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Estimation of the Parameters of Muskingum Methods for the Prediction of the Flood Depth in the Moudjar River Catchment

Fares Laouacheria, Said Kechida, Moncef Chabi

Abstract**—**The objective of the study was based on the hydrological routing modelling for the continuous monitoring of the hydrological situation in the Moudjar river catchment, especially during floods with Hydrologic Engineering Center–Hydrologic Modelling Systems (HEC-HMS). The HEC-GeoHMS was used to transform data from geographic information system (GIS) to HEC-HMS for delineating and modelling the catchment river in order to estimate the runoff volume, which is used as inputs to the hydrological routing model. Two hydrological routing models were used, namely Muskingum and Muskingum routing models, for conducting this study. In this study, a comparison between the parameters of the Muskingum and Muskingum-Cunge routing models in HEC-HMS was used for modelling flood routing in the Moudjar river catchment and determining the relationship between these parameters and the physical characteristics of the river. The results indicate that the effects of input parameters such as the weighting factor "X" and travel time "K" on the output results are more significant, where the Muskingum routing model was more sensitive to input parameters than the Muskingum-Cunge routing model. This study can contribute to understand and improve the knowledge of the mechanisms of river floods, especially in ungauged river catchments.

Keywords**—**HEC-HMS, hydrological modelling, Muskingum routing model, Muskingum-Cunge routing model.

I. Introduction

FLOOD routing is used practically to solve many problems associated with using water, and it considers process to predict the magnitude and celerity changes of the propagation of flood wave down rivers or through reservoirs [1], [9]. There are many classifications of flood routing methods like flood and synthesis routing, reservoir and river routing. But, the most important flood routing classification may be hydraulic and hydrologic routing [4]. The main difference between these two types is that the first class depends on the basic differential equation of flow moment equation and continuity equation. Also, these equations are governed by solving the equations of Saint Venant. While the hydrological routing does not directly use the basic differential equation, but it uses another equation like storage equation.

Two commonly used hydrological methods in HEC-HMS are the Muskingum and the Muskingum-Cunge methods.

Previous researches widely approved and used Muskingum and Muskingum-Cunge methods in flood routing models due to their simplicity and applicability on most natural rivers and streams [8], [12], [7], [13]. The Muskingum routing method was used for estimating the travel time “k” and the weighting factor “x” [5]. References [3], [2], [14] have marked their footprints in the flood routing field, using new methods for estimating Muskingum model parameters (K and x), where these parameters have a great significance in the exploitation, the use of water resources and hydrological prediction.

The objective of this study was to compare two flood routing models in order to establish the relationships between the Muskingum parameters (k and x) and the physical characteristics of the channel cross section in the Moudjar river catchment in order to predict the water depths in the channel and discharge volume arrived to Zit-Emba Dam.

Fares Laouacheria is with the Badji Mokhtar University, Algeria (e-mail: fares.laouacheria@gmail.com).

II. Material and Method

A. Study Area

The study area is located in Bekkouche Lakhdar in the north-eastern of Algeria, exactly in the south of Skikda department, between (36°32’13.42’’ N to 36°35’0.21’’N latitude) and (7°3’45.87’’ E to 7°18’19.47’’ E). It occupies an area of 263.211 km² (Fig. 1). The study area is located in the subtropical Mediterranean region, which is characterized by a hot dry summer and a relatively mild and humid winter. The area studied is characterized by the irregular distribution of rain on land. There is a clear altimetric differentiation which is expressed by the increase of the rainfall as a function of altitude.

Fig. 1 Location of the study area

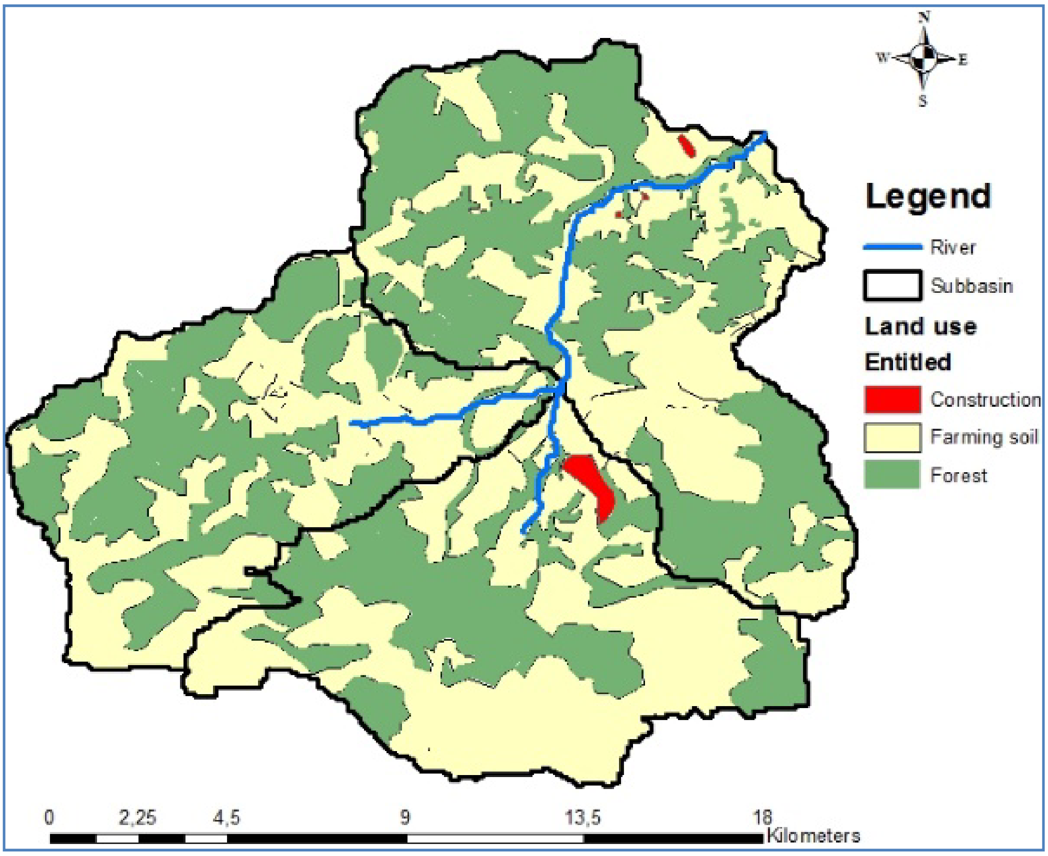

Fig. 2 The land use of the study area

The main river crossing the region is Moudjar river, the land use of the study area is composed of three types, namely construction, farming soil, and forest (Fig. 2). Surface flow of the study area, which includes the overland flow and the river channel flow, is an important part of the hydrological cycle and plays an important role in river runoff generation for modelling the unsteady flow in the river.

B. Application of HEC-HMS

The HEC-HMS hydrological model (Fig. 3) and the geospatial hydrologic analysis module HEC-GeoHMS were used to extract channel, catchment characteristics and delimitation of sub-catchments. In addition, the SCS-CN method computes runoff by empirical rainfall-runoff relationships. The catchment curve number (CN) can be assessed through a function of land use, soil type, and soil antecedent moisture of the catchment, as published by SCS tables. This model takes into consideration soil surface conditions, such as soil condition, land use, and the impact of human activities on runoff volume. Excess precipitation is estimated using:

$$P_e = \frac{(P - I_a)^2}{(P - I_a) + S} \tag{1}$$

where P_e is the depth of excess rainfall at time t, P is the accumulated rainfall depth at time t, and S is the potential maximum retention. S and Ia, the soil moisture deficit, can be determined by the relationships with curve number (CN) [11]. The CN and S are related by -:

$$S = \frac{25400}{CN} - 254 \tag{2}$$

where the empirical relation for initial abstraction is as:

$$I_a = 0.2S \tag{3}$$

The SCS unit hydrograph method was used to estimate runoff volumes, the direct runoff hydrograph, respectively.

In this study, the hydrologic parameter (CN) was used to describe the storm water runoff potential for drainage area. The CN is a function of land use, hydrologic soil group, and antecedent soil moisture condition (AMC). The determination of CN is based on the hydrologic soil group (HSG), which indicates the amount of infiltration that the soil will allow. The hydrologic soil group of Moudjar river catchment corresponds to the soil class B (Sandy loam), and C (sandy clay loam). The Muskingum and Muskingum-Cunge models with variable parameters were then applied in this study. The rainfall data for the study area was obtained from Bouati Mahmoud Rainfall station for period between1995 to 2014.

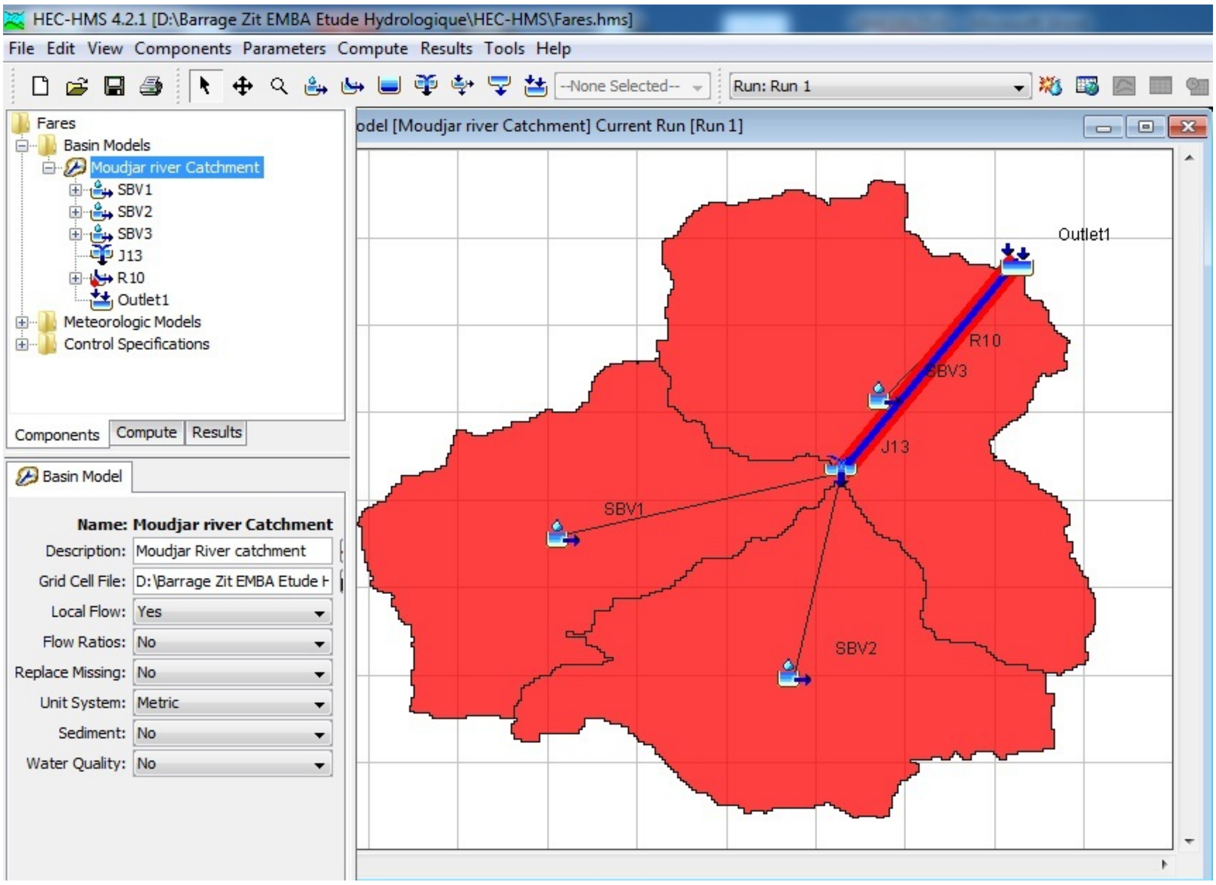

Fig. 3 The study area under HEC-HMS

C. Routing Model Development

Hydrological models have been developed to simulate water movement through rivers and streams. Most of these models are based on the St. Venant equations for gradually varied, unsteady open channel flow. The St. Venant equations consist of the continuity and momentum equations. The continuity equation is expressed as:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \tag{4}$$

where A is the cross-sectional area of flow (m^2), Q is the discharge (m^3/s), t is the time (h), and x is the distance along the channel (m). The momentum equation is given by:

$$\frac{1}{g}\frac{\partial V}{\partial t} + \frac{V}{g}\frac{\partial V}{\partial x} + \frac{\partial h}{\partial x} + \left(S_f - S_0\right) = 0 \tag{5}$$

in which g is acceleration due to gravity (m/s^2), V is the velocity (m/s), h is the depth of flow (m), and S_f and S_0 are the friction and bed slopes (m/m), respectively.

1. Muskingum Model

In this method, the downstream outflow can be predicted by using:

$$O_{j+1} = C_0 I_{j+1} + C_1 I_j + C_2 O_j \tag{6}$$

where C_0, C_1, and C_2 are the routing coefficients, O_{j+1}: downstream outflow at time (j+1) (m^3/sec). O_j: downstream outflow at time (j) (m^3/sec). I_{j+1}: upstream inflow at time (j+1) (m^3/sec). I_j: upstream inflow at time (j) (m^3/sec).

If the observed inflow and outflow hydrographs are available for a river reach, the values of K and x can be determined by the following equation:

$$K = \frac{0.5\Delta t[(I_{j+1}+I_j)-(O_{j+1}+O_j)]}{x(I_{j+1}-I_j)+(1-x)(O_{j+1}-O_1)} \tag{7}$$

where, K: wave travel time (hr). x: weighting factor. Δt: time interval (hr).

2. Muskingum-Cunge Model

The Muskingum-Cunge model was developed based on differencing and approximating of the kinematic wave equation [6]. According to [10], the choice of reference discharge, which is used to calculate the kinematic wave and the diffusion coefficient, can also affect the accuracy of the channel routing with lateral inflow. The routing equation is:

$$Q_{i+1}^{j+1} = C_0 Q_i^{j+1} + C_1 Q_i^j + C_2 Q_{i+1}^j \quad \text{fig} \tag{8}$$

where, C_0, C_1, and $C_2$are the routing coefficients; Q_{i+1}^{j+1} refers to position i+1 in space and j+1 in time.

The resolution of (9) requires the parameters K and x which are calculated from:

$$K = \frac{\Delta x}{C_k} = \frac{\Delta x}{\partial Q/\partial A} \quad (9)$$

$$X = \frac{1}{2}\left(1 - \frac{Q}{BC_k S_0 \Delta x}\right) \quad (10)$$

where: C_k: is the celerity corresponding to Q and B (m/sec). B: is the width of the water surface (m). Q: is the discharge (m^3/sec). A: is the cross-sectional area (m^2). So: is the bed slope (dimensionless). Δx: is the increment in space (m).

III. Results

The simulation of the flood propagation of the Moudjar river catchment by the Muskingum and Muskingum-Cunge routing models under HEC-HMS led us to achieve the following results: Figs. 4 and 5 illustrate the comparison between the inflow and discharge hydrographs, during the simulation of the response of the Moudjar river catchment, by two routing models, namely Muskingum and Muskingum - Cunge. The results of simulation by Muskingum method showed significant mitigation in peak flow and larger time of peak compared to the Muskingum-Cunge method with closer results of discharge volume for both methods (Table I).

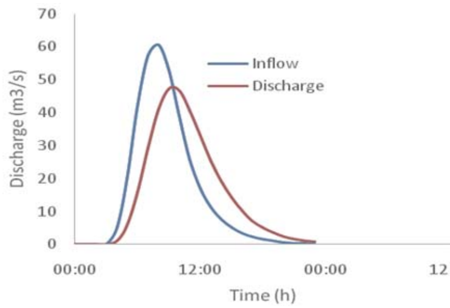

Fig. 4 Inflow vs discharge by Muskingum

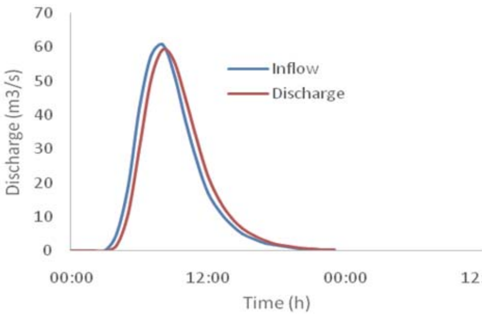

Fig. 5 Inflow vs Discharge by Muskingum-Cunge

IV. Conclusion

This work allowed us to determine the weight factor (x) applicable to the Moudjar river catchment, and the travel time relative to the propagation of floods in the Moudjar river catchment. These parameters helped us to obtain a decision support tool during a flood to conserve and protect agricultural land and ensure good regulation of the flow upstream of the Zit-Emba dam. The Muskingum routing model yielded acceptable results than the Muskingum-Cunge routing model with respect to the discharge value in the downstream of the catchment, where the Muskingum-Cunge routing model overestimates the discharge value in the downstream of the catchment relative to the Muskingum routing model, on the other hand it is better to validate the results found, especially improving the hydrometric data which represent one of the problems and obstacles that meet the researchers to validate their work.

TABLE I
Results of Simulation by Two Routing Models

Characteristics	Muskingum	Muskingum-Cunge
Peak inflow (m^3/s)	60.70	60.70
Inflow volume (mm)	8.01	8.01
Time of peak inflow (h)	8h00	8h00
Peak discharge (m^3/s)	47.32	59.26
Discharge volume (mm)	7.99	8.00
Time of peak discharge (h)	9h00	8h00

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