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A Review on Hydrological Models

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Abstract

Various ongoing researches are there on topics like which model will give more compatible results with that of observed discharges. It was argued that even complex modeling does not provide better results. Climate change and soil heterogeneity has got an important role in finding out surface runoff. In this paper, we are going to discuss briefly about variable infiltration capacity model (VIC), TOPMODEL, HBV, MIKESHE and soil and water assessment tool (SWAT) model. VIC performs well in moist areas and can be efficiently used in the water management for agricultural purposes. Requirement of large data and physical parameters makes the use of MIKE SHE model limited to smaller catchments. Only a little direct calibration is required for SWAT model to obtain good hydrologic predictions. HBV model gives satisfactory results and TOPMODEL can be used in catchments with shallow soil and moderate topography.
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1. Introduction

The term hydrology can be treated as an important subject for the people and their environment. It treats water of the earth, their occurrence, circulation and distribution, their chemical and physical properties and their reaction with the environment including their relation to living things (Ray 1975). It also deals with the relationship of water with the environment within each phase of hydrologic cycle. Due to rapid urbanisation and industrialisation including deforestation, land cover change, irrigation, various changes have been occurred in hydrologic systems. Along with

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climate change, soil heterogeneity has also got a direct impact on the discharges of many rivers in and around the world.

Different hydrologic phenomena and hydrologic cycle are to be thoroughly studied in order to find out these variations. Now days, various hydrological models have been developed across the world to find out the impact of climate and soil properties on hydrology and water resources. Each model has got its own unique characteristics. The inputs used by different models are rainfall, air temperature, soil characteristics, topography, vegetation, hydrogeology and other physical parameters. All these models can be applied in very complex and large basins.

2. Hydrological modeling

According to Sorooshian et al. (2008), a model is a simplified representation of real world system. The best model is the one which give results close to reality with the use of least parameters and model complexity. Models are mainly used for predicting system behaviour and understanding various hydrological processes. A model consists of various parameters that define the characteristics of the model. A runoff model can be defined as a set of equations that helps in the estimation of runoff as a function of various parameters used for describing watershed characteristics. The two important inputs required for all models are rainfall data and drainage area. Along with these, water shed characteristics like soil properties, vegetation cover, watershed topography, soil moisture content, characteristics of ground water aquifer are also considered. Hydrological models are now a day considered as an important and necessary tool for water and environment resource management.

3. Types of models

Rainfall-runoff models are classified based on model input and parameters and the extent of physical principles applied in the model. It can be classified as lumped and distributed model based on the model parameters as a function of space and time and deterministic and stochastic models based on the other criteria.

Deterministic model will give same output for a single set of input values whereas in stochastic models, different values of output can be produced for a single set of inputs. According to Moradkhani and Sorooshian (2008) in lumped models, the entire river basin is taken as a single unit where spatial variability is disregarded and hence the outputs are generated without considering the spatial processes where as a distributed model can make predictions that are distributed in space by dividing the entire catchment in to small units, usually square cells or triangulated irregular network, so that the parameters, inputs and outputs can vary spatially.

Another classification is static and dynamic models based on time factor. Static model exclude time while dynamic model include time. Sorooshian et al. (2008) had classified the models as event based and continuous models. The former one produce output only for specific time periods while the latter produces a continuous output. One of the most important classifications is empirical model, conceptual models and physically based models.

3.1. Empirical models (Metric model)

These are observation oriented models which take only the information from the existing data without considering the features and processes of hydrological system and hence these models are also called data driven models. It involves mathematical equations derived from concurrent input and output time series and not from the physical processes of the catchment. These models are valid only within the boundaries. Unit hydrograph is an example of this method. Statistically based methods use regression and correlation models and are used to find the functional relationship between inputs and outputs. Artificial neural network and fuzzy regression are some of the machine learning techniques used in hydro informatics methods.

3.2. Conceptual methods (Parametric models)

This model describes all of the component hydrological processes. It consists of a number of interconnected reservoirs which represents the physical elements in a catchment in which they are recharged by rainfall, infiltration and percolation and are emptied by evaporation, runoff, drainage etc. Semi empirical equations are used in this method and the model parameters are assessed not only from field data but also through calibration. Large number of meteorological and hydrological records is required for calibration. The calibration involves curve fitting which makes the interpretation difficult and hence the effect of land use change cannot be predicted with much confidence. Many conceptual models have been developed with varying degree of complexity. Stanford Watershed Model IV (SWM) is the first major conceptual model developed by Crawford and Linsley in 1966 with 16 to 20 parameters.

3.3. Physically based model

This is a mathematically idealized representation of the real phenomenon. These are also called mechanistic models that include the principles of physical processes. It uses state variables which are measurable and are functions of both time and space. The hydrological processes of water movement are represented by finite difference equations. It does not require extensive hydrological and meteorological data for their calibration but the evaluation of large number of parameters describing the physical characteristics of the catchment are required (Abbott et al. 1986 a). In this method huge amount of data such as soil moisture content, initial water depth, topography, topology, dimensions of river network etc. are required. Physical model can overcome many defects of the other two models because of the use of parameters having physical interpretation. It can provide large amount of information even outside the boundary and can applied for a wide range of situations. SHE/ MIKE SHE model is an example. (Abbott et al. 1986 a, b)

Table 1. Characteristics of three models.

Empirical model	Conceptual model	Physically based model
Data based or metric or black box model	Parametric or grey box model	Mechanistic or white box model
Involve mathematical equations , derive value from available time series	Based on modeling of reservoirs and Include semi empirical equations with a physical basis.	Based on spatial distribution, Evaluation of parameters describing physical characteristics
Little consideration of features and processes of system	Parameters are derived from field data and calibration.	Require data about initial state of model and morphology of catchment
High predictive power, low explanatory depth	Simple and can be easily implemented in computer code.	Complex model. Require human expertise and computation capability.
Cannot be generated to other catchments	Require large hydrological and meteorological data	Suffer from scale related problems
ANN, unit hydrograph	HBV model, TOPMODEL	SHE or MIKESHE model, SWAT
Valid within the boundary of given domain	Calibration involves curve fitting make difficult physical interpretation	Valid for wide range of situations.

4. Brief description of few models

4.1. SWAT model (Soil and Water Assessment Tool)

Development of SWAT model is an ongoing process and it is the successor of “the Simulator for Water Resources in Rural Basins” model (SWRRB). SWAT model is a complex physically based model and was designed to test and forecast the water and sediment circulation and agriculture production with chemicals in ungauged basins. It is efficient in performing long term simulations. The model breaks the entire catchment in to sub catchments which are further divided in to hydrologic response units (HRU), land use, vegetation and soil characteristics. Daily rainfall data, maximum and minimum air temperature, solar radiation, relative air humidity and wind speed are the inputs used by this model and is able to describe water and sediment circulation, vegetation growth and nutrients circulation. Based on amount of precipitation and mean daily air temperature rate of snowfall can be determined. Penman Monteith, Priestly- Taylor and Hargreaves methods are used for the estimation of evapotranspiration. In order to obtain accurate forecasting of water, nutrient and sediment circulation, it is necessary to simulate hydrologic cycle which integrates overall water circulation in the catchment area and hence the model uses the following water balance equation in the catchment.

$$SW_t = SW_o + \sum_{i=1}^{t}(Rv - Qs - Wseepage - ET - Qgw) \quad (1)$$

Where SW_t is the humidity of soil, SW_o is base humidity, R_v is rainfall volume in mm water, Q_s is the surface runoff, $W_{seepage}$ is seepage of water from soil to underlying layers, ET is evapotranspiration, Q_{gw} is ground water runoff and t is time in days).

4.2. MIKE SHE model (Systeme Hydrologique European)

It is a physically based model and hence it requires extensive physical parameters and was developed in 1990. The model accounts various processes of hydrological cycle such as precipitation, evapotranspiration, interception, river flow, saturated ground water flow, unsaturated ground water flow etc. It can simulate surface and ground water movement, their interactions, sediment, nutrient and pesticide transport in the model area and various water quality problems and can be applied for large watersheds. The method use Kristensen and Jensen (1975) method for finding evapotranspiration. The full detail and manual of MIKE SHE code is given in the user's guide (DHI-WE, 2005). Refsgaard and Storm (1995) have provided the detailed description of the structure and set up of the model. The code involves pre-processing and post processing modules and has various options for displaying results.

4.3. HBV model (Hydrologiska Byrans Vattenavdelning model)

This model is an example of semi distributed conceptual model (Bergstrom, 1976). The entire catchment is divided into sub catchments, which are further divided into different elevation and vegetation zones. It runs on daily and monthly rainfall data, air temperature and evaporation. Air temperature data are used for calculating snow accumulation. The general water balance equation used is (2).

$$P - E - Q = \frac{d}{dt}(SP + SM + UZ + LZ + lakes) \quad (2)$$

Where P is precipitation, E is evaporation, Q is runoff , SP is the snow pack, SM is the soil moisture, UZ and LZ are the upper and lower ground water zone and lakes represent the volume of lake.

Different model versions are now available and are used in different countries with different climatic conditions. Degree day method is used to simulate snow accumulation and snow melt. Ground water recharge, runoff and actual evaporation are simulated as functions of actual water storage. HBV-light is a new version of HBV model and it uses a warm-up period, in which the state variables will get its appropriate values as per meteorological data and parameter values.

4.4. TOPMODEL

It is a semi distributed conceptual rainfall runoff model that takes the advantage of topographic information related to runoff generation. But according to Beven and Kirby (1979), Beven et al. (1986), the TOPMODEL is considered as a physically based model as its parameters can be theoretically measured. In other words, it can be defined as a variable contributing area conceptual model. It can be used in single or multiple sub catchments using grided elevation data for the catchment area. It helps in the prediction of hydrological behaviour of basins. The major factors considered in this are the catchment topography and soil transmissivity.

The main aim is to compute storage deficit or water table depth at any location. The storage deficit value is a function of topographic index ($a/\tan\beta$) (Beven 1986), where a is drained area per unit contour length and $\tan\beta$ is the slope of the ground surface at the location. Since the index is based on basin topography, the model give calculations only for representative values of indices. It is obtained by manual analysis of contour maps. The model use exponential Green-Ampt method of Beven (1984) for calculating runoff and it is advised to reduce the number of parameters. The output will be in the form of area maps or simulated hydrographs.

4.5. VIC model (Variable Infiltration Capacity model).

It is a semi distributed grid based hydrology model which uses both energy and water balance equations. The main inputs are precipitation; minimum and maximum daily temperature and wind speed and allows many land cover types within each model grid. The processes like infiltration, runoff, base flow etc are based on various empirical relations. Surface runoff is generated by infiltration excess runoff (Hortonian flow) and saturation excess runoff (Dunne flow). VIC simulates saturation excess runoff by considering soil heterogeneity and precipitation. It consists of 3 layers. Top layer allows quick soil evaporation, middle layer represent dynamic response of soil to rainfall events and lower layer is used to characterise behaviour of soil moisture.

Improvised VIC model has included both infiltration excess runoff and saturation excess runoff and also the effects of variability of soil heterogeneity on surface runoff characteristics. It can deal with the dynamics of surface and ground water interactions and calculate ground water table (Gao, 2010) and can be applied in cold climate. The model is now a day applied to a number of river basins and helps in predicting climate and land cover changes over the study area.

5. Discussion

Nijssen et al. (1997) coupled VIC model with simple grid based network and found that it perform well in moist areas. Subramanian et al. (1999) used this model for irrigation planning in a small watershed and conclude that it can be efficiently used for the management of water for agricultural purposes. Yang et al (2000) compared 3 models and suggests that MIKE SHE model can be used in smaller catchments. HBV model can be used flood forecasting and many other purposes. Borah and Bera (2003) have made a comparison between SWAT, HSPF and DWSM model and found 17 applications of SWAT and conclude that it can be applied for continuous simulations of flow, soil erosion, nutrient and sediment transport etc.

MIKE SHE model requires extensive model data and physical parameter which may not be available all the time and make it difficult to set up the model. Also users are unable to modify the code but it had high processing ability compared to other models. It has extensive graphical capabilities for pre and post processing and thus makes the modelling easier. Yang et al. (2000) and Abu Nasr et al. (2005) found that it will produce models of equal or superior ability compared to other codes. Easton et al. (2010) used SWAT model to determine runoff and erosion in Blue Nile basin in order to find out the respective sources. They found that the model can predict sediment load peaks. Only a very little direct calibration is required to obtain good hydrologic predictions. Grillakis et al. (2010) used HBV model in a flash flood case in Slovenia and it gives somewhat satisfactory results. TOPMODEL can be used in catchments with shallow soil and moderate topography. (2011) used this model to study the runoff response of Ammammeh watershed in Iran and results shows the ability of the model in both event based and daily simulations. More accurate results was obtained in daily modelling as it uses soil moisture conditions. Park and Markus (2014) made an analysis of flood regime and suggest that VIC can be used in snow melt driven flood peak studies.

6. Conclusion

In general, rainfall-runoff models are the standard tools used for investigating hydrological processes. A large number of models with different applications ranges from small catchments to global models has been developed. Each model has got its own unique characteristics and respective applications. Some of them are comprehensive and uses the physics of underlying hydrological processes and are distributed in space and time. The models are used for the modelling of both gauged and ungauged catchments, helps in flood forecasting, proper water resource management and evaluation of water quality, erosion and sedimentation, nutrient and pesticide circulation, land use and climate change etc. Each model has various drawbacks like lack of user friendliness, large data requirements, absence of clear statements of their limitations etc. In order to overcome these defects, it is necessary for the models to include rapid advances in remote sensing technologies, risk analysis, etc. By the application of new technologies, new distributed models can be developed for modelling gauged and ungauged basins.

One of the challenges is regarding the use of large quantity of data and hence new facilities are to be included for the efficient storing, managing and manipulation of extensive data. Each model should give a clear statement of their limitations and must provide a proper guidance and include require description of dominant physical processes. For accurate prediction, different means of model evaluation is required. Also it should be kept in mind that the calibrated parameter values will reflects the source of errors in modelling. Both meteorological data and soil properties have got a large influence on the performance of each model. A proper knowledge of subsurface flow pathways and hydraulic characteristics is necessary otherwise it will create adverse effect on model calibration. Various researches are still going on to make better predictions and to face major challenges. It is necessary to improve the existing theories or to develop new theories in order to find the impact of climate change and land use changes on the system.

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