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Comparison of artificial neural network and decision tree models in estimating spatial distribution of snow depth in a semi-arid region of Iran

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ABSTRACT

There is no doubt that snow cover plays an important role in the hydrological cycle of mountainous basins. Therefore, it is essential to measure snow parameters such as snow depth and snow water equivalent in these areas. The aim of this study is to estimate the snow depth from terrain parameters in the Sakhvid Basin, Iran using artificial neural networks (ANNs) and M5 algorithm of decision tree. For this purpose, snow depths were measured in 206 sites based on systematic network. Furthermore, 30 terrain parameters were extracted from a digital elevation model (DEM) of the basin. The results indicated that the decision tree model is the most suitable method to estimate snow depth in the study area with a Nash–Sutcliffe Efficiency (E_{ns}) of 0.80, followed by ANNs with an E_{ns} of 0.73. Moreover, the most significant parameters in the M5 decision tree algorithm are: channel network base level, stream power, wetness index and height.

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1. Introduction

Snowfall makes up a significant part of total annual precipitation in a variety of high latitude areas (Marofi et al., 2011). Measurement of the amount of water stored in the snowpack is essential for management of water supply (Shi and Dozier, 2000). In recent years, there is an urgent requirement to predict the snowpack. This is not only because of a rising demand for fresh water, but also due to the concerns about the effects of climate change (Gleick, 1993; López-Moreno et al., 2009). Climate change is likely to change the snow cover area and alter the water availability in the future making long term water management more challenging (Khadka et al., 2014). Simona et al. (2015) analyzed the snow depth and snowfall data in the western Italian Alps during the period of 1961–2010 and showed a significant decrease of snow depth in all the stations over seasonal time scale. The earth warming is ascribable to the threat posed by climate change and snow accumulations throughout the world. This requirement in arid and semi-arid regions such as Yazd Province in Iran with seasonal snowfall is apparent. In the Sakhvid basin of Yazd Province, although snow events may take place only once or twice a year, this small quantity of snowfall has a principle function to drinking water supplies of downstream regions (Yazd Regional Water Authority, 2015).

In order to analyze, quantify, and model the snowmelt runoff, it is necessary to account for spatial differences in snow accumulation (Luce et al., 1998; Seyfried and Wilcox, 1995). Generally, the spatial resolution of snow data and in situ observations of snow distribution are sparse and poor (Tarboton et al., 2000). Because of the enormous spatial variability of snow properties (i.e. snow depth and snow water equivalent), these few snow samples may not be illustrative of spatial patterns (Elder et al., 1991). Snow accumulation is heterogeneous, and once on the ground, the snow may be redistributed by some secondary agents such as wind, avalanching and sloughing (Blöschl et al., 1991; Elder et al., 1991; Kind, 1981).

Snow depth (SD) is an important variable in climate and hydrological model simulations (Dressler et al., 2006; Gong et al., 2007). Snow depth presents an extra dimension for snow cover studies by providing information relevant to water resources, soil processes, moisture and energy balance, and ecosystems (Dyer and Mote, 2006). As was previously mentioned, since the number of snow survey stations in mountainous areas is inadequate, employing a prediction technique to overcome this deficiency is necessary. In parallel with the research into snowpack, new modeling approaches, such as machine learning (ML) are emerging. ML approaches (i.e. artificial neural networks (ANNs), fuzzy logic, decision trees, support vector regression) are being employed in all fields of water resource sciences as an alternative to traditional methods (i.e. regression or auto-correlation-based statistical method such as ARIMA) to find a functional relationship between input (terrain attributes) and output (snow depth) variables. (Deka, 2014; Nourani et al., 2014).

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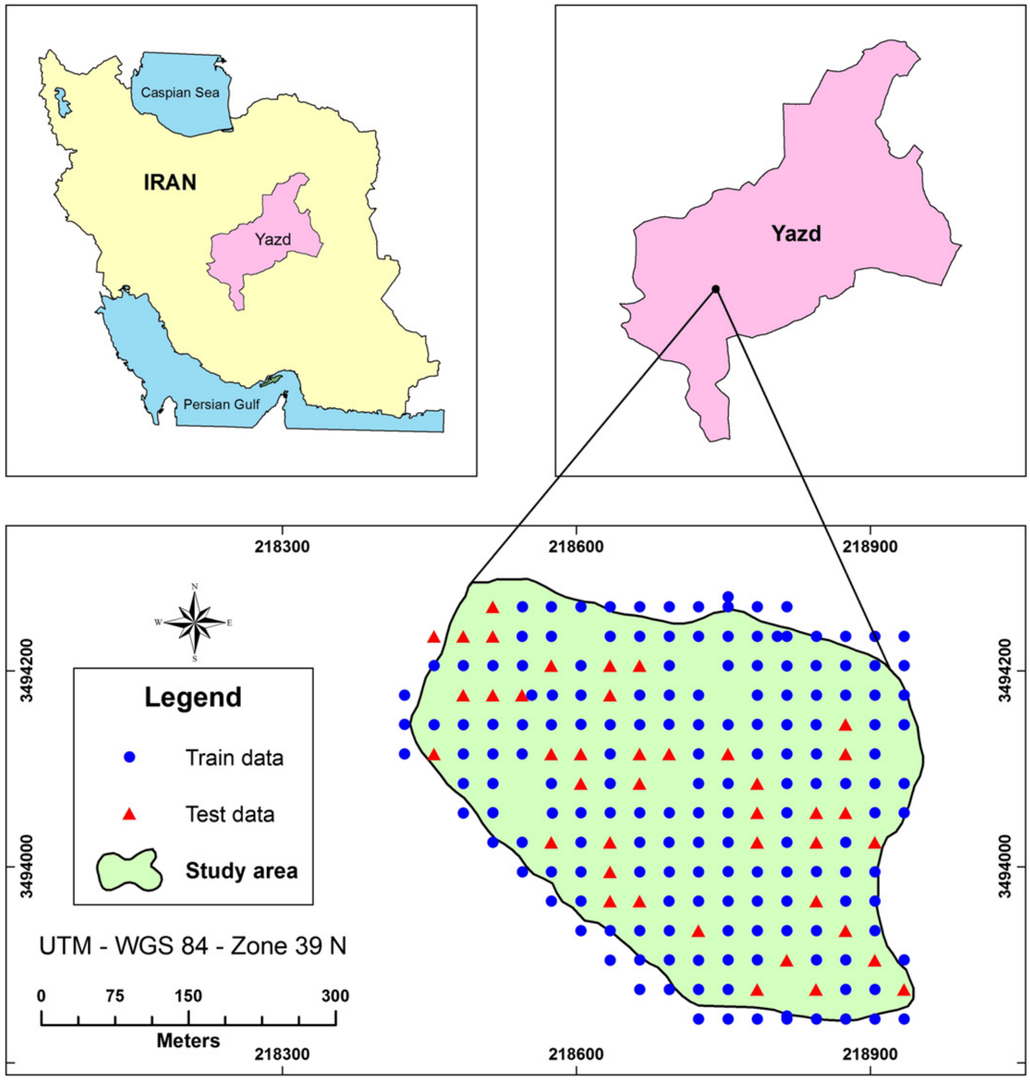

Fig. 1. The study area and location of measured data and spatial distribution of testing and training points.

ANNs are one of the ML algorithms that have been widely applied in hydrology science (Govindaraju, 2000). An ANN model can overcome large scale complex problems such as non-linear modeling, classification and association by learning and generalizing the knowledge from adequate pairs of data (Govindaraju, 2000). There is no need to have the knowledge about the physical process being modeled by the ANN technique (Nourani et al., 2011). Therefore, due to these features of ANNs, they are suitable methods for prediction in hydrologic science. Although, the ANN methods are applied widely in predicting hydrological variables, they have some difficulties. For instance, using trial and error method in order to detect the number of hidden layers and neurons is time consuming. Furthermore, the regression based models are black box models (Etemad-Shahidi and Mahjoobi, 2009).

Another type of ML algorithms is the model tree (Quinlan, 1992) that produces binary decision trees and is a spread of regression trees (Etemad-Shahidi and Mahjoobi, 2009). According to some researches, the advantages of decision tree against neural networks are that they demonstrate clear rules and can be trained faster. The rules are simple and they can be easily understood. In addition, the model tree does not require the optimization of geometry and internal network (Etemad-Shahidi and Mahjoobi, 2009; Solomatine and Xue, 2004).

Balk and Elder (2000) in their study modeled the spatial distribution of snow using binary decision tree and geostatistical techniques in Loch Vale Watershed (LVWS), Rocky Mountain National Park, Colorado. The

Table 1
The terrain parameter used for both of the ANN model and the model tree.

No.	Parameters	No.	Parameters
1	Longitude (X)	16	Strahler order
2	Latitude (Y)	17	Stream power
3	Slope	18	Flow accumulation
4	Slope length	19	Flow direction
5	Mid-slope position	20	Flow connectivity
6	Ls factor	21	Analytical hill shading
7	Catchment slope	22	Aspect
8	Slope height	23	Convergence index
9	Height	24	Catchment area
10	Normalized height	25	Modified catchments area
11	Curvature	26	Wind effect
12	Plan curvature	27	Multi resolution index of valley bottom flatness
13	Profile curvature	28	Multi resolution ridge top flatness index
14	Valley depth	29	Altitude above channel network
15	Wetness index	30	Channel network base level

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