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Prediction of roughness coefficient of a meandering open channel flow using Neuro-Fuzzy Inference System

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ABSTRACT

Almost all the natural water resource channels meander. Accurate estimation of discharge capacity in a meander open channel is important from river engineering point of view. It helps the practitioners to provide essential information regarding flood mitigation, construction of hydraulic structures and prediction of sediment loads so as to plan for effective preventive measures. Reliable estimation of discharge capacity of a natural channel depends on selection of proper value of roughness in terms of Manning's *n*. Evaluation of Manning's *n* for a meandering channel is a complex procedure because of its dependence on many geometrical, hydraulic and surface parameters of the channel. Experimental investigation concerning the variation of roughness coefficient of meandering channels with flow depth, aspect ratio, slope and sinuosity are presented in this paper. An effort has been made to predict the roughness co-efficient of a meandering channel based on ANFIS. The results are compared with well established methods available in the literature. Statistical error analysis is also carried out to know the degree of accuracy of the models. Finally the present model is found to give better results as compared to others. It is concluded that, in practice ANFIS model can be used as a suitable and effective method to predict the non-linear relationship between roughness coefficient and the non-dimensional factors affecting it.

1. Introduction

River serves as a major source of water for drinking, irrigation and industrial uses. River flows are utilized in sediment transportation, fishing, recreation, electricity generation, water and energy supply. Knowledge of the flow and energy loss of river has immense value in understanding the characteristics of river towards its protection and flood management. A large number of engineering projects have been conducted to manage and use this valuable resource. However, research projects could not able to meet the particular targets and conjointly created new environmental hazards because of improper prediction of river flow causing due to combined effect of channel slope, surface resistance, channel alignment and other geometrical parameters. Rivers are naturally sinuous and it has been widely reported that the distance of any straight river does not exceed 10 times its width. Therefore almost all natural river channel patterns are exclusively found to be meandering. Prediction discharge in a meandering river section is required in several river hydraulic problems such as for river engineering, environmental engineering and intake designs.

Evaluation of discharge in a channel for a given geometry, surface and flow condition directly depends on the proper calculation of roughness coefficient. The basic equations are used to compute the section mean velocity. While using these equations, selection of a suitable value of roughness coefficient in terms of Manning's *n*, Chezy's *C*

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Nomenclature

S_r	sinuosity	R^2	coefficient of determination
α	aspect ratio	MAE	mean absolute error
R_e	Reynolds number	RMSE	root mean squared error
γ	roughness ratio	MAPE	mean absolute percentage error
MSE	mean square error		

or Darcy-Weisbach friction factor f is the single most important parameter for the proper estimation of discharge in an open channel because the variation of roughness coefficient for a channel due to slope, geometry and flow depth is considered to be not significant. This is true for a straight channel reach. The natural flow mechanism is intricate causing a river meandering so the variations of roughness coefficients due to these parameters are found to be more significant which cannot be ignored. The traditional approaches provide large errors in prediction of discharge for meandering channels for different hydraulic, geometric and surface conditions. Therefore a simple but reliable method is highly desirable for estimating roughness of a meandering open channel flow.

2. Literature related to the work

A number of methods have been developed to supplement basic roughness coefficients so that bed friction contribution can be accurately calculated when analyzing the open channel flow. Chezy was the first to consider the wetted perimeter of a channel as an analog to boundary resistance. The equation proposed by Chezy, Darcy-Weisbach or Manning given in Chow [1] is used to compute the section mean velocity. While using these equations, selection of a suitable value of roughness coefficient in terms of Manning's n, Chezy's C or Darcy-Weisbach friction factor f is the single most important parameter for the proper estimation of discharge in an open channel. It is believed that the variation of roughness coefficient for a straight reach of a channel due to slope, geometry and flow depth is not significant as compared to that for meandering channels (e.g. Acrement and Schneider [2], Khatua et al. [3]). The traditional approaches provide large error in prediction of discharge in meandering channels having different hydraulic conditions. Many investigators have carried out research and proposed modified approaches for selection of roughness coefficients in a meandering channel. The basic approach proposed by Cowan [4] was modified by Arcement and Schneider [2] was designed specifically to account for selecting n values for natural channels. Each variable values were selected from tables in Arcement and Schneider [2]. Suggested values for Manning's n are tabulated by Chow [1]. The US Army Corps of Engineers [5] conducted a series of stage-discharge experiments in meandering channels at the waterways experiments station in Vicksburg. The main purpose of these experiments was to investigate the effect of the geometric parameters on the conveyance capacity of meandering channels. The Soil Conservation Service (SCS) method [6] for selecting roughness coefficient values for channels accounted for meander losses introduces discontinuities at the limits of the defined sinuosity ranges, with consequent ambiguity and uncertainty. To overcome this problem the relationship was linearised, known as the Linearised SCS (LSCS) method by James and Wark [7]. Visual estimation of n values can be made at each site using Barne's [8] guideline. Jarrett [9] developed a model to determine Manning's n for natural high gradient channels having stable bed flow without meandering coefficient. The equation was developed for natural channels having stable bed and bank materials (boulders) without bed rock. It was intended for channel gradients from 0.002 to 0.04 and hydraulic radii from 0.15 to 2.1 m. Shiono et al. [10] reported the effect of bed slope and sinuosity on discharge estimation of a meandering channel. Jena [11] predicted the stage-discharge relationship in meandering channels of low sinuosity using dimensional analysis. Lai Sai Hin et al. [12] expressed that estimation of discharge capacity in river channels was complicated by variations in geometry and boundary roughness. Maria and Silva [13] expressed the friction factor of rough turbulent meandering flows as the function of sinuosity and position. Khatua et al. [3], Shiono et al. [10], Sellin [14], Patra and Kar [15], Patra and Khatua [16], and others have shown that the structure of the flow is surprisingly more complex for meandering channels as compared to that of straight channels. They have shown that Manning's n not only denotes the roughness characteristics of a channel but also the energy loss in the flow. Consequently, the use of design methods based on straight channels is inappropriate when applied to meandering channels, results in large errors while estimating the discharge. Further, the modified approaches are providing better results for a particular geometry and flow conditions and fails to give good results to other data sets (Khatua et al. [3], Shiono et al. [10]). The review shows the importance of different parameters to choose a suitable roughness coefficient of a meandering channel which is further helpful for the discharge estimation.

Presently rapid development in intelligence computing not only lessening the cumbersome effort of experimentation but also eliminates arduous computations. When relationship between input and output is difficult to establish using mathematical, analytical and numerical methods and it becomes cumbersome and time consuming, an easily implementable computing technique like ANFIS (Adaptive Neuro-Fuzzy Inference System) can be adopted. The natural flow mechanism is intricate and hence, an adaptive model should be attempted for predicting the roughness coefficient accurately. The calculation of discharge in a meandering open channel flow is complex so conventional