans.

Figure 1 presents the detailed schematic representation of the different steps involved in floodplain modelling. Rainfall-runoff modelling could be performed using HEC-HMS. Then peak flow probabilities need to be evaluated using the flood hydrograph resulted from the simulation of HEC-HMS and flow statistics. This analysis will yield a hydrograph that requires for specifying the boundary condition in hydraulic analysis using HEC-RAS.

The water-surface elevation, flow rate, and velocities at various cross-sections of a river reach could be traced through performing HEC-RAS simulations using the digital terrain model (DTM) and inflow hydrographs. HEC-GeoRAS is a set of procedures, tools, and utilities for processing geospatial data in ArcGIS. The GeoRAS helps in preparing the geometric data for importing into HEC-RAS and processing results exported from HEC-RAS. To create the import file, the DTM of the river system in TIN or GRID format is necessary. The RAS layers include layers created for stream centreline, cross-section cut-lines, flow-path centrelines, and main channel banks. Additional layers like land use (for Manning's 'n' extraction), ineffective flow areas, bridges and culverts, storage areas, etc., could be developed and imported.

VI. SUMMARY AND CONCLUSIONS

This paper presented an integrated soft computing for floodplain modelling. Floodplain mapping requires both hydrologic and hydraulic analysis. For ungaged watersheds rainfall-runoff modelling is inevitable and it could be effectively carried out using HEC-HMS. As watershed possesses drastic spatial and temporal variation GIS became an important tool for floodplain modelling. HEC-GeoRAS is an ideal package that could map the floodplain areas and flood water-surface elevation for various design storms with different return periods.

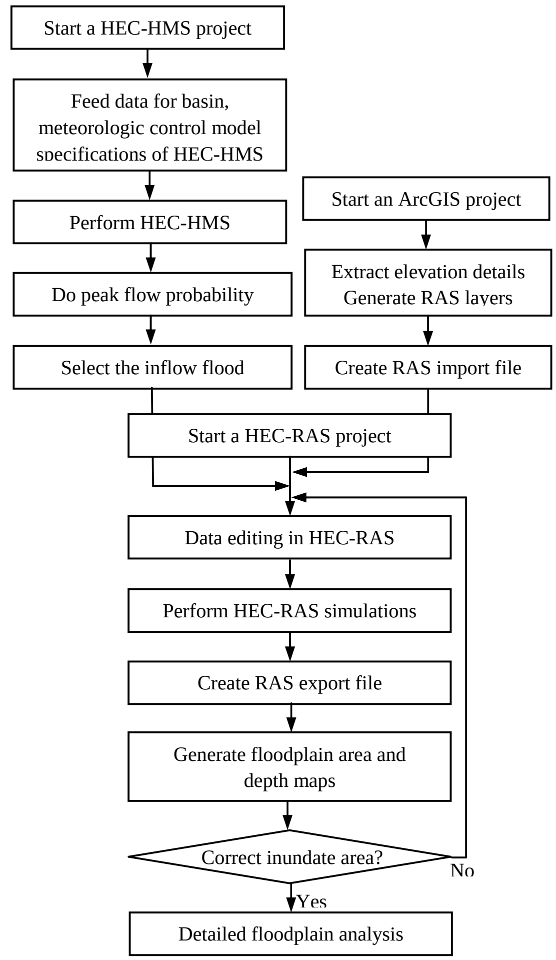

Figure 1 Methodology flow chart for floodplain modelling

REFERENCES

[1] Cooperative Research Centre for Catchment Hydrology, "Series on model choice: General approaches to modelling and practical issues of model choice," 2006 from http://www.toolkit.net.au/pdfs/MC-1.pdf.

[2] D. H. Hoggan, *Computer-Assisted Floodplain Hydrology and Hydraulics*, 2nd ed, McGraw-Hill, New York, 1997.

[3] V.S. Kale, "Flood studies in India: A brief review," *J. Geological Society of India*, vol. 49, pp. 359-370, 1997.

[4] V.S. Kale, "Geomorphic effectiveness of extraordinary floods on three large rivers of the Indian Peninsula," *Geomorphology*, vol. 85, pp. 306-316, 2007.

[5] G. Nageswara Rao, "Occurrence of heavy rainfall around the confluence line in monsoon disturbances and its importance in causing floods". Proceedings of Indian Academy of Sciences Earth and Planetary Science, pp. 87-94, 2001.

[6] J. M. Scheuren, de Waroux, O., Below, R., Guha-Saphir, D. Ponserre, "Annual Disaster Statistical Review," CRED Brussels, Belgium, 2008.

[7] K. Singh, and A. K. Sharma, "GIS and a remote sensing based approach for urban floodplain mapping for the Tapi catchment, India," Hydroinformatics in Hydrology, Hydrogeology and Water Resources at the Joint IAHS & IAH Convention, Hyderabad, India, September 2009.