ORIGINAL RESEARCH PAPER

Engineering

KEY WORDS: HEC-HMS, Rainfall Runoff Modeling, Rainfall, Runoff, Hydrological cycle.

RAINFALL RUNOFF MODELLING USING HEC-HMS & GIS TECHNIQUES - A REVIEW

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ABSTRACT

Hydrologic models are simplified, conceptual representations of a part of the hydrologic cycle. The Hydrological Cycle is the journey water takes as it circulates from the land to the sky and back again. The water cycle is never -ending cycle. Rainfall-runoff modeling in the broader sense a hydrological, mathematical model gives a detailed account of Rainfall-Runoff relationships of a catchment area or watershed. Hydrological models are primarily used for hydrologic prediction and for understanding hydrologic processes. Watershed hydrological modeling and associated calibration and validation processes require a large set of spatial and temporal data. In practice, the availability and quality of these data are often an issue to cope with. The current paper describes the study of various literatures on development such a strategy by combining fine-scale event and course scale continuous hydrological modeling with hydrologic engineering center's hydrologic modeling system (HEC-HMS.

I.INTRODUCTION

The hydrological cycle has many interconnected components, with runoff connecting precipitation to bodies of water. Surface runoff is precipitation that does not infiltrate into the soil and runs across the land surface into surface waters (streams, rivers, lakes or other reservoirs) Perlman (2016) [14]. The HEC-HMS is designed to simulate the precipitation-runoff processes of a watershed system. Its design allows the applicability in a wide range of geographic areas for solving diverse problems including large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Knebl et.al (2005) [7].

If the long range data is available flood control, flood forecasting and reservoir analysis can be done and a model is established. From this model one can predict the flow for extended period also. All hydrologic models are simplified characterization of the real world system into models. The rainfall - runoff model is a mathematical model which describes the relation between rainfall – runoff of a watershed or catchment area. It is seen that infiltration is the governing factor for the computation of runoff in a watershed. If the watershed is flat, the infiltration is increases while the runoff reduces and vice-versa if the watershed having steep slope. Neerav et al. (2016) [12].

The parameters and structure of traditional hydrological models are not adaptable for the data derived from remote sensing . With the help of prepare Soil map and LULC map for using different tools in ArcGIS. Therefore, a hydrological model based on geographical information system and remote sensing (USACE 2003) must be deployed to develop the basin model. HEC-HMS (Hydrologic Engineering Centre - Hydrologic Modeling System) (USACE, 2006) is proved hydrological modeling tool developed by the U.S. Army Corps of Engineers which is available free of cost to the general public. The HEC-HMS (USACE 2000) was chosen for simulating the rainfall runoff response. HEC-GeoHMS 4.3 is an extension of ArcGIS 10.3 and the spatial analyst extension. The spatial analyst tool not only saves time and effort; it also improves the accuracy over conventional methods. HEC-GeoHMS allows the user to visualize spatial information, document the watershed characteristics, perform spatial analysis, delineate subbasins and streams, construct input to hydrological models, and assist with report generation. It creates background map files, basin model files, meteorologic model file, and a grid cell parameter to develop a hydrological model by HEC-HMS.

II.TYPES OF RAINFALL-RUNOFF MODELS

The rainfall runoff models are mainly divided into three categories: empirical, conceptual and physically based models.

1)Empirical models

Empirical models, sometimes called data-driven models, use non-linear statistical relationships between inputs and outputs.. They are observation-oriented and depend heavily on input accuracy (Kokkonen et al., 2001) [9].

2)Conceptual Models

Conceptual models interpret runoff processes by connecting simplified components in the overall hydrological process. They are based on reservoir storages and simplified equations of the physical hydrological process, which provide a conceptual idea of the behaviors in a catchment (Devi et al., (2015) [3]; Vaze, (2012) [17].

3)Physical Models

Physical models, also called process-based mechanistic models, are based on the understanding of the physics related to the hydrological processes (Vaze, 2012) [17].

Physically based models depend directly on the hydrological processes involved uses spatial discretization or other types of hydrological based units for the generation of stream flow using this model.

III.HEC-HMS & GIS TECHNIQUES FOR RUNOFF ESTIMATION

This part of the paper deals with the research work done on rainfall-runoff modelling and HEC-HMS model. Research work principles, model development methodology and conclusions have been discussed briefly.

Rainfall-Runoff modelling:

Keith Beven (1982) [1] developed a simple theory for predicting the response times of saturated and unsaturated flows on hill slopes using kinematic wave equations.

Xu, (2002) [18] Modeling runoff helps gain a better understanding of hydrologic phenomena and how changes affect the hydrological cycle.

Goswami et al. (2007) [4] for simulating stream flows in ungauged catchments a regeneralized multi model was developed. Seven different models were used for regionalization and three methods were tested for each model that includes discharge, transposition of discharge data of the nearest neighbour and regional pooling of data.

Their results concluded that soil moisture accounting and routing model (SMAR) was the best approach for simulating flows in ungauged catchments

Devi et al. (2015) [3] defines a runoff model as a set of equations that aid in the estimation of the amount of rainfall that turns into runoff as a function of various parameters used to describe the watershed.

HEC–HMS Model:

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) was designed as a part of the U.S. Army Corps of Engineers Hydrologic engineering Centers "Next Generation Software Development Project". It is designed for event-based as well as continuous hydrologic modeling. Principally it was planned to simulate the rainfall-runoff modeling of watershed. However its latest version can be used to solve a wide range of problems such as large catchment basin water supply, flood hydrographs and watershed runoff, etc. For the modeling, mode it contains various components viz. basin model, meteorological model, control specification model, and input data.

Hammouri and Naqa (2007) [5] modeled the rainfall-runoff process using HEC-HMS and GIS in a selected ungauged basin for the purpose of groundwater artificial recharge at Zarqa catchment, Jordan. Two model runs were carried out using precipitation data of the Intensity-Duration-Frequency (IDF) curves for 10 years and 50 years return periods. The total direct runoff volume and the peak discharge for 10 years return period were estimated to be 151,000 m3 and 5.43 m3/s respectively and for 50 years return period, it was 280,000 m3 and 12.77 m3/s, respectively. The model was optimized against observed runoff data measured during a storm event that occurred between 2nd and the 4th of April, 2006. This calibration was performed by applying different curve numbers in the simulated model. The flow comparison graph for calibrated model fits well with the observed runoff data with a peak-weighted root mean square error (RMSE) of less than 2 percent.

Parag (2008) [13] used HEC-HMS model for rainfall–runoff modeling for Maheshgad watershed of 45.03 ha in semi-arid region of Maharashtra with sub-basins named as W1, W2, W3 and W4. The hydrological event recorded on 27th July 1998 was considered for rainfall-runoff simulation. The model was calibrated manually for two parameters such as initial loss (14 to 24 mm) and constant rate of infiltration (1.0 to 4.2 mm/hr) for the given watershed. Result of the study indicated better agreement between calibrated and observed runoff hydrographs for all sub-watersheds for their peak rate, its timing of occurrence and lag time.

Chu and Steinman (2009) [2] discussed the application of joint event and continuous hydrologic modeling with the HEC-HMS to the Mona Lake watershed in West Michigan. Four rainfall events were selected specially for calibration and verification of event model and identified the model parameters. The calibrated parameters were then used in the continuous hydrograph model. The SCS-CN and SMA methods in HEC-HMS were used for simulating surface runoff in the event and 92 continuous models, respectively, and the relationship between the two rainfall-runoff models was analyzed. The model output suggest that the fine scale event hydrological modeling, support by intensive field data, was found useful for improving the coarsescale continuous modeling by providing more accurate and well-calibrated parameters.

Kumar and Bhattacharjya (2011) [8] simulate the rainfall-runoff process using of HEC-HMS (with both Distributed and Lumped modeling), remote sensing and GIS techniques for estimating infiltration parameters in the Ranganadi river basin of North-Eastern India. The required precipitation and stream flow data were collected for 3 years (2006–2008) together with topographic maps, and DEM images of the study area. The input file for the proposed hydrologic models was prepared using remote sensing and GIS techniques. For simulating stream flow by the HEC-HMS model, the SCS unit hydrograph transform method was used to compute direct surface runoff hydrograph, the SCS curve number loss method was used to compute runoff volumes and the constant monthly method was used for base flow separation. Lumped and Distributed modeling was simulated and validated using the rainfall-stream flow data of May 2006 to May 2007, and rainfall-stream flow data of 2008 respectively. Finally, the performance of HEC-HMS model was assessed using various statistical and graphical indicators. It was shown that the HEC-HMS Distributed approach simulated daily stream flow better than the Lumped simulatedparameters and for simulating daily stream flow in the Ranganadi river basin of North- Eastern India.

M. M. G. T. De Silva et al (2013) [11] Paper represented by M. M. G. T. De Silva et al describes a Modeling of event and continuous flow hydrographs with HEC– HMS; A case study in the Kelani River basin SriLanka. An extremely high rainfall event in November 2005 was used for calibration of model parameters and extremely high rainfall events in April – May 2008, May – June 2008, and May 2010 were used for validation of the event model. Two consecutive extreme flood events occurred during April to June 2008 were selected for model calibration under continuous simulations. The time series data from January 2005 to December 2007 and January 2009 to December 2010 were used for validation. The calibrated, direct runoff and baseflow parameters were then used in the continuous hydrologic model.

Majidi and Vagharfard (2013) [10] Calibrated and validated HEC-HMS hydrological model for simulation of surface run-off in Abnama watershed, south east of Iran. For choosing appropriate method between Green-Ampt and Soil Conservation Service (SCS), HEC-HMS model was separately run for four events. A result of the model calibration and validation showed that Green-Ampt method estimated peak discharge with lower difference and its time to peak was less than SCS method. Also comparison of simulated and observed hydrographs and correlation between their values in Minitab software showed that results based on the Green-Ampt method which had a higher coefficient of determination (R2 = 0.71) and Pearson correlation = 0.84 than the SCS method R2 = 0.46 and Pearson correlation = 0.7. Thus it could be concluded that simulation using Green-Ampt method was more precise than SCS method.

Kishor C et al (2014) [6] Paper represented by Kishor C et al describes Simulation of rainfall-runoff process using HEC-HMS model for Balijore Nala watershed. In this study, Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) hydrological model has been used to simulate runoff process in Balijore Nala watershed in Odisha, India. Estimation of accurate runoff for a given rainfall event is a difficult task due to various influencing factors. Several computer based hydrological model have been developed for simulation of runoff in watershed and water resource studies. The HEC-HMS model has been applied for 12 rainfall events of sub watershed of Balijore Nala watershed. The model has been calibrated for 12 rainfall events and validated for 12 rainfall events.

To compute runoff volume, peak runoff rate, base flow and flow routing methods SCS curve number, SCS unit hydrograph Exponential recession and Muskingum routing methods are chosen respectively.

The model has been calibrated and validated for the 12 rainfall events.

From the results, it is observed that HEC-HMS model has performed satisfactorily for the simulation runoff for the different rainfall events. The HEC-HMS model used for rainfall-runoff simulation in the selected watershed shows RMSE as 0.09 m3/sec and MARE as 0.06 for peak discharge and RMSE as 0.70 mm and MARE as 0.05 for runoff depth.

The model set-up was done with the help Arc-Map and Hec-GeoHMS tool that runs under Arc-GIS. The setup consisted of preparation of input data, delineation of watershed using the Digital Elevation Model (DEM) data, Soil map, slope, Land use land cover data, weather data definition and finally a test run of the model. Parameters such as initial abstraction, curve number, percentage of impervious area, basin lag time, Muskingum K were calculated using soil type and land use maps.

1) Digital Elevation Model (DEM), Land Use Land Cover (LULC) data was used for watershed delineation.
2) To compute infiltration, rainfall excess conversion to runoff and flow routing, methods like SCS Curve Number, SCS Unit hydrograph and Muskingum routing were chosen.

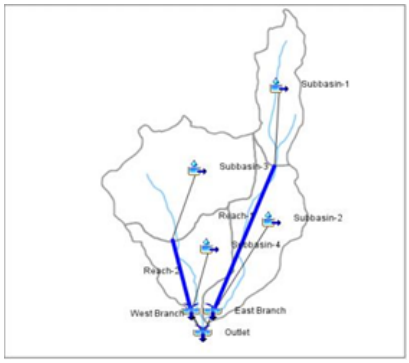

Figure 1: Representation of Basin Model Map (USACE, 2006)

Table 1 - Selected methods for HMS

HMS Processes	Method
Loss	SCS Curve Number
Transform	SCS Unit Hydrograph
Base-flow	Exponential Recession
Routing	Muskingum

Initial abstraction, curve number and impervious percentage for watershed were calculated. The equation is (Singh and Seth, 1984)[16]:

$$Q = \frac{(P-Ia)^2}{(P-Ia+S)} \qquad (1)$$

For Indian soil condition (Kumar et al 1991 [6]; Ratika et al (2010) [15] the above relation is modified as follows:
Substituting the value of Ia in the generalized runoff equation produces:-

$$Q = \frac{(P-0.3S)^2}{(P+0.7S)} \qquad (3)$$

$$S = \frac{24500}{CN} - 254 \qquad (4)$$

$$CN_w = \frac{(\sum_{i=0}^{N} CNi*Ai)}{A} \qquad (5)$$

Where,
Q= Runoff Depth in mm, P = Rainfall in mm, S = Potential maximum soil moisture retention in mm, Ia = 0.3S (Initial abstraction of rainfall by soil and vegetation in mm), CN = Curve Number, CNw = Weighted curve number , CNi = Curve number of the sub-area Ai (i = 1 to any number N), Ai = Area with curve number CNi and A = Total area of the watershed.

II.CONCLUSIONS

For study of many literatures related to rainfall-runoff modelling using HEC-HMS it is concluded that these type of studies provides good responce of different basin to various hydrological modelling. This study show the importance of HEC-HMS model in the applications of flood control , water management for medium size basin.

Based on the statistical and graphical indicators used in this study, it was found that the HEC-HMS distributed approach simulated daily stream flow satisfactorily and its performance was found to be reliable to estimate more desired peak values.

Considering the performance of model in simulating the runoff, it is suggested that the calibrated HEC-HMS model could be used to predict runoff for the rainfall for river basin.

The HEC– HMS is useful to analyze future extreme conditions by taking the advantage of the characteristics of distinct modeling approaches and the availability of various data.

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