Hydrological Modeling in Malaysia

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Abstract Hydrological modeling in Malaysia using two-dimensional fully distributed and physically based model is relatively new. Basic guidelines in choosing model dimensions (i.e., 1D, 1D–2D, 2D, and 3D) are discussed. The application of 3D model will give more accurate results if the groundwater movement is considered but requires more time to simulate and prepare input data. However, the 1D model is less accurate in representing the real topography of the study area, even though requires short time to simulate. This chapter also gives an overview about the hydrological modeling in Malaysia which ranges from 1D to 3D. Several researches on hydrology using different model were reviewed. The success of each model will be highlighted.

Keywords Hydrological modeling • Lumped model • Distributed model

1 Introduction

For the past 5 years, the frequency and magnitude of floods in Malaysia have been relatively high. Generally, floods happen between November and February each year due to the Monsoon climate. These floods have caused lots of damages but also provide lots of valuable information. In recent years, rapid development within a river watershed has resulted in higher runoff and decreasing river capacity. These, in turn, resulted in an increase in flood frequency and magnitude [1]. The government has been spending a lot of money on flood mitigation projects in urban and rural areas. Improper methods for predicting peak discharge, time to peak, and volume of water lead to inappropriate channel design [2].

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In Malaysia, the prediction of flood frequency using stochastic models is common. The statistical concept [3–6] and artificial neural network (ANN) [7–9] are the preferred methods as compared to other stochastic models. This method is well developed and widely tested. However, this method is reliable if the recurrence intervals of the peak discharge do not exceed the lengths of recorded peak discharges data [10, 11]. In addition to this, the maximum flood hydrographs are also important for the solution of many hydrological and environmental problems.

Increasing demands on computer models that can estimate more precisely the peak discharge, time to peak, and volume of water is a need. This is important to allow more adequate warning time to be issued, which leads to a better response from relevant agencies in protecting public, property, and infrastructure. However, computer models are still relatively new in Malaysia even though it has been widely used in many other countries [12].

Selection of one-dimensional model is the most common approach to carry out the hydrological modeling [13]. The engineers are aware of the importance of using two-dimensional model in simulating the hydrological events. However, in Malaysia, particularly, the lack of reliable basic data such as DEM, land use, and soil type are main obstacles.

The main purpose of this chapter is to review the use of hydrological modeling in Malaysia. The criteria for selection of the model also will be discussed and summarized.

2 For the Selection of Hydrological Model

There are several well-known hydrological models currently in use. The availability of source code is one of the main criteria for model selection. The model must also have the ability to support the fully distributed parameters and the two-dimensional overland routing approach. Some models use either a semidistributed or lumped (Fig. 1a) approach, which does not consider the spatial variability of processes, boundary condition, and watershed geometric characteristics. A fully distributed model (Fig. 1b) is expected to give better results than a semidistributed model [15]. The two-dimensional overland (Fig. 2b) routing is important as compared to one-dimensional overland (Fig. 2a) routing because it is very helpful to analyze outputs, which provides more information. An extra-added value to the model is the ability to work with raster GIS database. The availability of rainfall and flow data is also considered.

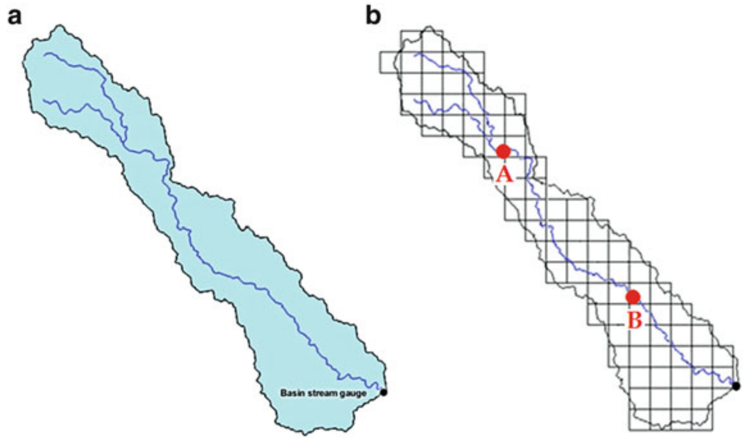

Fig. 1 Lumped and distributed [14]. (**a**) Lumped model. (**b**) Distributed model

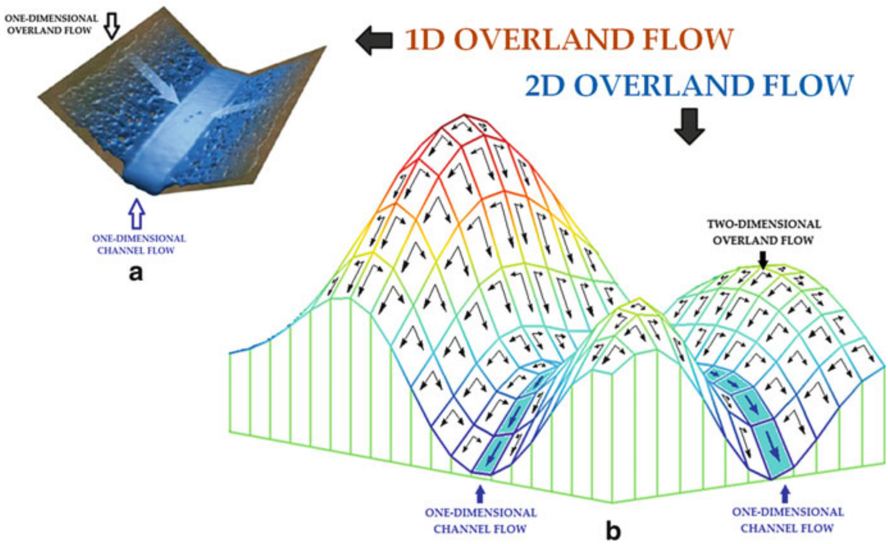

Fig. 2 Comparison of overland flow. (**a**) 1D overland flow (modified from [14]) and (**b**) 2D overland flow

3 Lumped Versus Distributed Models

Lumped models (Fig. 1a) have been used for more than 50 years to estimate flow at the watershed outlet. The simplification of many watershed characteristics may affect the simulation results. The parameters used in this model are spatially averaged and uniform across the watersheds [16, 17], and the number of parameters is less [18]. However, in reality, these input data vary.

A number of questions remain as to how the variability of rainfall and watershed characteristics impact runoff to generate the streamflow at the watershed outlet [19–22]. Nowadays, instead of lumped modeling, distributed modeling, as shown in Fig. 1b, is becoming a more favorable approach in research. This is because most of the models are compatible to work with GIS, the emergence of large data sets and the increased efficiency of powerful computer to simulate and display the results [21]. Distributed models better represent the spatial variability of factors that control runoff, thus enhancing the predictability of hydrologic processes [15, 23]. These models usually use parameters that are directly related to the physical characteristics of the watershed, including topography (i.e., elevation), soil type, channel properties, and land use. The climate variability can also be taken into account as reported by [24]. Results are presented in the form of spatial and temporal characteristics [25–27].

4 Selection of the Complexity of the Model

The risks of not being able to represent the topography of the watersheds, the difficulty in getting solution, and the application of the hydrological models at different size of watersheds are the main concerns in selecting the complexity of the hydrological model (CHM). Figure 3 shows the "trade-off diagram" for the CHM

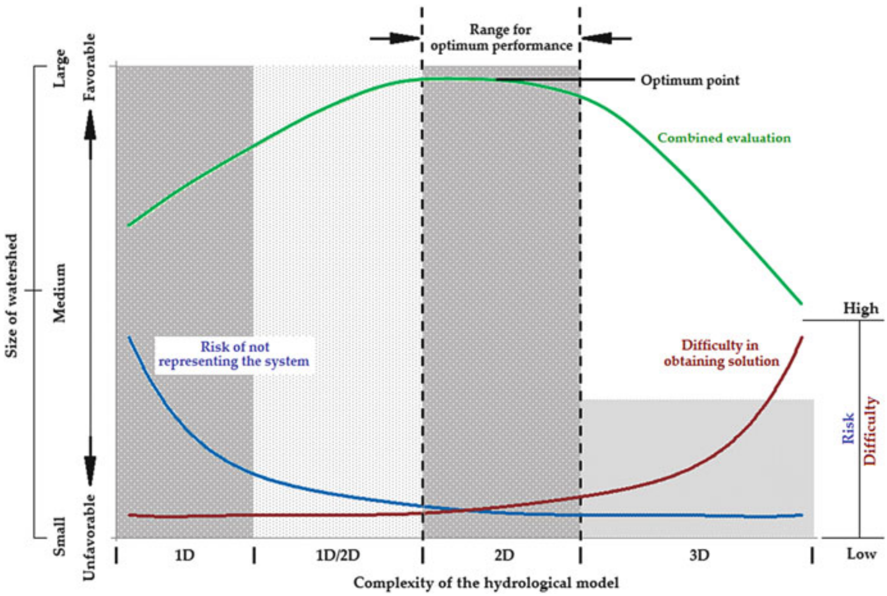

Fig. 3 "Trade-off diagram" in selecting dimensions of hydrological modeling (modified after [28])

(i.e., one-, integrated one-two, two-, and three-dimensional hydrological modeling) and size of watershed.

Generally, the choice of CHM depends on the project objectives [29, 30] and scopes, the knowledge and skills of the modeler, resources constrain [28], and time and length scale [31, 32]. In addition to these, the optimization and presentation of the final output should be considered, as described by [33]. Choosing a complex hydrological model will represent the characteristics of the watershed better, but it will be difficult to obtain the solution. Another factor that should also be considered is the size of watershed. A simpler model was usually selected when a large size of watershed is to be modeled. From Fig. 3, the 1D and 2D models are more favorable to simulate hydrological model for any size of watershed. Conversely, the application of 3D model in hydrological model to variety of size of watershed is scarce [31, 34]. According to them, a 1D or 2D model is sufficient to simulate this distribution as compared to 3D, which may not be realistic because it currently is very costly.

4.1 Risk of Not Presenting the System

In hydrological modeling, the representation of the system should be as accurate as it supposed to be. The representation of the system can be extracted directly from the digital elevation model (DEM). This is the most important data because topography controls runoff and watershed boundaries [35]. The shape and timing of the hydrograph have shown to be a function of size, slope, shape, soil types, storage capacity, land use, and climatic variables. When a model is able to reflect the principle of how a watershed functions hydrologically, then the possibility to extrapolate beyond current situation with reliable prediction may be possible [36]. Rainfall intensity and duration are the major driving forces of the rainfall-runoff process, followed by watershed characteristics that translate the rainfall input into an output hydrograph at any point of the watershed.

4.2 Difficulty in Obtaining Solution

The difficulty in obtaining solution covers: (1) ease to use and to prepare the input data, (2) model accuracy, (3) hydrologic parameters consistency, (4) sensitivity of the output when parameters change, (5) storage (in computer hard drive) require for the output, (6) data limitations, (7) computer time simulation, and (8) availability of data. The availability of data is the most important in selecting the CHM [37]. In general, the 1D model can predict flow and produce hydrograph when it has been calibrated and validated.

According to [38, 39], the basic idea in the selection of models is to adopt the simplest model (i.e., easy to use and apply) that will provide acceptable results. However, the ease of application will also depend upon the individual experience of the modeler, both in the use of the model and the knowledge of the watershed. Generally, the complexity of the model is strongly related to the ease of the application. That means, the simpler models normally require the least effort to apply and least effort in calibration and validation as compare to more complex model [40–42].

Study conducted by [43] concluded that the accuracy of the model may vary and mostly inconclusive, and therefore controversial. However, studies show that most rainfall-runoff models will predict runoff and streamflow with similar accuracy [40–42, 44–48]. The accuracy of the model is determined by availability of the input data and observed input and output time series at various locations in a watershed [37]. The accuracy of the model can be measured using model performance evaluation techniques as suggested by [49, 50], and [51]. The sensitivity analyses of a model will reveal information on the relative importance of many input parameters as well as uncertainty in the model output [52].

5 Hydrological Modeling in Malaysia

In Malaysia, models from the United Kingdom (UK), United States of America (USA), and Australia are widely used for rainfall-runoff simulations. References [53–57] used the commercial software InfoWorks River Simulation (IWRS), while [58] used InfoWorks Collection System (IWCS) from the UK to simulate rainfall runoff. Hydrological model from USA such as HEC [59–61], L-THIA program [62], MIKE [63–65], and MAYA 3D have been used to simulate flood events [66]. The 2DSWAMP and XP-SWMM models from Australia are used by [67] and [68] to simulate runoff. These models except L-THIA are not publicly available. Most hydrological modeling studies in Malaysia were carried out using a one-dimensional approach except [65] and [67], which are two-dimensional approaches.

Commercial softwares from the UK, namely IWRS and IWCS have been widely used in simulating hydrological processes. Reference [58] used the IWCS model in their case study at Tanjong Malim, Perak, to draft a comprehensive stormwater management and flood mitigation plan for local authority. They found that this model has the ability to model the interaction between rivers and urban drainage. These results were very useful to design the flood mitigation plan based on the impact of various design storm events to the study area. Additionally, the study also provides the local authority valuable information to plan for existing and future land use changes. References [53–56] used the IWRS model to simulate the impact of runoff on the floodplains and the water quality of the river before and after the floods. They successfully simulated these events, and the information is very useful to the city council for flood mitigation design and water quality management. The IWRS software simulated the flood events at the Damansara Catchment (Kg. Melayu Subang—upstream, Taman TTDI Jaya, Batu 3, and Taman Sri Muda) in 2006, 2007, and 2008 [57]. The model has the ability to simulate and produce hydrograph that is very useful in designing structures such as retention ponds and flood walls especially in the low-lying area (Taman TTDI Jaya and Batu 3 in Shah Alam, Selangor).

Reference [59] used the commercial software HEC-HMS to determine the runoff and hydrograph characteristics modeling for an oil palm plantation at the Skudai River watershed. From the high index of the model performance (calibrated and validated models efficiency index of 0.81 and 0.82, respectively), they suggested that the model can be used for filling the missing runoff from rainfall data. The HEC-HMS software estimated the flood at Johor River [60]. Good agreement was shown in the evaluation of peak discharge, and the model performance is close to unity. The HEC-2 model has been adopted by [61] to predict water surface profiles for Langat River at Selangor and Linggi River at Negeri Sembilan. The HEC-2 model was developed by the US Army Corps of Engineers especially to compute water surface profile. This model has successfully predicted the water level at Linggi River, Negeri Sembilan with a small error. However, the application of this model to the Langat River, Selangor, does not reach good agreement. Therefore, they concluded the model can be applied at tropical rivers with reasonable error if the input data is good.

Modeling the effects of mangroves on tsunamis has been applied using commercial software from Australia, namely 2DSWAMP by [67]. This model has been used to investigate the pattern of mangrove trees distribution and the diameter that can affect the attenuation of tsunamis at Merbok Estuary, Kedah. A one-dimensional hydrodynamic model, namely XP-SWMM, has been used by [68] to simulate flood water of the Damansara River at TTDI, Selangor. They studied the time of water filling and volume of flood discharge (m^3/s) over the flood plain. They were successful in producing a Flood Hazard Mapping for Urban Area (FHMUA). A free commercial program, L-THIA (developed by Purdue University), simulated the runoff at Pinang River, Pulau Pinang [62]. Reference [65] analyzed the flood event at Damansara River, Selangor using MIKE-FLOOD. The two-dimensional simulation provides crucial information with regard to the direction and rate of flood propagation, the flood inundation extents as well as flood depths and flood durations which cannot be achieved using one-dimensional simulation.

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