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Extending a Distributed Hydrological Model to Use Globally Available Topographic Data

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Synopsis

The KsEdge2D model is a distributed hydrological model developed at Kyoto University and it has been well studied and successfully applied for many basins in Japan. As the model was initially developed to utilize the Japanese topographical and river network data, it is not possible to apply for international basins due to the discrepancy of input topographical and river network data formats. This study presents the extension of the KsEdge2D model to use globally available topographic data. User friendly software named, DEM-V0-Maker was developed to generate the required topographical and channel network input data for the KsEdge2D model. Two basins, the Kamishiba Basin, Japan and the Mae Chaem basin, Thailand were selected to apply the KsEdge2D model using freely available topographic data. The results of both basins were compared with the observed data and it showed a good agreement.

Keywords: KsEdge2D model, globally available topographic data, Rainfall Runoff modeling, Mae Chaem Basin, Kamishiba Basin

1. Introduction

Understanding the hydrological response and quantification of available water in a basin is essential for proper management to cope with the possible water related disasters and to limited water resources. With regard to this, distributed hydrological models play an important role as it is capable of incorporating the basin heterogeneity. The KsEdge2D model (Tachikawa et al., 2004; Ichikawa et al., 2001) is a distributed hydrological model developed at Kyoto University and it has been well studied and successfully applied for many basins in Japan. As the model was initially developed to utilize the Japanese topographical and river network data, it is not possible to apply for international basins due to the discrepancy of input topographical and river network data formats. This study presents the extension of the KsEdge2D model to use globally available topographic data.

2. The KsEdge2D model

The model is based on the one dimensional kinematic wave theory and developed by Ichikawa et al., (2001). The basin's topography is represented in the model according to the methodology described in Shiba et al., (1999). In the model, it is considered that the basin consists of number of rectangular slope elements which drains to the deepest gradient of its surrounding (Fig.1).

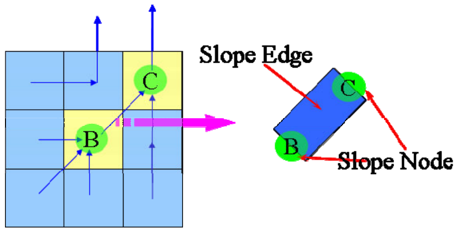

Fig.1 Representation of the Topography

The area of each element depends on the number of connections it has (Eq.1). Slope flow produced due to rainfall is routed one dimensionally. Then it flows to the channel network and routed to the basin outlet.

$$\left.\begin{array}{l} Area\ \ of\ \ the\ \ Cell\ \ = A, \\ Area\ \ of\ \ the\ \ Node\ \ B(a_b) = \dfrac{A}{4} \\ Area\ \ of\ \ the\ \ Node\ \ C(a_c) = \dfrac{A}{3} \\ Area\ \ of\ \ the\ \ Slope\ \ Edge\ \ BC = a_b + a_c \end{array}\right\} \quad (1)$$

It is assumed that the each slope segments of the basin covered with a permeable soil layer composed of capillary soil layer and non capillary soil layer. The flow processes of both soil layers and the overland flows are represented with kinematic wave model using a discharge–stage relationship introduced by Tachikawa et al., (2004). Figure 2 shows the flow process and the stage discharge relationship used in the KsEdge2D model.

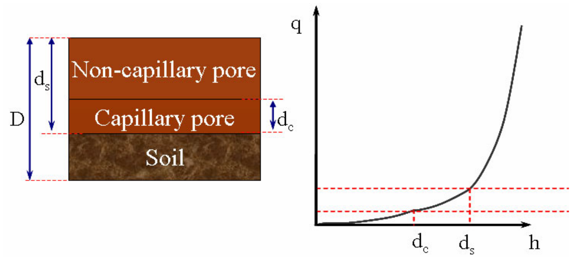

Fig.2 Flow process and Stage-discharge relationship

The relationship is described as follows;

$$q = \begin{cases} V_c d_c \left(\dfrac{h}{d_c}\right)^{\beta} & 0 \le h \le d_c \\ V_c d_c + V_a (h - d_c) & d_c < h \le d_s \\ V_c d_c + V_a (h - d_c) + \alpha (h - d_s)^m & d_s < h \end{cases} \quad (2)$$

Where, q is the discharge per unit width; h is the stage; Va and Vc are flow rates from the capillary pore and non capillary pore respectively

3. Methodology

The KsEdge2D model requires basically two files, one with coordinates and the elevation of grid cells center points (NodeV0) and the other having the connection details and the properties of each edges of the basin (EdgeV0), to represent the topography and the stream network of the basin. A computer model, referred as DEM-V0-Maker is developed to generate two files having the same data structure as the EdgeV0 and the NodeV0 files, using the globally available Digital Elevation Model (DEM).

3.1 Required data for the *DEM-V0-Maker*

Starting from DEM, the X, Y and Z Coordinates of the center point of all cells are obtained. After filling the sink and removing the pits using the sink and pit removing functions available in ArcInfo, the flow direction is derived according to D8 method (Jenson and Domingue, 1988). This method considers 8 surrounding cells to find the maximum slope direction of each cell and assign an identical number for the cell corresponding to the maximum slope. Figure 3 shows the numbering system used for the flow direction grid in the DEM-V0-Maker software.

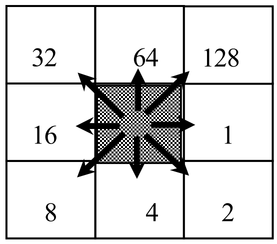

Fig.3 Eight flow directions numbering system used in DEM-V0-Maker

The flow accumulation grid is obtained from the flow direction grid and all these grid files are converted in to ASCII text file format as the DEM-V0-Maker designed to read the information directly from the ASCII text files. Gird functions, FLOWDIRECTION, FLOWACCUMULATION and GRIDASCII available in ArcInfo was used in this regard. In addition to these data, it is necessary to give the basin boundary information. Therefore, basin boundary grid is prepared in such a way that the cells which are inside the basin defined by the basin outlet are assigned an integer value and for out side cells are assigned the number –9999.

3.2 Representation of the channel network in *DEM-V0-Maker*

The original KsEdge2D models utilize the channel network detail available in Japan. But in general it is difficult to find such detail channel network information in other places specially in the developing countries. Therefore, channel network information also derived using flow accumulation information of the basin. In this regard, the cells having flow accumulation value grater than a threshold are treated as streams. Figure 4 described the Edge and Node arrangements at different places in the basin when representing the channel network for the KsEdge2D model.

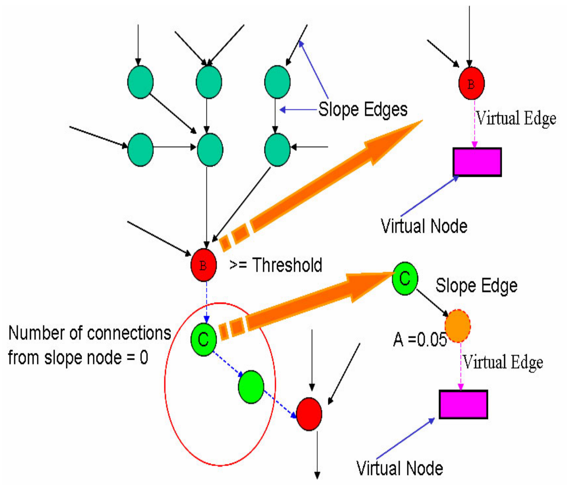

Fig.4 Edge and Node arrangements at different places in the basin

The model calculates the flow through slope edges due to the rainfall and stored at each river node (Virtual Node). In the KsEdge2D model, there are two ways of calculating the stream flow at the basin outlet.

[1] Without considering the river routing; here the stored values at each virtual node are added together.

[2] Include river routing model; virtual nodes connect to the River model and routed to the basin outlet.

3.3 Graphical User Interface (GUI) of the *DEM-V0-Maker* software

The DEM-V0-Maker was coded using Visual Basic 2005 programming language and it was design to have a user friendly graphical environment to locate the input data, arrange the output files and etc.

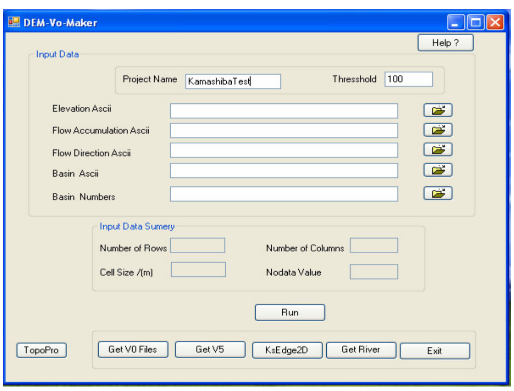

Fig.5 GUI of the DEM-V0-Maker software

4. Model application and Results

Two basins, the Kamishiba in Japan and the Mae Chaem in Thailand were selected to apply the KsEdge2D model using globally available topographic data.

4.1 The Kamishiba Basin Japan

The Kamishiba basin is situated in the Miyasaki Prefecture in Japan and having basin area of 211 km^2. Average annual rainfall of the area is about 3000 mm. The KsEdge2D model has been applied successfully to the Kamishiba basin by using Japanese topographic and river network data and the model parameters were calibrated. Several modelling studies are been carried out for this basin during past few years. Therefore it is a good basin to take as a test basin for DEM-V0-Maker software. Figure 6 shows the location of the Kamishiba basin and the 90m Shuttle Radar Topography Mission (SRTM) DEM of the basin (http: //seamless. usgs.gov/).

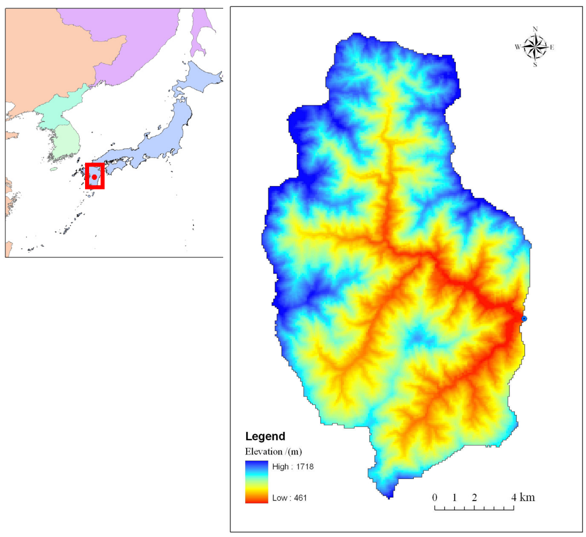

Fig.6 The Kamishiba Basin, Japan

After removing the sinks and pits of the DEM, the flow direction, flow accumulation grids were obtained. Then the basin boundary was delineated and converted all these raster grid data in to ASCII text file format using ArcInfo software. These files were then used as the input files for the DEM-V0-Maker and the required data files for the KsEdge2D model were generated. Observed rainfall and discharge data for one flood event (Sep.1997) was obtained. The same calibrated model parameters for Japanese topographic data were used to run the model for SRTM data and compare the results with observed and predicted discharges. The calibrated model parameters using Japanese topographic data are shown in Table 1and the Fig.7 shows the observed and model predicted hydrograph for the flood event.

Table 1 – Calibrated KsEdge2D model parameters

Parameter	Value
Manning coefficient ($m^{-1/3}$ s)	0.3
Kinematic parameter (-)	1.667
Hydraulic conductivity (m/s)	0.55
Depth of A-layer (m)	0.45
Depth of field capacity (m)	4
Beta (-)	0.65

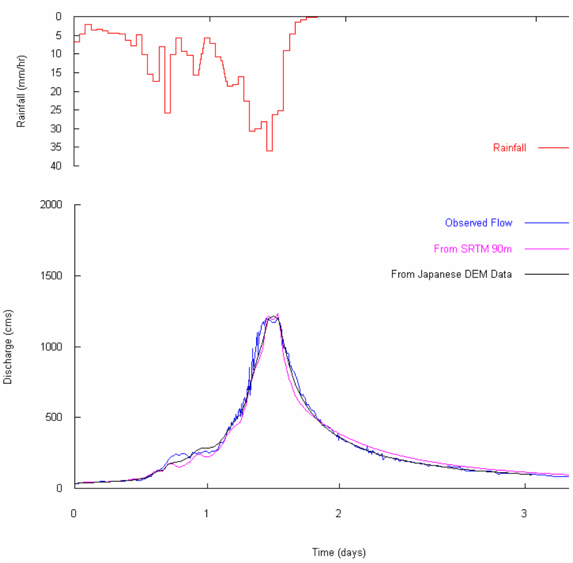

Fig.7 Observed and KsEdge2D model predicted hydrograph for Kamishiba Basin – 1997/September flood event

It is observed that the KsEdge2D model predictions using SRTM topographic data shows good agreement with the observed discharge. Therefore, it is good evidence to prove that the converted globally available topographic data in to the input data format of the KsEdge2D model using the DEM-V0-Maker software is correct.

Channel network represents in the DEM-V0-Maker by using a flow accumulation threshold value. Therefore it is important to study on the effect of threshold value on the model prediction. Study was carried out Using 90m DEM for the Kamishiba basin for different threshold values and the results are shown in Fig.8. Same model parameters shown in Table 1 are used.

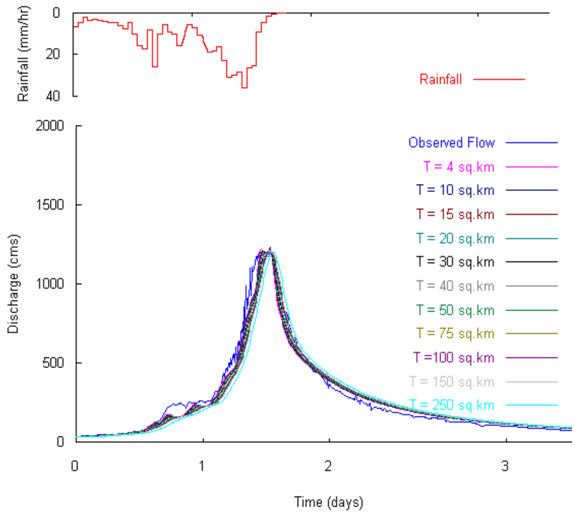

Fig.8 Effect of threshold on the predicted hydrograph

According to the figure, the time to peak of the predicted hydrograph increases with the increasing of the threshold value. When the threshold is 250 km^2, the whole basin treated as slope elements because in that case the basin size is less than the threshold. Therefore, the threshold value 250km^2 corresponds to the maximum deviation of the peak time for Kamishiba basin. According to the above results, it can be recommended to use a threshold value less than 30 km^2.

In addition to the effect of the threshold, the effect of the grid cell resolution on the predicted hydrograph is also studied. 1000m, 500m and 250m DEMs were prepared by re-sampling the 90m SRTM DEM. Required topographical input files for the KsEdge2D model were obtained for each case by using DEM-V0-Maker programme and applied the model with same model parameters shown in Table 1. Results are shown in Fig.9.

It is observed that the peak discharge increases and shows a quick resection with the increase of the grid cell size. To find out the reason for this model behaviour is needed and at present it is been studying.

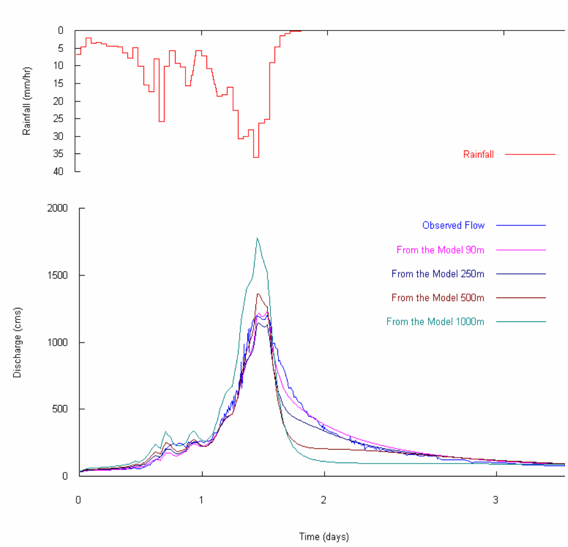

Fig.9 Effect of grid cell resolution on the predicted hydrograph

4.2 The Mae Chaem basin, Thailand

The basin is 3853 km2 in size and 90% of the area is covered with forest. Average annual rainfall and the discharge of the basin are 1426mm and 1020 MCM respectively. DEM (GeoTOPO 30) and daily hydro-meteorological data are obtained from the research project, "PUB-JP Blind Test in Mae Chaem Basin" (ICHARM, 2007). Figure 10 shows the location and the DEM of the basin.

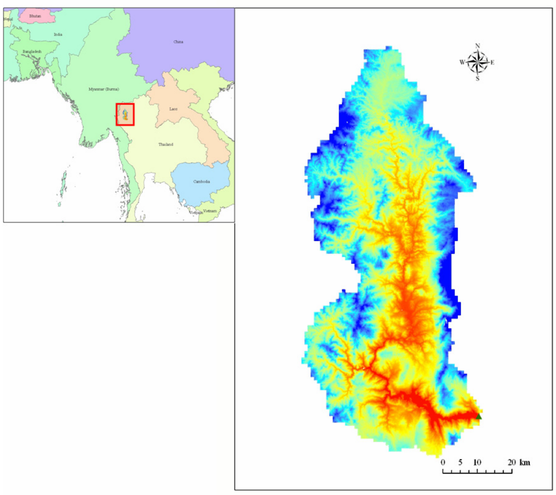

Fig.10 Mae Chaem Basin, Thailand

The EdgeV0 and NodeV0 data files for the basin are obtained using the DEM-V0-Maker programme developed under this study. Then the KsEdge2D model is successfully applied to the basin using the above data derived from the DEM-V0-Maker programme. The model predicted hydrograph and the observed hydrograph are shown in Fig.11.

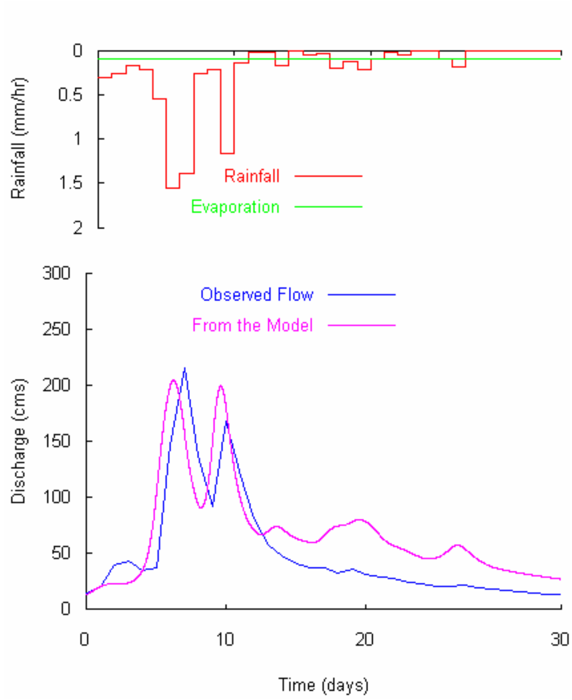

Fig.11 The model predicted and observed hydrographs

The channel routing of the basin is neglected at this stage and the model parameters are also not the optimum parameters for the basin. This study was carried out as an initial step to check the applicability of the KsEdge2D model for large basin using global topographical data. Therefore incorporating the channel network information in to the model is in progress.

5. Conclusions and future studies

5.1 Conclusions

The Kyoto University Distributed hydrological model, KsEdge2D was extended to applicable for any basin in the world using globally available topographical data. Additional software named DEM-V0-Maker was developed to generate the input topographical data required for the model. It was tested by applying the model to Kamishiba basin, Japan with SRTM 90m DEM. The results revealed that the DEM-V0-Maker successfully generates the topographical and channel network data required for the KsEdge2D model from global topographical data. The effect of the threshold value on model predictions were also studied and concluded that the threshold value less than 30 km^2 is suitable. Furthermore, the model was successfully applied to a large river basin, the Mae Chaem basin in Thailand.

5.2 Future studies

It is found that the model responds differently with the input DEM resolution and further study will be carried out to find out the governing factors for these differences. It is planned to apply the model for different basins in different hydrological regions in the world and study on the optimum model parameters for each region will be carried out. Study on the accuracy of the spatial stream flow prediction using distributed hydrological model will also be studied.

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グローバル地形情報を用いた分布型流出モデルの拡張

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要　旨

KsEdge2Dモデルは京都大学で開発された分布型流出モデルの一つであり，国内の多数の流域で研究され，適用されてきた。この分布型流出モデルは国土地理院が提供する国土数値情報を利用することを前提として開発されているため，そのままでは国外の流域に適用することは難しい。そこで本研究では，KsEdge2Dモデルを地球上のあらゆる陸域に適用することを可能とするために，グローバルに適用可能な標高情報(SRTM, Shuttle Radar Topography Mission, DEMs)を加工して，KsEdge2Dモデルのための地形情報と河道情報を作成する前処理プログラムDEM-VO-Makerを開発した。日本の上椎葉流域およびタイ国のMae Chaemを対象として，前処理プログラムDEM-VO-Makerが適切に動作することを確認した。これにより，あらゆる国際流域においてKsEdge2Dモデルを適用することが可能となった。両流域でKsEdge2Dモデルを適用し，観測流量を適切に再現できることを確認した。

キーワード: KsEdge2D モデル，グローバル地形情報，降雨流出モデル，Mae Chem 流域，上椎葉流域