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Prediction of flow discharge in compound open channels using adaptive neuro fuzzy inference system method

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ABSTRACT

Discharge estimation in rivers is the most important parameter in flood management. Predicting discharge in the compound open channel by analytical approach leads to solving a system of complex nonlinear equations. In many complex mathematical problems that lead to solving complex problems, an artificial intelligence model could be used. In this study, the adaptive neuro fuzzy inference system (ANFIS) is used for modeling and predicting of flow discharge in the compound open channel. Comparison of results showed that the divided channel method with horizontal division lines with the Coefficient of determination (0.76) and root mean square error (0.162) is accurate among the analytical approaches. The ANFIS model with the coefficient of determination (0.98) and root mean square error (0.029) for the testing stage has suitable performance for predicting the discharge of flow in the compound open channel. During the development of the ANFIS model, found that the relative depth, ratio of hydraulics radius and ratio of the area are the most influencing parameters in discharge prediction by the ANFIS model.

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1. Introduction

Flood is one of the most dangerous natural phenomena, which usually occur in the river consisting of a main channel flanked by one or two floodplains (Fig. 1). Studies on the hydraulic of rivers, specifically at the unsteady flow conditions are the major part of the hydraulic engineering researches which are named flood engineering [10]. Flood engineering includes two main concepts: hydrological and hydraulics fields. Hydrological field studies focus on topics such as the hydrograph of flood and in the hydraulics field studied on subjects such as flood routing, calculating the water surface profile, velocity distribution and sediment transport [8,9,24]. Calculating the discharge and water surface profile in rivers are the main common topics that are usually discussed in the flood engineering. Rivers hydraulic is more complex especially when the flood is occurring because the flow structure is fully turbulent and 3D dimensionality [7]. Although for calculating the discharge in rivers, conventional formulas such as Manning and Chezy formulas have been proposed, but to achieve greater accuracy in estimation, these formulas should be modified. Several ways such as analytical approaches have been proposed for this purpose and in this regard the compound open channel concept is punctual [24,41]. The normal river discharge flows in the main channel but when the flood happens, the water level begin to increase therefore, additional discharge flows in the flood plain area [6]. The floodplains are usually covered by vegetation so these are rougher than the main channel [12]. The difference between the roughness of the main channel and the floodplains leads to different velocity in the cross section of the flow. This difference in velocities, shown in the Fig. 1, creates an interactive area which includes the vortices flow and causes of the momentum transferring between the main channel and the floodplain. The main difference between the traditional channel concept and compound open channel is related to this area [19,36]. Calculating the capacity of the compound open channel by classical formulas leads to

Abbreviations: 2-D, two dimensional; 3D, three dimensional; A_{fp}, areas of main channel and floodplains; A_i, area of subsections; A_{mc}, areas floodplains; ANFIS, adaptive neuro fuzzy inference system; ANN, artificial neural network; APE, absolute percentage error; A_r, relative area; AVG, average; COHM, coherence method; DCM, divided-channel method; DISADF, discharge adjustment factor; D_r, depth ratio; E_R, relative error; f_{fp}, roughness of main channel; f_{mc}, roughness of floodplains; fp, subscription related to floodplains; f_r, relative roughness; GP, genetic programming; H, flow depth in main channel and floodplains; h, flow depth in floodplains; MAE, mean absolute error; MAPE, mean absolute percentage error; max, maximum; mc, subscription related to main channel; MDCM, modified divided-channel method; MFs, membership functions; min, minimum; Nfp, number of the floodplains; P_{fp}, wetted perimeters of floodplains; P_{mc}, wetted perimeters main channel; R^2, coefficient Of determination; R_{fp}, hydraulic radius of main channel; R_i, hydraulic radius of subsection; R_{mc}, hydraulic radius of floodplains; RMSE, root mean square error; R_r, relative hydraulic radius; S, longitudinal slope of compound open channel; S_b, longitudinal slope of compound open channel; SCM, single-channel method; STDEV, standard deviation; SVM, support vector machine

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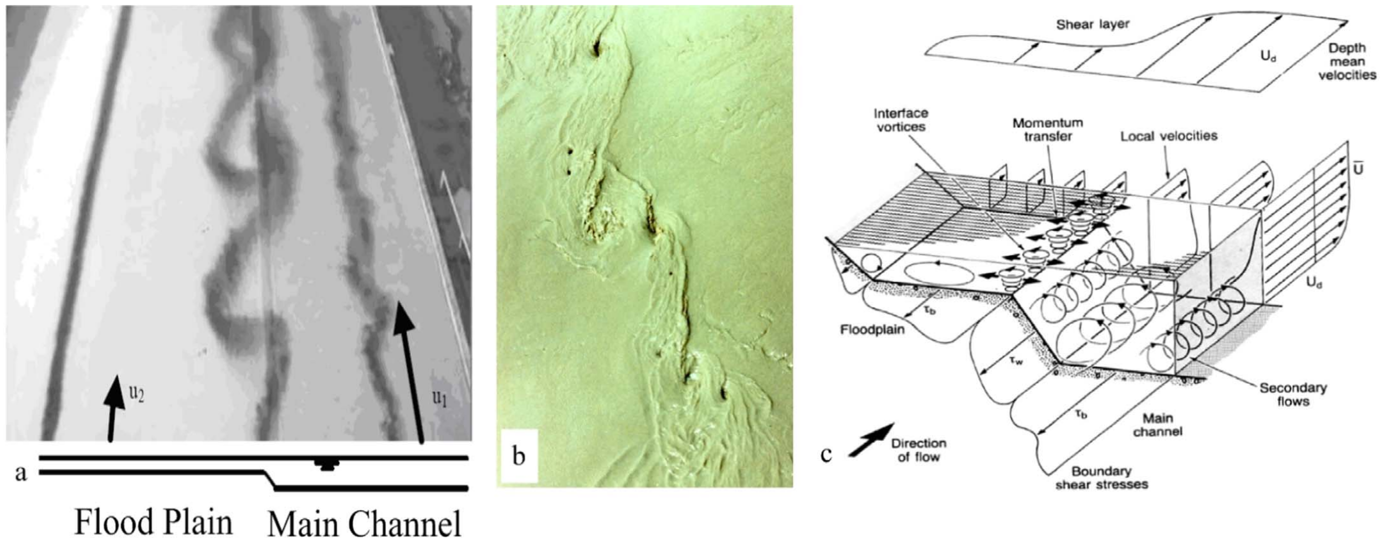

Fig. 1. (a) Large vortices experimentally observed at the main channel/flood plain interface [40], (b)Vortices form at the interface of main channel and floodplain [11] and (c) Flow structures in a straight two-stage channel [33].

Table 1
Summary of collected data range related to discharge of flow in the compound channel.

Author	Range	H	h	(H-h)	B	b	n (fp)	n (mc)	S	Q (m)
Knight et al. [16]	min	0.085	0.08	0.009	0.15	0.08	0.01	0.01	0.001	0.0049
	max	0.154	0.08	0.078	0.31	0.08	0.01	0.01	0.001	0.0294
	AVG	0.112	0.08	0.036	0.23	0.08	0.01	0.01	0.001	0.0116
	STDEV	0.022	0	0.022	0.06	0	0	0	0	0.0068
Wormleaton and Hadjipanos [41]	min	0.135	0.12	0.015	0.75	0.29	0.011	0.0099	0.0004	0.0009
	max	0.21	0.12	0.09	0.75	0.29	0.021	0.0099	0.0018	0.48
	AVG	0.167	0.12	0.047	0.75	0.29	0.016	0.0099	0.0006	0.0372
	STDEV	0.023	0	0.023	0	0	0.0042	0	0.0003	0.0735
Wormleaton and Merrett [42] (UK Flood Channel Facility)	min	0.058	0.05	0.006	0.61	0.2	0.0091	0.0091	0.0001	0.01
	max	0.302	0.15	0.152	5	0.75	0.091	0.021	0.002	1.1142
	AVG	0.169	0.12	0.05	2.4	0.58	0.022	0.0113	0.0007	0.323
	STDEV	0.066	0.05	0.04	1.47	0.26	0.0239	0.003	0.0009	0.2946
Tang et al. [37]	min	0.056	0.05	0.006	0.61	0.2	0.0056	0.0079	0.002	0.013
	max	0.22	0.05	0.17	0.61	0.2	0.0957	0.039	0.002	0.218
	AVG	0.092	0.05	0.042	0.61	0.2	0.0346	0.017	0.002	0.0499
	STDEV	0.042	0	0.042	0	0	0.0228	0.0093	0	0.0546
Seckin [31]	min	0.06	0.05	0.01	0.61	0.2	0.009	0.009	0.002	0.0148
	max	0.168	0.05	0.118	0.61	0.2	0.049	0.009	0.002	0.0553
	AVG	0.09	0.05	0.04	0.61	0.2	0.0288	0.009	0.002	0.0299
	STDEV	0.027	0	0.027	0	0	0.0177	0	0	0.0117
Atabay and Knight [4]	min	0.061	0.05	0.011	0.61	0.2	0.0063	0.0091	0.002	0.018
	max	0.12	0.05	0.07	0.61	0.2	0.0112	0.0115	0.002	0.183
	AVG	0.072	0.05	0.022	0.61	0.2	0.0081	0.0098	0.002	0.0474
	STDEV	0.014	0	0.014	0	0	0.0013	0.0006	0	0.0391
Khatua et al. [15]	min	0.136	0.12	0.016	0.22	0.06	0.01	0.01	0.0019	0.0087
	max	0.223	0.12	0.103	0.22	0.06	0.01	0.01	0.0019	0.0391
	AVG	0.174	0.12	0.054	0.22	0.06	0.01	0.01	0.0019	0.0212
	STDEV	0.031	0	0.031	0	0	0	0	0	0.0111
Ikeda and McEwan [14]	min	0.207	0.2	0.007	0.81	0.28	0.01	0.01	0.0001	0.026
	max	0.278	0.2	0.078	0.81	0.28	0.01	0.01	0.0003	0.073
	AVG	0.242	0.2	0.042	0.81	0.28	0.01	0.01	0.0002	0.0486
	STDEV	0.018	0	0.018	0	0	0	0	0.0001	0.0133
Mohanty and Khatua [18]	min	0.071	0.07	0.006	1.98	0.17	0.01	0.01	0.0011	0.013
	max	0.115	0.07	0.05	1.98	0.17	0.01	0.01	0.0011	0.1062
	AVG	0.091	0.07	0.026	1.98	0.17	0.01	0.01	0.0011	0.0467
	STDEV	0.016	0	0.016	0	0	0	0	0	0.0326
Yonesi et al. [45]	min	0.195	0.18	0.015	0.6	0.2	0.0139	0.0139	0.0009	0.0335
	max	0.333	0.18	0.153	0.6	0.2	0.0165	0.0139	0.0009	0.0682
	AVG	0.257	0.18	0.077	0.6	0.2	0.0154	0.0139	0.0009	0.0511
	STDEV	0.036	0	0.036	0	0	0.0011	0	0	0.0098

incorrect estimations of the discharge flow in comparison with real measured data [2,3,13,17]. Recently, analytical approaches have been proposed to increase the accuracy of the discharge calculation. In this regard, the single-channel method (SCM), divided-channel method (DCM), and the coherence method (COH) can be stated [43,44]. Seckin [31] applied the SCM, DCM and COH methods to calculate the discharge of flow in compound channel and showed that the COH method is more accurate among the

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