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Clustering-based hybrid inundation model for forecasting flood inundation depths

Li-Chiu Chang [a,*], Hung-Yu Shen [a], Yi-Fung Wang [b], Jing-Yu Huang [a], Yen-Tso Lin [a]

[a] Department of Water Resources and Environmental Engineering, Tamkang University, Taiwan, ROC
[b] Water Resources Agency, Ministry of Economic Affairs, Taiwan, ROC

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SUMMARY

Estimation of flood depths and extents may provide disaster information for dealing with contingency and alleviating risk and loss of life and property. We present a two-stage procedure underlying CHIM (clustering-based hybrid inundation model), which is composed of linear regression models and ANNs (artificial neural networks) to build the regional flood inundation forecasting model. The two-stage procedure mainly includes data preprocessing and model building stages. In the data preprocessing stage, K-means clustering is used to categorize the data points of the different flooding characteristics in the study area and to identify the control point(s) from individual flooding cluster(s). In the model building stage, three classes of flood depth forecasting models are built in each cluster: the back-propagation neural network (BPNN) for each control point, the linear regression models for the grids that have highly linear correlation with the control point, and a multi-grid BPNN for the grids that do not have highly linear correlation with the control point. The practicability and effectiveness of the proposed approach is tested in the Dacun Township, Changhua County in Central Taiwan. The results show that the proposed CHIM can continuously and adequately provide 1-h-ahead flood inundation maps that well match the simulation flood inundation results and very effectively reduce 99% CPU time.

Introduction

Floods are one of the most dangerous natural hazards and the greatest challenge for hydrologists due to their mass force and short response time. It can be seen that floods occur regularly, both nationally and globally, and more frequently and severely in the past decades due to land use and climate change. Disastrous floods can cause major loss of life and result in catastrophic outcomes. Taiwan is located in the northwestern Pacific Ocean where the activities of the subtropical jet stream are frequent. In the last century, there were about 360 typhoons, an average of 3.6 annually, that hit the Taiwan Island. Typhoons are usually coupled with huge amounts of rain from June to October, and disastrous flooding results from the intense bursts of rainfall. The rivers in this island are short and steep, and their flows are relatively quick with floods lasting only for a few hours. The large flood peaks with fast-rising limbs would unavoidably cause serious disasters. For example, in 1996 Typhoon Herb triggered a storm with maximum accumulated precipitation reached 160 mm/h and 1748 mm/day, causing considerable casualties and property damage, and severely harming the basic infrastructure of the country (Cheng and Wang, 2004); Typhoon Nari struck north Taiwan with stunning rainfall on September 17th, 2001 with the highest precipitation reaching 149 mm/h. It caused 27 deaths, many civilian injuries, and severely damaged the city functions, resulting in countless economic effects.

The recent sequence of floods has raised public awareness of flooding. As a result, increased expenditure is being made on flood defenses. Historically, hard engineering solutions, such as levee and flood detention, have been preferred with associated environmental disbenefits, but alternative approaches may have significant environmental benefits. In the last decades, the Water Resources Agency (WRA), Taiwan, has devoted a great deal of effort in flood defense strategies. To provide protection for rare floods would not be economically viable; consequently, in recent years, flood damage reduction and prevention in Taiwan has also been more focused on non-structural efforts, such as flood alert and warning system.

Establishing flood and inundation forecasting systems could extent information that would be helpful in dealing with contingencies and emergencies, and then alleviate the risk and losses of life and property. The ability to model potential flood inundation and produce maps is not only of major concern for disaster response and flood management but it also poses a key task for hydrologists to generate a reference for damage estimation. During past decades, predictions of flood inundation extent have been made possible by advances in numerical modeling techniques and the synergistic use of radar and optical remote sensing in conjunction

* Corresponding author. Address: 151 Ying-Chuan Rd., Tamsui, Taipei County 25137, Taiwan, ROC. Tel.: +886 2 26258523; fax: +886 2 26209651.
E-mail address: changlc@mail.tku.edu.tw (L.-C. Chang).

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with GIS modeling. For example, Hsu et al. (2002) proposed a two-dimensional (2D) inundation model to simulate flood inundation due to storm rainfall. Horritt and Bates (2001, 2002) indicated that simulated topographic properties significantly affect simulation results and that topography is a major factor in determining flood inundation patterns. Kang (2009) has applied an integrated urban inundation model to estimate the influence on the extent of flood inundation with a high building density. On the other hand, remote sensing has proved invaluable in mapping flood extent for deterministic model calibration (Horritt, 2000) and validation (Horritt and Bates, 2002). The Flood Space Monitoring Information System had been operated in Kazakhstan for several years. It can decode space image to localize high flooding and to forecast development of flooding (Spivak et al., 2004). Bates et al. (2004) have estimated spatially distributed uncertainty in models conditioned against binary pattern data contained in flood inundation maps by using the generalized likelihood uncertainty estimation procedure. Horritt (2006) presented a comparison of uncertain spatial predictions of flood extent with observed data. SAR (synthetic aperture radar) is combined with LiDAR (light detection and ranging) measurements to improve estimation of flood extent delineation or flood parameters (Mason et al., 2007; Zwenzner and Voigt, 2008). Schumann et al. (2007) presented an improvement version of regression and elevation-based flood information extraction model (REFIX) to fit river bank elevation from SAR.

The conventional inundation models need large computational times as iterative solutions to carry out the high-resolution spatial discretization. Moreover, to implement appropriate mitigation strategies, they require analyzing different flood scenarios under varied hydro-meteorological conditions as well as with different mitigation alternatives. Consequently, it is very difficult to reach on-line simulation and/or forecast of the inundation extent by using conventional inundation models. Artificial neural networks (ANNs) have been applied within the field of hydrological modeling in recent years (Imrie et al., 2000; Chang et al., 2001; Sivakumar et al., 2002; Rajurkar et al., 2004; Anctil and Rat, 2005; Chaves and Chang, 2008; Chiang and Chang, 2009). This computational method offers real advantages over conventional modeling, especially when the underlying physical relationships are not fully understood. However, relatively little attention has been paid to the use of the ANNs for flood estimation in ungauged catchments (Dastorani and Wright, 2001; Dawson et al., 2006; Lin and Wu, 2007) and/or inundation maps. The main purpose of this study is to propose a novel methodology of the regional flood inundation

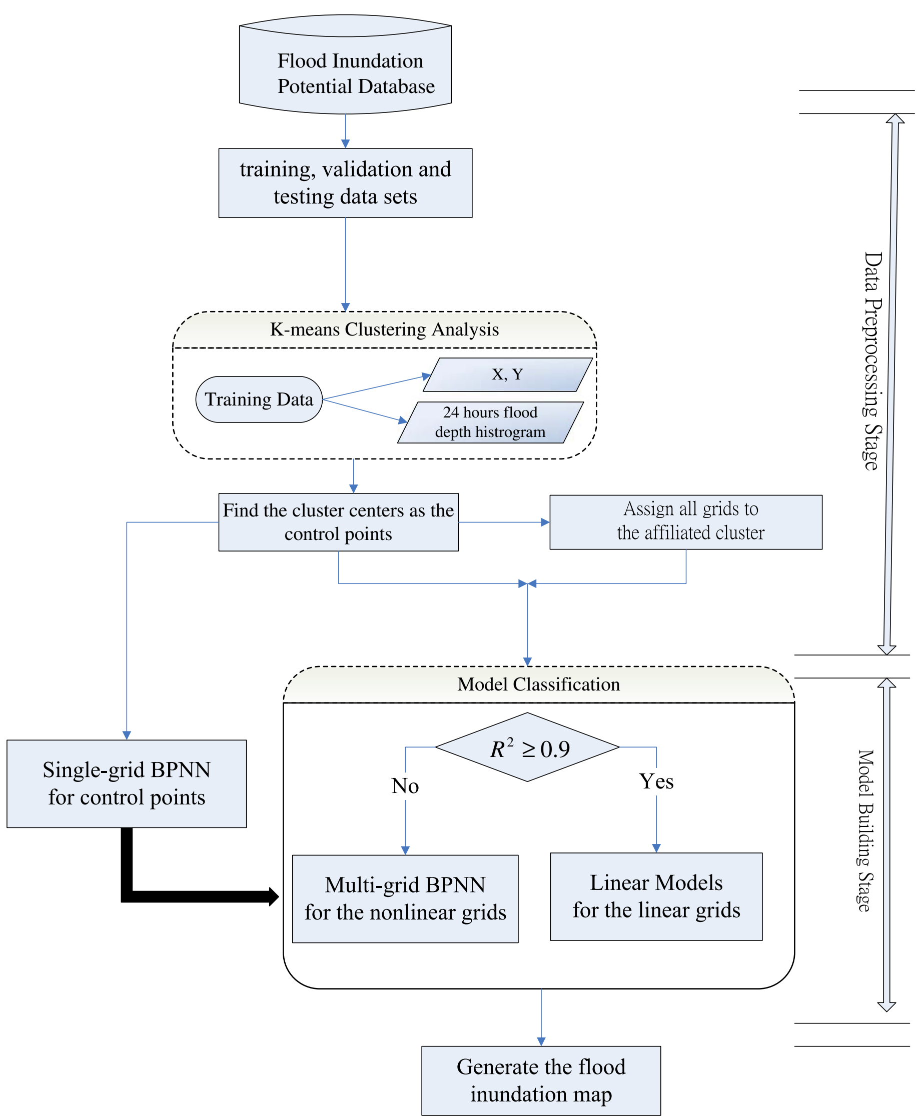

Fig. 1. The flowchart of the proposed CHIM.