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A grid-cell based distributed flood runoff model and its performance

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Abstract Distributed parameter runoff models were recently developed and are expected to be used in practice. They have the ability to define model parameter values with spatially-distributed data such as topographic data, land-use data, radar rainfall and remote sensing images. This paper introduces a grid cell based kinematic wave runoff (GC-KWR) model that was developed by the authors in 1998, and discusses the effect of spatial resolution of the grid cell based distribution runoff model. The authors compare the 50-m resolution model with the 250-m model. The 250-m model tends to give earlier peak time and larger peak discharge. This paper also compares the distributed runoff model with two models conventionally used in Japan: the storage function model and the slope-channel system KWR (SC-KWR) model. The GC-KWR model and SC-KWR model can reproduce the observed hydrographs well, while the performance of the storage function model depends on flood events and study areas.

Key words DEM; flood precipitation; GIS; grid cell based distributed model; kinematic wave model; storage function model

INTRODUCTION

Distributed parameter runoff models have recently been developed and are expected to be used in practice. They have the ability to define model parameter values with spatially distributed data such as topographical data, land-use data, radar rainfall and remote sensing images. The authors developed a grid-cell based distributed kinematic wave runoff (GC-KWR) model in 1998. This distributed runoff model needs geographical data such as flow direction, slope and land cover on each grid cell for the hydrological modelling. The model parameters, equivalent roughness coefficients, are defined using land cover/use developed by the Geological Survey Institute Japan (GSI) or generated from remote sensing imageries. This paper introduces the development of the GC-KWR model and describes its applications to two basins. The performance of the GC-KWR model is compared with two conventionally used models in Japan: the storage function model and the slope-channel system KWR (SC-KWR) model.

GRID CELL BASED KINEMATIC WAVE RUNOFF (GC-KWR) MODEL

The grid cell based KWR (GC-KWR) model has the following features:

(a) A square area on a node point of a DEM is considered as a sub-basin, which is called a grid cell. A river basin is modelled as a network of grid cell.

(b) Grid cells are connected to each other with a drainage path defined by the steepest direction. Each grid cell receives flows from upper grid cells and rainfall on it.

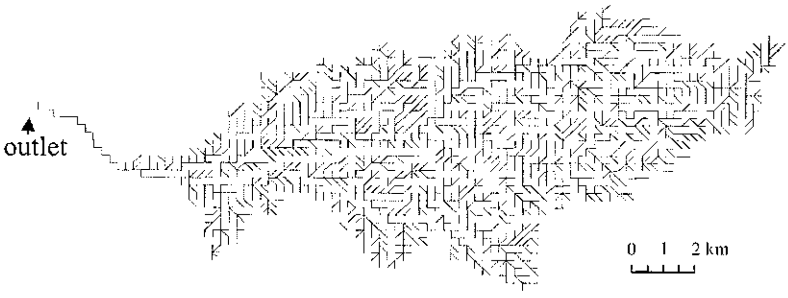


Fig. 1 Drainage paths with 250-m resolution at the Yada River basin.

(c) Runoff from each grid cell is calculated by the kinematic wave model.

Necessary model parameters for each grid cell are equivalent roughness value and topographic properties. Equivalent roughness values are assigned according to land-use/cover. Topographic properties such as slope angle and length are defined with a DEM. The grid cell based model is also applied to sediment yield prediction in an Indonesian river basin covered with volcanic ash (Kojima *et al.*, 2002)

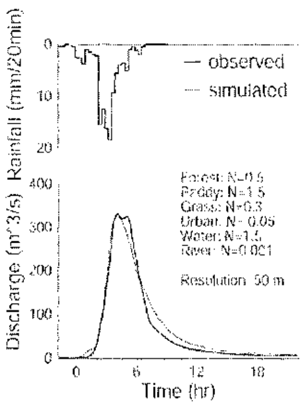
APPLICATION TO THE YADA RIVER BASIN

The GC-KWR model is applied to the Yada River basin (110 km^2), tributary of the Shonai River in Japan. Figure 1 shows the drainage paths with 250-m resolution. The effect of grid cell resolution is investigated. Figure 2(a) and (b) shows the hydrographs with the 50-m and 250-m resolution models, respectively. Both models use the same model parameters (equivalent roughness). The 250-m model has a tendency to give earlier peak time and larger peak discharge than the 50-m model. The reason is that the total length of the 250-m drainage paths is shorter than the 50-m model.

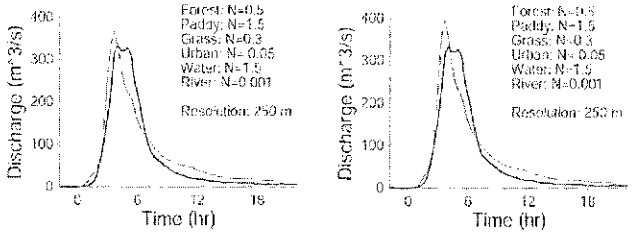
Using the 250-m model the effect of rainfall distribution on runoff at the outlet is examined. The spatial resolution of radar rainfall is about 2 km. Figure 2(b) and (c) shows the hydrographs with the spatially distributed radar rainfall and spatially-averaged (uniform) rainfall, respectively. The model with the spatially uniform rainfall estimates the larger peak discharge than that with spatially distributed radar rainfall. Figure 3 shows the movement of the rainfall field. In this case the heavy rainfall area moved from the downstream to the upstream. Thus, ignoring the movement of the rainfall area overestimates the peak discharge in this flood event.

APPLICATION TO THE SHONAI RIVER BASIN

The GC-KWR model is applied to the Shonai River (Shonai-gawa) basin (1010 km^2, see Fig. 4) and compared with a conventional lumped model and a traditional kinematic wave model. Simulated discharges are evaluated at the outlets of sub-basins Shidami, Tajimi, Toki and Mizunami for seven flood events between 1990 and 1995.



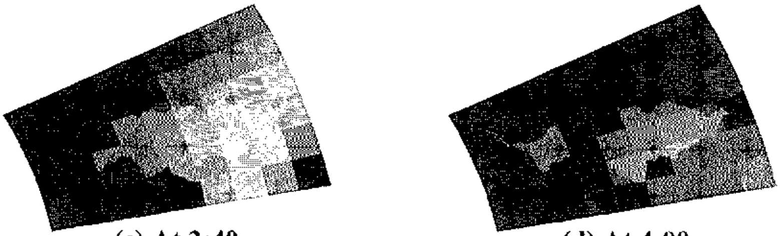
(a) 50-m resolution with spatial distributed rainfall.



(b) 250-m resolution with spatial distributed rainfall. (c) 250-m resolution with spatial averaged rainfall.

Fig. 2 Comparison of simulated and observed hydrographs.

(a) At 3:00 **(b) At 3:20**



(c) At 3:40 **(d) At 4:00**

Fig. 3 Movement of rainfall fields.

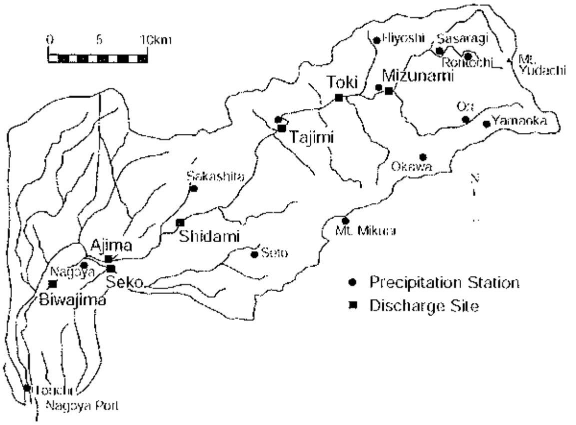


Fig. 4 The Shonai River basin.

Storage function model

In the storage function runoff model, the storage-discharge relation is given as follows:

$$S = Kq^{P} \tag{1}$$

$$\frac{\mathrm{d}S}{\mathrm{d}t} = r_e(t-T) - q \tag{2}$$

where S is volume of storage, q is discharge, K and P are model parameters, $r_e(t)$ is effective rainfall, t is time and T is lag time.

The model has been applied and used for flood prediction in the Shonai River by the Shonai River Work Office, Ministry of Land, Infrastructure and Transport (MLIT), Japan. Based on the model parameter values K and P calibrated by the office, the authors simulated the hydrographs with the fixed values of P and K multiplied by the magnification factor in the study area. Figure 5 shows the variations of the three evaluation indices such as correlation coefficient between observed and simulated hydrographs during the runoff event (COR), mean relative error (MRE) and relative root mean square error (R.RMSE). Figure 5 shows that if we use 0.2 × K as the value of K, we may minimize the error between observed and simulated hydrographs for Flood 1.

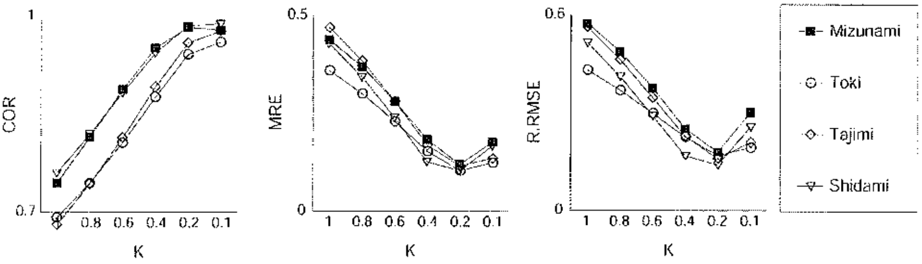
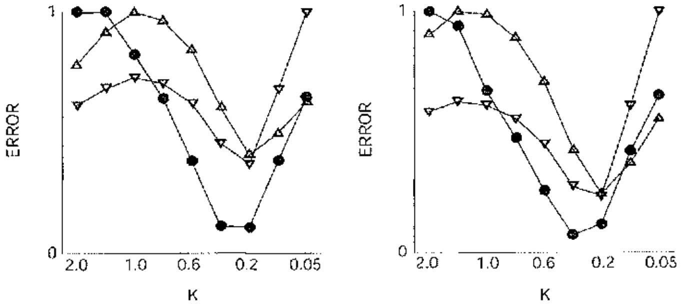
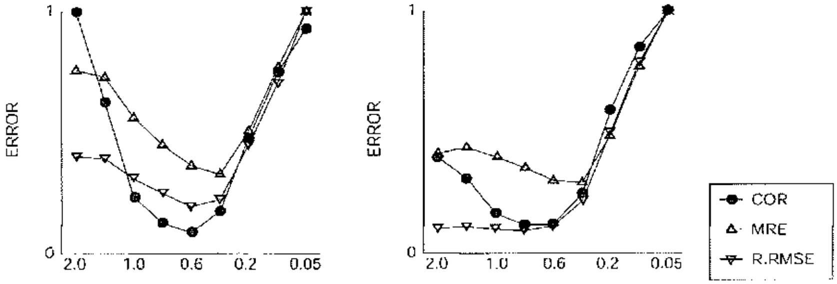


Fig. 5 Variations of the evaluation indices of the storage function model applied for Flood 1.



(a) Flood 2 (b) Flood 3



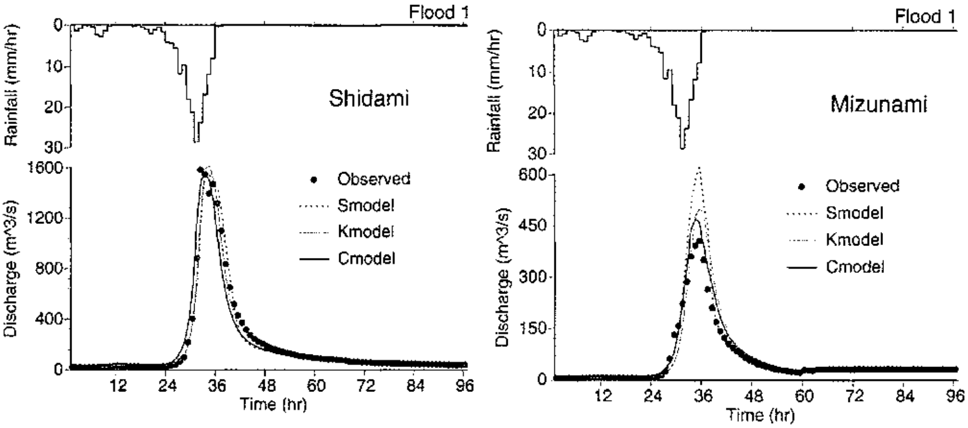
(c) Flood 4 (d) Flood 5

Fig. 6 Variations of the evaluation indices of the storage function model for the several flood events at Shidami.

Figure 6 shows the variations of evaluation indices for several flood events at Shidami. Figure 6 shows that the optimum magnification factors of K are 0.2 for Flood 2, 0.2–0.4 for Flood 3, 0.4–0.6 for Flood 4 and 0.4–0.6 for Flood 5. The optimum parameters of the storage function model change much depending on the flood events.

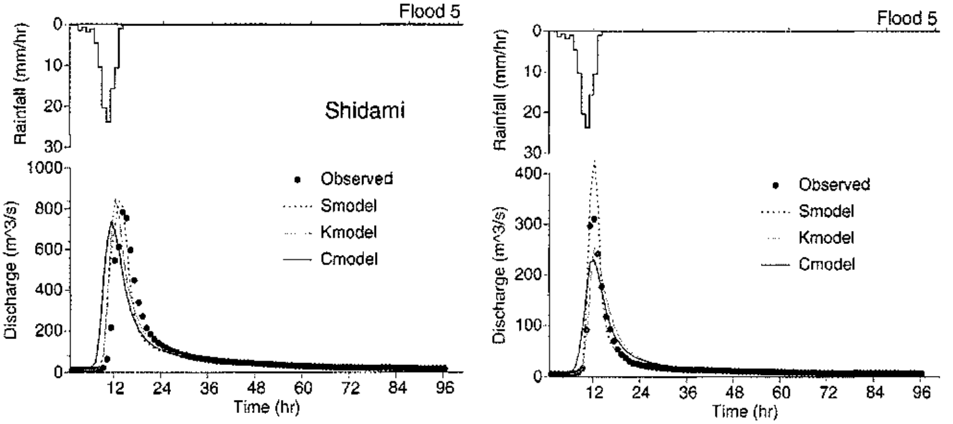
Slope-channel system KWR model

The Slope-channel system KWR (SC-KWR) model consists of sub-basins with a river channel section and rectangular slopes connected along the river channel section, on which the kinematic wave model is applied to simulate overland flow. This runoff model requires the topographic properties such as slope angle, slope length and river length. These topographic properties are automatically calculated by tracing the drainage path based on 50-m DEM. The equivalent roughness coefficients are defined by land-use class of each slope. The authors verified the effect of the urban area roughness value. The fixed roughness values ($m^{-1/3}$ s) of each land-use class are 1.0, 0.05, 0.3, 1.5 and 0.025 for forest, urban area, grass land, paddy field and river, respectively. These values are conventionally used in Japan (River Bureau, Ministry of Construction, 1998).



(a) Shidami (b) Mizunami

Fig. 7 Comparison of the simulated and the observed hydrographs for Flood 1.



(a) Shidami (b) Mizunami

Fig. 8 Comparison of the simulated and the observed hydrographs for Flood 5.

MODEL PERFORMANCE COMPARISON

Figures 7 and 8 are simulated hydrographs at Shidami and Mizunami with three runoff models for Flood 1 and Flood 5. For Flood 1, any runoff models can simulate hydrographs well at the outlet of the study area, Shidami, while the storage function model (S model) overestimates the peak discharge at the upper sites such as Mizunami and Toki. The GC-KWR model (C model) simulates the hydrographs well with slightly early peak time. The SC-KWR model (K model) can reproduce the observed hydrographs well with conventionally used roughness coefficients.

CONCLUSIONS

In this paper, we obtained the following findings:

(a) The 250-m resolution GC-KWR model tends to give earlier peak time and larger peak discharge than the 50-m model.

(b) The GC-KWR model represents the effect of the storm movement. Time and space rainfall distribution is effectively incorporated into the runoff model.

(c) The optimum model parameters depend on flood events in the storage function model.

(d) The SC-KWR model can reproduce the observed hydrographs well.

(e) The GC-KWR model can also reproduce the observed hydrographs well with a slightly earlier peak than the observed one. Further investigation is necessary to improve this tendency.

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