Journal of Hydrology 538 (2016) 587–597

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

# Hydrograph estimation with fuzzy chain model

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ARTICLE INFO

*Article history:*
Received 5 February 2016
Received in revised form 17 April 2016
Accepted 26 April 2016
Available online 30 April 2016
This manuscript was handled by Andras Bardossy, Editor-in-Chief, with the assistance of Fi-John Chang, Associate Editor

*Keywords:*
Fuzzy
Hydrograph
Peak discharge
SCS
Snyder
Clark

SUMMARY

Hydrograph peak discharge estimation is gaining more significance with unprecedented urbanization developments. Most of the existing models do not yield reliable peak discharge estimations for small basins although they provide acceptable results for medium and large ones. In this study, fuzzy chain model (FCM) is suggested by considering the necessary adjustments based on some measurements over a small basin, Ayamama basin, within Istanbul City, Turkey. FCM is based on Mamdani and the Adaptive Neuro Fuzzy Inference Systems (ANFIS) methodologies, which yield peak discharge estimation. The suggested model is compared with two well-known approaches, namely, Soil Conservation Service (SCS)-Snyder and SCS-Clark methodologies. In all the methods, the hydrographs are obtained through the use of dimensionless unit hydrograph concept. After the necessary modeling, computation, verification and adaptation stages comparatively better hydrographs are obtained by FCM. The mean square error for the FCM is many folds smaller than the other methodologies, which proves outperformance of the suggested methodology.



## 1. Introduction

Due to intensive rainfall events surface water in the forms of floods or flash floods has occasional harms on human life and properties. Many cities, industrial and agricultural areas are subject to inundation. Rainfall, snowfall and snowmelt are taken into account in various water disasters related damages (Norbiato et al., 2008).

First time in the history of water disasters, O'Connell (1868) proposed flood forecasting even without rainfall measurements. He expressed the peak discharge as a non-linear function of the watershed area. With the start of rainfall measurements, Kuichling (1889) introduced the rational method, for peak discharge estimation in small basins. The first written report on floods was on Passaic River (Garfield, New Jersey, United States) (Hollister and Leighton, 1903), which included flood hydrographs and their consequent damages with numerical examples, without peak discharge estimation. With the start of simultaneous rainfall and runoff measurements Fuller (1914) presented statistical analysis for flood calculations. Later, Foster (1924), Hazen (1921) and Gumbel (1941) demonstrated the importance of the flood forecasting based on the normal (Gaussian), logarithmic-normal, Gamma and Pearson probability distribution functions (pdf's).

On the other hand, unit hydrograph (UH) methodology as rainfall–runoff model is suggested by Sherman (1932). Later, Snyder (1938) suggested a synthetic UH for flood forecasting based on the geomorphological features of drainage basin. Kirpich (1940) and Clark (1945) also proposed slightly different hydrograph methodologies. Subsequently, Soil Conservation Service (SCS) method (1972), Sacramento Soil Moisture Accounting (Sac-SMA) model (Burnash et al., 1973) and other techniques started to appear in the literature (Bhunya et al., 2005; Saghafian, 2006; Koutroulis and Tsanis, 2010; Zhang et al., 2012; Singh et al., 2013; Che et al., 2014).

Recently, the researchers started to use intelligent methods for hydrograph peak discharge estimation. Among these methods are the fuzzy inference system approaches (Chau et al., 2005; Casper et al., 2007; Talei et al., 2010a,b; Kar et al., 2012), artificial neural networks (Tayfur and Singh, 2006; Mukerji et al., 2009; Feng and Lu, 2010; Lohani et al., 2014), Kalman filter (Shamir et al., 2010; Wu et al., 2013) and genetic algorithm (Sedki et al., 2009; Chen et al., 2013). Additionally, Gericke and Smithers (2014) have presented a review of the time parameter estimation methods used internationally for the purpose of peak discharge estimation.

On the other hand, as for the rainfall–runoff transformation modern fuzzy logic methodology, especially Adaptive Network-based Fuzzy Inference Systems (ANFIS), has been employed in recent years for different water resources aspects such as water management and operation, drought and flood. As for the reservoir

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http://dx.doi.org/10.1016/j.jhydrol.2016.04.057
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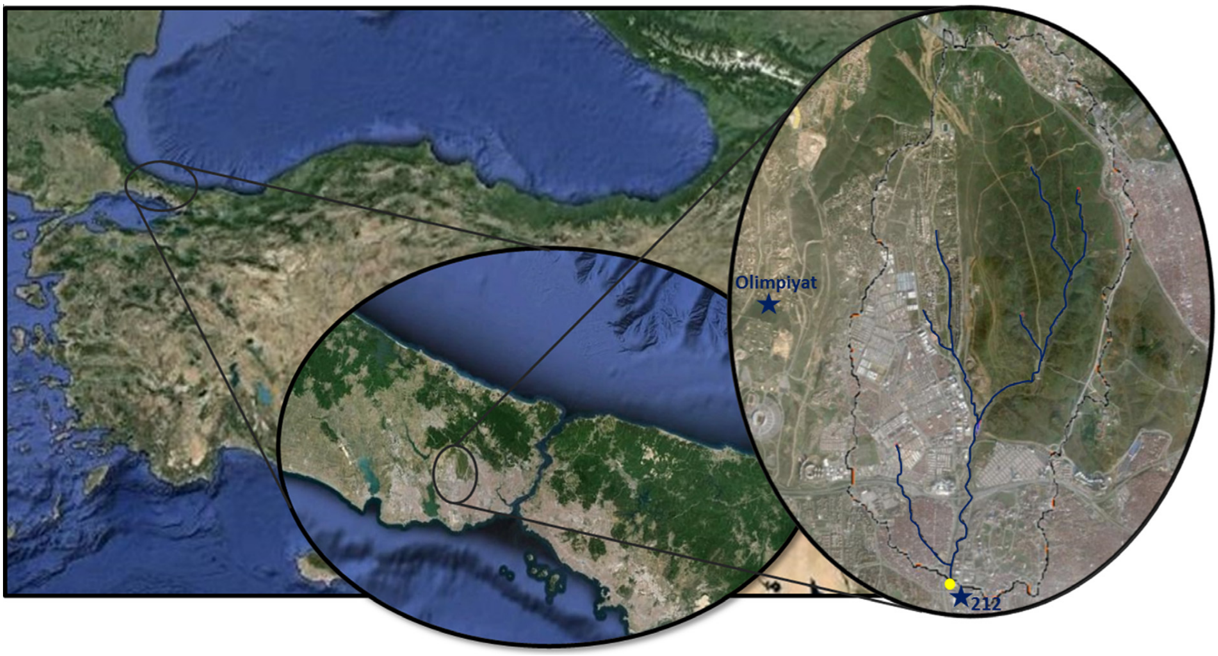


**Fig. 1.** Ayamama basin with the meteorology stations (stars) and the outlet (yellow point). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

**Table 1**
Storm rainfall records.

| Event number | Previous rainfall amount, $R_P$ (mm) | Duration between the previous and the next rainfall event, $D_B$ (h) | Average temperature between the previous and the next rainfall event, $T$ (°C) | Rain duration, $R_D$ (×10 min) | Olimpiyat rainfall amount, $R_O$ (mm) | 212 AVM rainfall amount, $R_{212}$ (mm) | Peak discharge, $Q_P$ ($m^3/s$) |
|---|---|---|---|---|---|---|---|
| 1 | 2.0 | 30 | 20.0 | 2 | 11.8 | 0.8 | * |
| 2 | 2.0 | 50 | 25.6 | 4 | 3 | * | 1.21 |
| 3 | 3.4 | 0.75 | 17.2 | 5 | * | 2.8 | 2.01 |
| 4 | 2.8 | 1 | 22.0 | 2 | 5 | 0.6 | 2.37 |
| 5 | 2.0 | 300 | 22.5 | 3 | 5.8 | 4.6 | 3.85 |
| 6 | 2.8 | 25 | 13.0 | 3 | 1.2 | 3.4 | 5.26 |
| 7 | 1.4 | 95 | 7.6 | 3 | 5.4 | 2.6 | * |
| 8 | 4.0 | 5 | 11.5 | 4 | 14.2 | * | 11.59 |
| 9 | 8.0 | 150 | 24.5 | 3 | * | 2.8 | 4.01 |
| 10 | 2.0 | 250 | 21.5 | 3 | 2.8 | 2 | 2.81 |
| 11 | 2.6 | 1 | 17.5 | 5 | 5 | 1.8 | 1.65 |
| 12 | 0.6 | 17 | 22.0 | 3 | 4.8 | 2.0 | 2.77 |
| 13 | 4.0 | 12 | 17.7 | 4 | 6.8 | 1.8 | * |
| 14 | 3.0 | 2 | 14.5 | 3 | 2.8 | * | 5.22 |
| 15 | 1.0 | 0.4 | 22.6 | 4 | * | 3.8 | 42.72 |
| 16 | 6.0 | 10 | 16.0 | 4 | 6 | 1.6 | 3.55 |
| 17 | 2.0 | 1.5 | 21.5 | 2 | 7 | 1.2 | 2.96 |
| 18 | 0.4 | 0.5 | 14.3 | 3 | 7.8 | * | 5.52 |
| 19 | 3.0 | 0.5 | 13.3 | 3 | * | 3.6 | 13.61 |
| 20 | 15.0 | 125 | 24.5 | 4 | 8.2 | 2.6 | 3.43 |
| 21 | 2.0 | 1.5 | 6.8 | 3 | 5.2 | 1.2 | 3.31 |
| 22 | 2.0 | 11 | 7.6 | 5 | 8.6 | * | 3.56 |
| 23 | 8.0 | 30 | 15.0 | 4 | * | 1.8 | 3.52 |
| Mean | 3.48 | 48.66 | 17.3 | 3.4 | 9.1 | 2.5 | 5.77 |

* Covered data.

operation fuzzy rule base principles are applied as optimization and operation techniques coupled with other approaches by Saad et al. (1996), Russell and Campbell (1996) and Shrestra et al. (1996). Along this line rule base derivations from observations are presented by Bárdossy and Duckstein (1995). In the meantime, Russell and Campbell (1996) suggested that specifically increase in the fuzzy rule number may cause to unidentifiable and unmanageable solutions. In this paper by the chain affect this point is relieved to a certain extent.

A spatio-temporal lumping of radar rainfall modeling inflow forecasts to mitigate time-lag problems is suggested as forecast accuracy improvement by Chang and Tsai (2016). They have employed Adaptive Neuro Fuzzy Inference System (ANFIS) models coupled with a 2-staged Gamma Test (2-GT) procedure that identified the optimal non-trivial rainfall inputs. It is observed that ANFIS models with only two fuzzy if-then rules can effectively categorize inputs into two levels (i.e. high and low) and provide an insightful view (perspective) of the rainfall–runoff process, which