A Concise Review on Introduction to Hydrological Models

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Abstract

In recent scenario of rapid urbanization and industrialization causes various changes in our natural resources like air, water, soil etc. Various problems are caused due to these changes such as drought, frequent floods, pollution, change in climate, loss of biodiversity, extinction of many varieties of flora and fauna, land use and land cover changes, degradation of land and many more. Various researches are carried out to on the topics to comate the impact of these physical changes regarding our natural resources. So there is need of reliable hydrological model which will give more compatible results with the observed parameters. It is not always true that a complex hydrological model give the more accurate output. So there was an argued that even the use of complex models does not provide better results. This paper is regarding various hydrological models, their classification and short description about them.

Keywords- Hydrology, Hydrological Process, Hydrological Models, Classification

I. INTRODUCTION

In simple words, Hydrology is the science of water which deals with the water of earth and its atmosphere. It is the study of occurrence, circulation, distribution, chemical and physical properties of all forms of water and also their reaction with the nature including human (Ray 1975). It is an important aspect for the living being including both human and the environment. It concerns with the water in streams, lakes, rainfall, snowfall, snow, ice on the land and even water occurring below the earth's surface in the pores of the soil and rocks. Hydrology finds its utility in various applications and tasks which includes, Design and operation of hydraulic structures; Water supply; Waste water treatments and disposal; Irrigation, drainage, hydropower generation ; Flood control; Navigations; Erosion, sediment control; Salinity control; Pollution abatement; Recreational use of water; Fish and wildlife protection and many more.

The role important role of applied hydrology is to help to analyze the problems involved in above mentioned tasks and to provide guidance for the planning and management of water resources. Hydrologic cycle is treated as a system and its components like precipitation, evaporation, runoff etc are treated as subsystem of overall hydrological cycle. The hydrologic cycle is divided into three subsystems:

The atmospheric water system - containing processes of precipitation, evaporation, interception and transpiration

The surface water system - containing the processes of overland flow, surface flow, subsurface and ground water outflow, and runoff to streams and the ocean

The subsurface water system - containing the processes of infiltration, groundwater recharge, subsurface flow, groundwater flow

Hydrological phenomena are extremely complex in nature and it is too difficult to understand these phenomena fully. These are represented in simplified way by means of the system concept A system is a set of connected parts that form a whole. Rapid urbanization and industrialization and standard of life of human altered the dynamic equilibrium of the hydrological systems and causes problems like deforestation, land cover change, change in climate, soil properties, urgent need of irrigation etc. Now a day, various hydrological models have been developed across the world to find out the impact of various hydrological problems as mentioned above and even many other related to hydrology and water resources.

II. HYDROLOGICAL MODEL AND THEIR CHARACTERISTICS

Hydrological models simply, the simplified representation of real world system (Sorooshian et al., 2008). Models are considered as an important and necessary tool for water and environment resource management. Each model has its own unique characteristics. Some of these models can be applied in very complex and large basins. All these models are mainly used for predicting system behavior and understanding various hydrological processes. The best model is the one which give results close to reality with the least use of input parameters and model complexity. All Models are consists of various input parameters which define their characteristics. Some of the input parameters used by different hydrological models are rainfall, air temperature, soil characteristics, topography, vegetation, hydrogeology etc.

The hydrological models are approximations of reality. The outputs of the actual system can never forecast with certainty because the hydrological phenomena vary in all three space directions and in time. The simultaneous consideration of all five

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sources of variations (randomness, three space dimensions, and time) has been accomplished for only a few idealized cases. A practical model usually considers only one or two sources of variation. Generally hydrological model are represented by the given formula,

$$O = f(I, P, t) + \varepsilon$$

Where,
O is an n × k matrix of hydrologic responses to be modeled
f is a collection of/ functional relationships
I is an n × m matrix of inputs
P is a vector of p parameters
t is time
ε is an n × k matrix of errors
n is the numbers of data points
k is the number of responses
m is the number of inputs

Responses O may range from a single number such as a peak flow or a runoff volume to a continuous record of flow, soil water content, evapotranspiration and other quantities. Model classification refers to the nature of f. Generally I represents inputs, some of which are time varying, such as rainfall, temperature, and land use , while P represents coefficients particular to a watershed that must be estimated from tables, charts, correlations, observed data or some other means. The error term, ε, represents the difference between what actually occurs, O and what the model predicts Op.

$$Op = f(I, P, t)$$
$$\mathcal{E} = O - Op$$

For most practical problems, only a few processes of hydrological cycle are considered at a time, and then only considering a small portion of the earth's surface. A hydrologic system is defined as a structure or volume in space, surrounded by a boundary, that accepts water and other inputs, operate them internally and produces as outputs. Most hydrologic systems are inherently random because their major input is precipitation, which is highly variable and unpredictable phenomenon Statistical analysis plays a large role in hydrologic analysis. The objective of hydrologic system analysis is to study the system operation and predict its outputs.

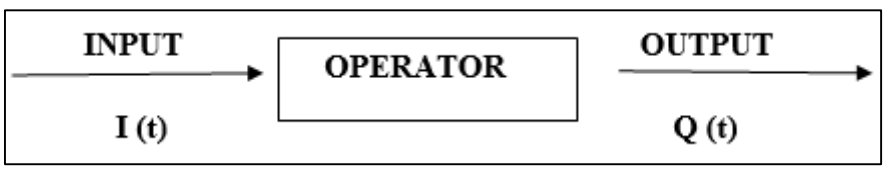

Fig. 1: Schematic representation of system operation

Hydrological models simulate natural processes of the flow of water, sediment, chemicals, nutrients, and microbial organisms and quantify the impact of human activities on these processes. These models are main tool in addressing a wide spectrum of environmental and water resources problems such as water resources planning, development, design, operation, and management; flooding; droughts; upland erosion; stream bank erosion; Coastal erosion; sedimentation; migration of microbes; deterioration of lakes; desertification of land; degradation of land; nonpoint source pollution; water pollution from industrial, domestic, agricultural, and energy industry sources; decay of rivers; irrigation of agricultural lands; conjunctive use of surface and groundwater; reliable design of hydraulic structures; river training works etc. Design problems in hydrological model are classified as

- Long-run – design of multiple purpose reservoir system – huge capital investment – benefits after & over a long time
- Intermediate run – irrigation & cultivation for a season
- Short- run – how much water to be released for flood control

III. HYDROLOGICAL MODEL- TYPES AND CLASSIFICATION

Each requires model requires various criteria to modeled hydrological phenomena are accuracy, simplicity, consistency, sensitivity. A hydrologic model is an approximation of the actual system, their inputs and output are measurable hydrologic variables and structure is a set of equations linking the inputs and outputs. These hydrologic models are classified as:

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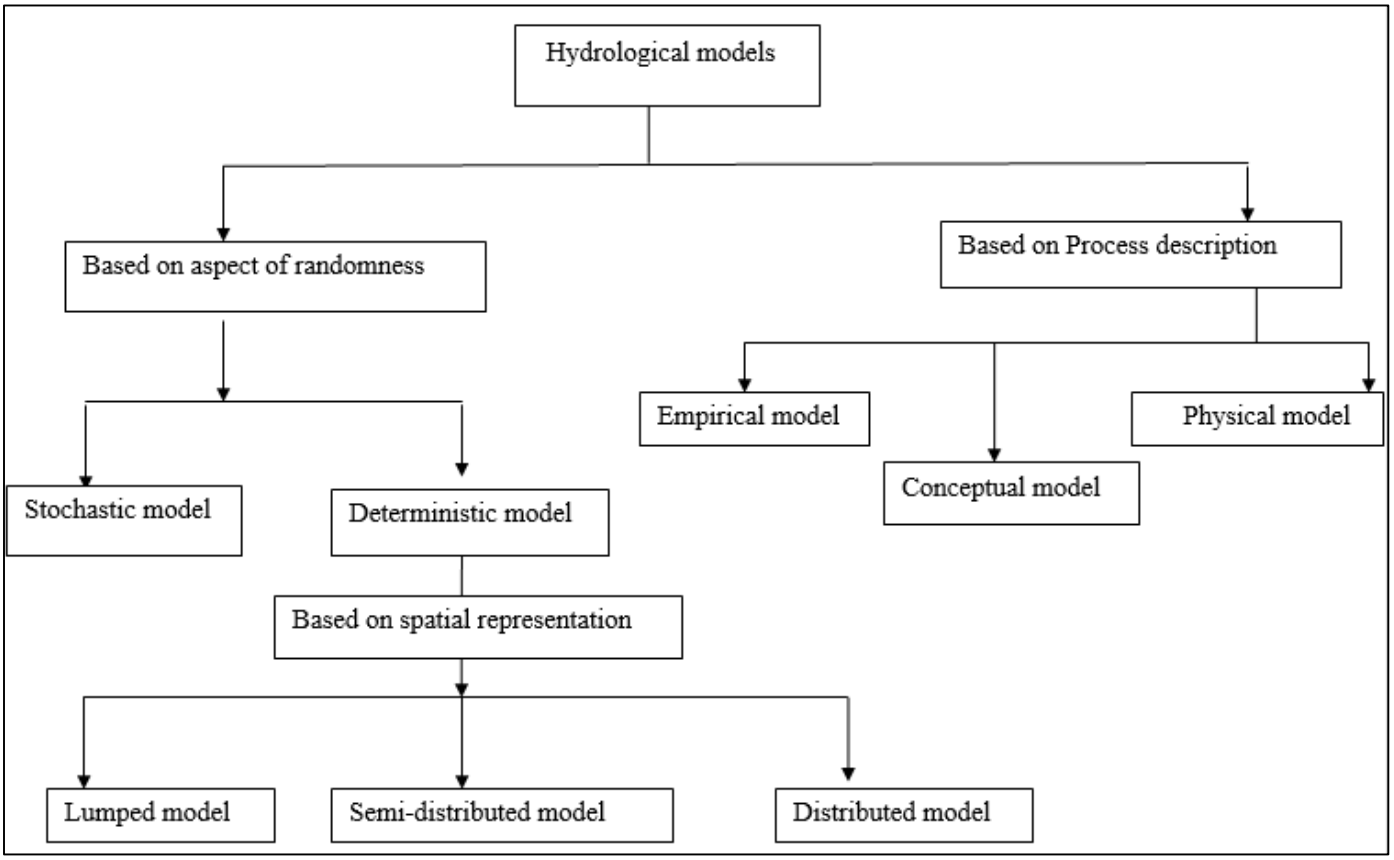

Fig. 2: Classification of hydrologic model

Hydrologic models based on randomness categorized under-

A. Deterministic Model

Deterministic hydrological model will give the same output for a single set of input values. It does not consider randomness. Deterministic model make forecasts. It is further divided into steady flow hydrological model and unsteady flow hydrological model.

B. Stochastic Model

In stochastic hydrological models, different values of output can be produced for a single set of input valves. These models have output that are at least partially random. Stochastic model make predictions. They are divided into time independent, time correlated space independent and space correlated.

Deterministic hydrological model based on spatial representation divided into-

1) Lumped Model
2) Semi-Distributed Model
3) Distributed Model

1) Lumped model

Input parameters do not vary spatially within the basin in lumped model and the response is evaluated only at the outlet without explicitly accounting for the response of individual sub basin. Even the system in lumped model is spatially averaged or regarded a single point in a space without dimensions. Example- many model of rainfall runoff process treats the precipitation input as uniform over the watershed and ignores the internal spatial variations of watershed flow. In this type of hydrological model the input parameters do not represent the physical features of hydrological processes and the model parameters are area weighted average. These models are not applicable to event based processes. These hydrological models predict discharge only at outlet. These models are very simple in nature and require minimal input data. These models are easy to use. Some examples of lumped model are SCS-CN based models, IHACRES, WATBAL etc. Lumped models worked on the basis by taking entire basin as a single unit and disregarding the spatial variability. Hence it calculated the outputs without considering the spatial variability of natural processes.

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2) Semi-Distributed Model

The input parameters in semi- distributed model are allowed to vary in space partially by dividing the basin into a number of smaller sub basins. These models are mainly two types. First one is Kinematic wave theory models which includes HEC-HMS model and many other is simplified version of surface flow equations of physically based model. Second is Probability distributed models in which spatial resolution is accounted for by using probability distributions of input parameters across the basin. The advantage of these models is that their structure is more physically based than the lumped models. Even these models are less demanding on input data than distributed models. Some examples of these models are SWMM, HEC HMS, TOPMODEL, etc.

3) Distributed Model

The input parameters in distributed models are allowed fully to vary in space at a resolution chosen by the user. These models considered the hydrological processes taking place at various point in space and defined the model variables as function of the space dimensions. An attempt has been made in these models to incorporate data concerning the spatial variability distribution of parameters along with the computational algorithms. These models requires large amount of input data. The governing physical processes occurring in nature are modeled in detail in these models. The results obtained through these models are at any location and time. If accurate data regarding inputs are available, highest accuracy is achieved with these hydrological models while modeling the natural process such as rainfall-runoff modeling. These models require high computational time and are bit cumbersome in nature. Even good experts are required to handle these models. Some examples of these models are HYDROTEL; MIKE11/SHE, WATFLOOD etc. 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.

Table 1: Characteristics of lumped model, semi-distributed model and distributed model

Lumped model	*Semi distributed model*	*Distributed model*
Input parameters do not vary spatially within the basin.	*Input parameters are allowed partially to vary in space.*	*Input Parameters are allowed fully to vary in space at a resolution chosen by the user.*
Response or output is evaluated only at the outlet without considering the response of individual sub basin. .	*Response is evaluated by dividing the basin into a number of smaller sub basins.*	*Response is evaluated by considering whole basin into small sub basins.*
Not applicable to event based processes		*Applicable for event based processes*
Parameters do not represent physical features of hydrologic processes; model parameters area weighted average	*Lies between lumped and distributed models*	*Consider the hydrologic processes taking place at various points in space and defines the model variables as function of the space dimensions.*
Less data requirements.	*Less demanding on data than distributed models*	*Requires large amount of data.*
Easy in use		*Experts are required*
Result prediction at outlet only		*Results prediction at any location and time*
Simple in nature and minimal computational time		*Cumbersome in nature and high computational time*
Example: SCS-CN based models, IHACRES, WATBAL etc.	*Example- SWMM, HEC HMS, TOPMODEL, etc.*	*Example- HYDROTEL; MIKE11/SHE, WATFLOOD etc.*
Not consider governing processes during result predictions.		*All governing physical processes are modeled in detail.*
Not very accurate		*Highest accuracy is achieved if accurate data is available*

One of the most important classifications is empirical model, conceptual models and physically based models based on process description.

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.

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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) 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 2: Showing characteristics of Empirical model, Conceptual model and physically based model

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*

C. Some other Classified Hydrologic Model

Physical model and abstract model-Physical model include scale model which represent the system on a reduced scale such as a hydraulic model of dam. Abstract model represent the system in mathematical form.

Based on time factor- Static and dynamic models. Static model exclude time while dynamic model include time.

Event based and continuous models: The former one produce output only for specific time periods while the latter produces a continuous output. (Sorooshian et al. 2008)

IV. CONCLUSION

In general, hydrological models are the standard tools which used to study various hydrological processes occurring in nature. In today's environment a large number of hydrological models with different utility and applicability have been developed. These models may ranges from small catchment model to global models. Each hydrological model has its own unique characteristics and respective applications. These models are classified under different categorized according to various parameters. Distributed models are comprehensive in nature and use the spatial variability of hydrological processes. These models are distributed both in space and time. These hydrological models are used for the modeling of both gauged and ungauged catchments. They helps in various task including flood forecasting, water resource management, planning and its design, water quality evaluation, control of erosion and sedimentation, nutrient and pesticide circulation monitoring, impact of climate change, land use, land cover changes

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etc. All hydrological models which were discussed in this paper have various drawback such as large data requirements, lack of user friendliness etc. To overcome these drawbacks, it is necessary that all hydrological models include latest remote sensing technologies, risk analysis etc. Numerous researches are still going on to make better predictions in hydrological models and make them more efficient than earlier to face major challenges in the coming days. So it is necessary to improve the existing theories or to develop new theories regarding hydrological models in order to find the impact of various physical processes associated with nature such as climate change, land use, land cover changes and many more.

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