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A Generalised Storage Function Model Considering Rating Curve Relationship and Spatial Rainfall Distribution

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1. INTRODUCTION

Flood prediction is very important in both urban and rural watersheds due to the associated risk and costs. For this purpose, the spatially lumped, conceptual storage function (SF) models are important tools and they have been widely used in many parts of the world. However, most of the SF models require effective rainfall estimation for the prediction of direct runoff which is a subjective process and derives uncertainties in the model predictions. In order to overcome these problems, Baba et al. (1999) and Takasaki et al. (2009) developed SF models that use the observed rainfall, and total runoff directly and applied in different types of basins in Japan. Hence, there is a need for an SF model that can be applied in all types of watersheds without requiring the effective rainfall as their input. All the existing SF models require discharge data for their calibration and subsequent runoff analysis. The observed discharge is generally obtained from water level observations which are further converted to the discharge estimates using a well-defined rating curve. However, there will be inaccuracies in the discharge data resulting from errors in rating curves derived from stream gauging operations as well as due to extrapolation outside the limits of the rating curve. The direct prediction of observed water level will reduce the model uncertainties which is often sufficient to make an early warning about the flooding and to carry out control and evacuation activities from the disaster point of view. Based on the above discussions, this study aims to propose a generalized SF (GSF) model for the water level prediction from the rating curve relationship by considering the spatial distribution of rainfall over the basin and incorporating all the possible inflow and outflow components. Generally, there will be spatial variability in rainfall across a catchment and this spatial variability has not been considered in the SF models so far and thereby an attempt has been made for the first time to address this issue by introducing a new parameter called rainfall distribution factor, hereafter termed as γ, in the proposed GSF model.

2. METHODOLOGY

GSF model can be characterized by the following storage equation, $s = k_1(Q)^{p_1} + k_2 \frac{d}{dt}(Q)^{p_2}$ (1) where s: storage (mm), Q: observed river discharge (mm/min), t: time (min), and k_1, k_2, p_1, p_2: model parameters. The above equation can be utilized for the water level prediction by replacing the Q with the rating curve relationship as follows: $s = k_1(a(H-b)^2)^{p_1} + k_2 \frac{d}{dt}(a(H-b)^2)^{p_2}$ (2) where H: water level (m), a,b: rating curve constants. Combining this expression of storage with the following continuity equation yields the nonlinear expression of the GSF model: $\frac{ds}{dt} = \gamma R + I - E - O - a(H-b)^2 - q_l$ (3) where γ : rainfall distribution factor. The other components are shown in Fig. 1. Numerical solution of Eqs. (2) and (3) can lead to the prediction of water level. The SCE-UA method proposed by Duan et al. (1992) was used to estimate the optimum parameter values of GSF model. The Iga watershed, one of the tributaries of the Yahagi River, is a typical small to medium sized semi-urban watershed in Aichi prefecture, Japan which was selected as the target basin. Five flood events were selected from the data to assess the effectiveness of the proposed GSF model with and without parameter γ.

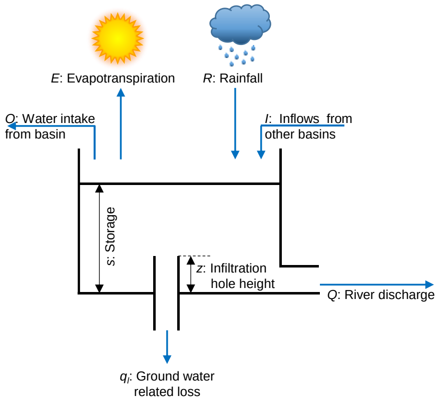

Fig. 1. Schematic diagram of all inflow and outflow components of a conceptual watershed.

3. RESULTS

The hydrograph reproducibility of GSF model with and without parameter γ was analysed for five selected events and only two events were plotted out of five due to the page constraints as shown in Fig. 2. It is clear from Fig. 2 that the GSF model nearly overlaps with the observed water level hydrograph and reproduces the shape with slight deviations in the Iga basin. It is also capable of accurate reproduction of the peak water level during all the events, except in event 1. On the contrary, the GSF model without γ highly deviated from the observed hydrograph especially at the rising and recession limbs. The model also failed to exactly reproduce the peak water level. During event 1, the GSF model without γ was unable to reproduce the peak water level precisely even though it was most close to the observed peak compared with the peak estimated by the GSF model.

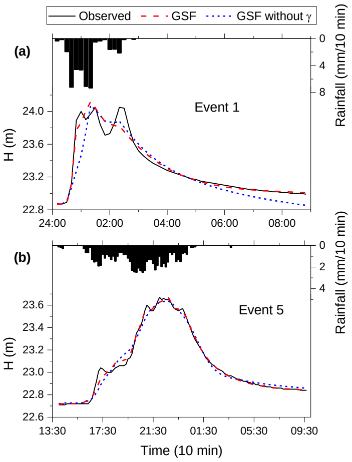

Fig. 2. The reproduced hydrographs.

Further, we evaluated the performance of these models using root mean square error (RMSE), Nash-Sutcliffe efficiency (NSE), and other error functions of percentage error in peak (PEP), and percentage error in area (PEA) as shown in Fig. 3, since it is not easy to clearly portray the difference between the simulated stage hydrographs of the two models. From Fig. 3(a) and (b), we can see that the GSF model generates low RMSE close to zero and high NSE close to 100% in all events. The PEP and PEA become positive for underestimation and Fig. 3(c) depicts that the GSF model received PEP values close to zero compared with the GSF model without γ except in event 1. During event 1, the GSF model without γ exhibited better PEP values. The GSF model shows the best ranges of PEA values in Fig. 3(d) which is close to zero compared with the GSF model without γ in all events. The higher values of NSE coupled with the lower values of RMSE, PEP, and PEA for GSF model in all the events indicated that the hydrograph reproducibility by GSF model is the highest compared with the GSF model without γ.

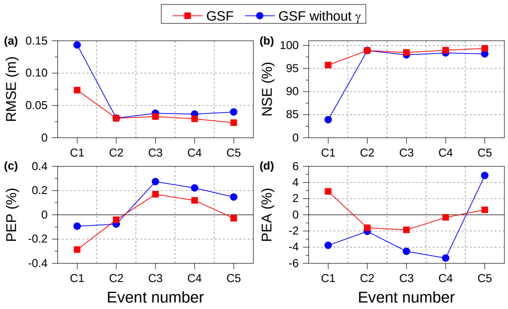

Fig. 3. Comparison of RMSE, NSE, PEP, and PEA by the GSF model with and without γ.

5. CONCLUSION

A generalized storage function (GSF) model was proposed for the prediction of water level from the rating curve relationship by considering the spatial distribution of rainfall over the basin. The GSF model was applied to five selected flood events in the Iga watershed along with GSF model without γ in order to evaluate the effectiveness of GSF model with γ. The results revealed that the GSF model has the least RMSE (high NSE) compared with the GSF model without γ for all events. The lower values of PEP and PEA received by GSF model in most of the events further indicate its higher hydrograph reproducibility. This can be attributed to parameter γ in the GSF model that describes the rainfall variability.

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Keywords：GSF model, Rainfall spatial distribution, Hydrograph reproducibility, Watersheds, SCE-UA method