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Modeling river total bed material load discharge using artificial intelligence approaches (based on conceptual inputs)

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SUMMARY

This study presents Artificial Intelligence (AI)-based modeling of total bed material load through developing the accuracy level of the predictions of traditional models. Gene expression programming (GEP) and adaptive neuro-fuzzy inference system (ANFIS)-based models were developed and validated for estimations. Sediment data from Qotur River (Northwestern Iran) were used for developing and validation of the applied techniques. In order to assess the applied techniques in relation to traditional models, stream power-based and shear stress-based physical models were also applied in the studied case. The obtained results reveal that developed AI-based models using minimum number of dominant factors, give more accurate results than the other applied models. Nonetheless, it was revealed that *k*-fold test is a practical but high-cost technique for complete scanning of applied data and avoiding the over-fitting.

1. Introduction

It is crucial to have a reasonable estimation of sediment transport rate due to its importance in the planning, design and management of water resources projects. Sediment transport phenomenon has been widely investigated so far, leading to development of numerous models for predicting transport rates of total bed material in alluvial streams. However, the derived models may predict values for the total sediment concentration that are drastically different from each other with the lowest agreement with the measured datasets in natural channels (e.g. Dohmen, 1999; Graf, 1998; Grasmeijer, 2002; Stevens and Yang, 1989).

Consequently, none of the published sediment transport models have gained universal acceptance as predictors for total bed material load transport rates, and so far, there is no single theoretical or empirical apparatus or procedure with globally acceptance (Soulsby, 1997; Van Rijn, 1993; Yalin, 1977). Further, most of the complex aspects of sediment transport are not yet understood and still have remained challenging subjects requiring future study. Therefore, it is extremely difficult to choose an appropriate model for a given river and situation.

Recent promising applications of Artificial Intelligence (AI) approaches demonstrated their contribution in solving such complicated problems. Different AI models [e.g. artificial neural networks (ANN), adaptive neuro-fuzzy inference system (ANFIS) and genetic programming (GP)] have been successfully applied in water resources systems modeling (e.g. Karimi et al., 2013; Kisi, 2005; Kisi and Shiri, 2011; Nagy et al., 2002; Nourani et al., 2011; Nourani and Kalantari, 2010; Shiri et al., 2012; Tsai et al., 2012; Yang et al., 2009). Noatable applications of ANN technique in sediment transport rate estimation have been reported in literature, e.g. Hamidi and Kayaalp, 2008; Lin and Namin, 2005; Sasal et al., 2009; Tayfur and Guldal, 2006.

Among others, Bae et al. (2007) applied weather forecasting information and neuro-fuzzy technique for predicting monthly dam inflow. Kisi et al. (2008) investigated the accuracy of ANFIS and ANN techniques in modeling daily suspended sediment of rivers in Turkey. Shiri and Kisi (2010) introduced a new wavelet-ANFIS model for predicting short term and long term streamflow values. Shiri et al. (2011) used ANFIS for predicting short term operational water levels. Azamathulla and Ghani (2011) used ANFIS for predicting scour depth at culvert outlets and they found ANFIS to be more effective when compared with the results of regression equations and ANN. Kisi and Shiri (2012a) introduced a wavelet-neuro-fuzzy model for predicting short term groundwater table depth fluctuations.

GP (i.e. GEP) also has been applied in modeling various components of water resources systems including rainfall–runoff process (e.g. Kisi et al., 2013; Savic et al., 1999), sedimentary particle

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settling velocity equations (Babovic et al., 2001), suspended sediment modeling (e.g. Aytek and Kisi, 2008; Kisi and Shiri, 2012b; Kisi et al., 2012a; Shiri and Kisi, 2012), predicting the depth and location of maximum scour downstream of grade-control structures (Guven and Gunal, 2008), predicting longitudinal dispersion coefficients in streams (Azamathulla and Ghani, 2011), modeling bridge pier scour (Azamathulla et al., 2010), modeling daily evaporation and evapotranspiration (Shiri and Kisi, 2011a; Shiri et al., 2012), forecasting rainfall amount (Kisi and Shiri, 2011), predicting short term groundwater depth fluctuations (Shiri and Kisi, 2011b; Shiri et al., 2013) and modeling energy dissipation over spillways (Roushangar et al., 2014). The present paper aims at enchancing the pediction level of sediment models using GEP and ANFIS techniques.

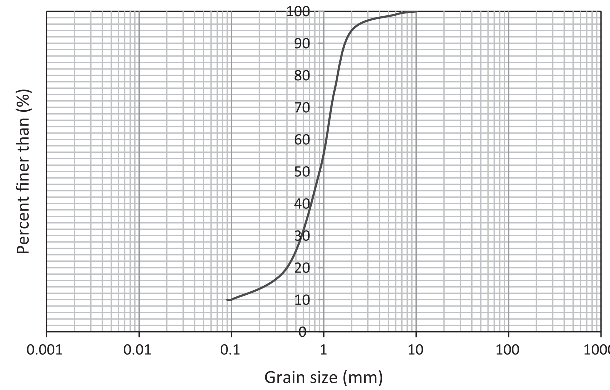

Fig. 2. Particle distribution curve of the field data.

2. Materials and methods

2.1. Study area and used data

Data from Qotur river [located in Aras catchment, Northwestern Iran (latitude: 38°24′33.3″ and longitude: 44°46′13.2″)] were used in the present study for modeling total sediment load. The watershed area is about 1672 km^2 with the longest flow path of 147 km. Fig. 1 shows the geographical position of the studied regions. The selected reach in this study is located on the upstream of Yazdkan station, with a length of 181 m and a 0.011 general slope. For the average annual flood ($Q = 48.7$ m^3/s) the corresponding average surface water width and depth are respectively, 22.97 m and 1.086 m. Specific density of alluvial quartz materials is 2.65. Fig. 2 displays the particle distribution curve of the field data. According to the UGA classification, grading of the surface and subsurface layer of the bed is respectively coarse and medium-coarse gravel with an average roughness coefficient of about 0.035. Further, the developed ANFIS and GEP models were tested using the field data from Aland River (located in Northwestern Iran with latitude of 38°33′01.00″ and longitude of 44°57′08.00″). The used sediment data are attributed to a reach that is placed downstream of Badalan station of the Aland River. Badalan reach with a length of 150 m and a 0.007 general slope, has average surface water of 17.8 m and depth of 0.86 m for the average annual flood of $Q = 48.7$ m^3/s.

2.2. Sediment estimation models

The sediment estimation models on which are based input configurations to feed the GEP and ANFIS models are listed in Table 1. From the sedimentary physics view point, the rate of energy used in transporting materials should be related to the rate of materials being transported. Bagnold (1966) defined stream power as the power per unit bed area which can be used to transport sediment. Nonetheless, Engelund and Hansen (1967) and Ackers and White (1973) used the stream power concept as the theoretical background for developing sediment transport functions. Further, Laursen (1958) developed a functional relationship between the flow condition and the resulting sediment discharge based on shear stress. These models are well-known sediment

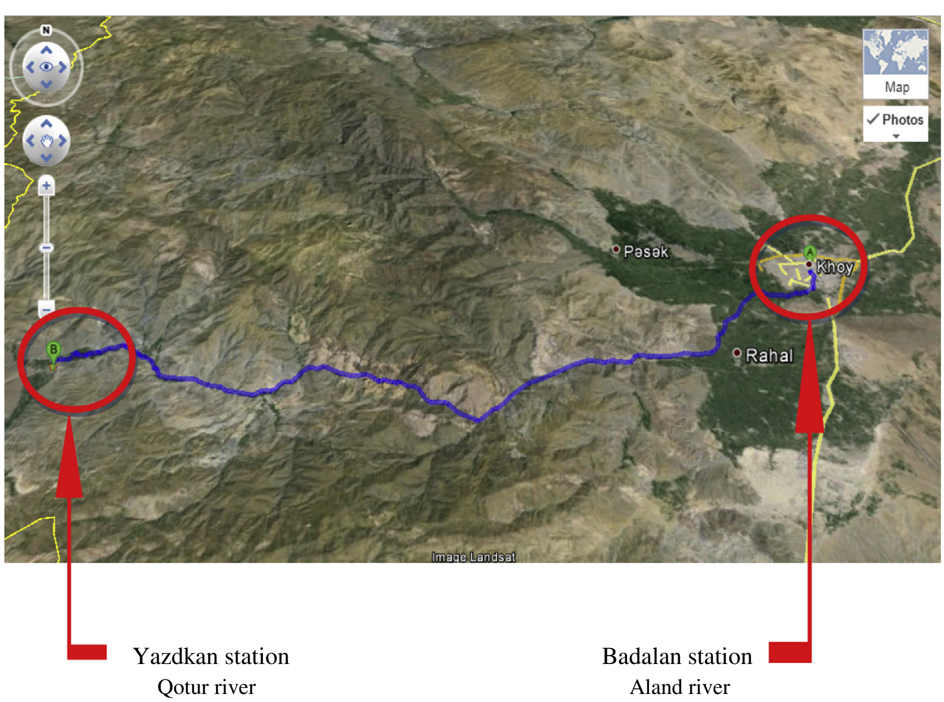

Fig. 1. Geographical position of the studied rivers.