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# Modeling of groundwater level fluctuations using dendrochronology in alluvial aquifers

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SUMMARY

Groundwater is the most important water resource in semi-arid and arid regions such as Iran. It is necessary to study groundwater level fluctuations to manage disasters (such as droughts) and water resources. Dendrochronology, which uses tree-rings to reconstruct past events such as hydrologic and climatologic events, can be used to evaluate groundwater level fluctuations. In this study, groundwater level fluctuations are simulated using dendrochronology (tree-rings) and an artificial neural network (ANN) for the period from 1912 to 2013. The present study was undertaken using the *Quercus Castaneifolia* species, which is present in an alluvial aquifer of the Caspian southern coasts, Iran. A multilayer percepetron (MLP) network was adopted for the ANN. Tree-ring diameter and precipitation were the input parameters for the study, and groundwater levels were the outputs. After the training process, the model was validated. The validated network and tree-rings were used to simulate groundwater level fluctuations during the past century. The results showed that an integration of dendrochronology and an ANN renders a high degree of accuracy and efficiency in the simulation of groundwater levels. The simulated groundwater levels by dendrochronology can be used for drought evaluation, drought period prediction and water resources management.



## 1. Introduction

Groundwater currently accounts for more than seventy percent of Iran's total water consumption. Therefore, it is the most important water resource in Iran and other regions with similar types of semi-arid and arid climates. Unfortunately, this water resource is endangered. Iran's groundwater resources have decreased due to inappropriate usage and over exploitation. In recent decades, agricultural development has caused a decrease in Iran's groundwater resources. Most agricultural lands in Iran are irrigated by groundwater. Yet, the temporal distribution of precipitation is quite irregular in Iran. Most precipitation falls in the autumn and winter, and the precipitation during the growing seasons (i.e., spring and summer) is less. In areas with high groundwater levels, trees fulfill their needs for water from groundwater via their root systems (Lewis and Burgy, 1964; Willms et al., 1998). Radial growth of root system occurs in the early spring when the surface flows are high and the ground water is shallow (Horton et al., 2001). Additionally, seedling survival is often dependent on the ability of the seedling roots to remain in contact with the alluvial water table and its associated capillary fringe (Horton and Clark, 2000). Records for precipitation, streamflow and groundwater levels are imperative for water resource management, agriculture, potable water administration and manufacturing. A study of historical climatologic and hydrometric variability is important for understanding current and future hydro-climatic trends and their relationship with social and economic stability (Timmerman et al., 1999). A complicated linkage exists between precipitation, streamflow and groundwater. When precipitation decreases in a region, the groundwater levels decline, and when precipitation increases, the groundwater levels rise (Liu et al., 2010). Tree-ring chronologies can provide proxy records to characterize precipitation, streamflow, droughts and other hydrological and climatological variables for periods as long as several hundred years; these records are longer than other available instrumental records (Watson and Luckman, 2005). The extent of a tree-ring is dependent on tree growth, and therefore, it is also dependent on ecological conditions especially precipitation and access to water. In other words, changes in environmental moisture affect a tree's growth and its tree-ring diameter. In this

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study, we evaluated the relationship between tree-ring diameter and environmental moisture (precipitation and groundwater levels). Temporal changes in groundwater levels during the past are useful for water resources management. Drawdown of groundwater is defined as a lowering of the groundwater level. Intensive drawdown of the water table occurs during droughts. The term drought is a multiple concept (climatic, hydrologic and hydrogeologic). A hydrogeologic drought can be evaluated by measuring the drawdown in groundwater levels. Therefore, drawdown in groundwater levels can be used to define droughts during different periods. Currently, dendrochronology is used in climatologic and hydrologic studies. Dendrochronology is the science of extracting past climatic and hydrologic variability from tree-ring data. Tree-ring chronologies are often used to construct histories of unmeasured events in the past. Standard reviews of the sampling methods and other techniques, which are used in dendrochronology, are given by Stokes and Smiley (1968), Fritts (1976, 1991) and Cook and Kairiukstis (1990). Each tree-ring record corresponds to a single growing season, and a clear boundary between seasons is provided by the contrast that exists between latewood, which is formed near the end of the current growing season, and the larger, lighter in color earlywood cells, which form in the spring. Tree growth is dependent upon ecological parameters such as precipitation, temperature, and moisture. Trees will produce thicker annual rings in wet years compared to dry years. Previous dendrochronology applications include drought occurrence studies (Meko et al., 2001; Knight et al., 2010; Cook et al., 2010; Woodhouse et al., 2010), precipitation studies (Gray et al., 2007; Villanueva-Diaz et al., 2007; Kleppe, 2005), temperature studies (Salzer and Kipfmueller, 2005), and streamflow studies (Carson and Munroe, 2005; Woodhouse et al., 2006; Watson et al., 2009; Barnett et al., 2010). Dendrochronology studies require cross-dated ring-width data from trees that correspond to the variable of interest, typically moisture or water (Irby et al., 2013). Previous studies have shown that precipitation, soil depth, temperature and elevation (groundwater level and precipitation changes) influence tree-ring diameters, and these parameters should be considered in chronology studies (Fritts, 1976; Hidalgo et al., 2000; Wise, 2010). Different studies show that there is a relationship between precipitation and tree-rings. Please refer to Sarris et al. (2007) and Griggs et al. (2013). Their studies showed that in the year before growth, trees mainly use the precipitation that occurs from January to December rather than the precipitation that occurs from September to December, and in the year of growth, trees mainly use the precipitation that occurs from January to August. In Iran, there is a correlation between the growing season precipitation, which occurs from April to August, and the tree-ring extent. Additionally, there is a correlation between the annual precipitation and the precipitation that occurs during the growing season. Past studies have shown that there is a correlation between the groundwater levels and precipitation (Braithwaite and Muller, 1997). During the winter, higher precipitation and lower evapotranspiration cause a progressive rise in the groundwater levels, which ultimately saturates large parts of the alluvial plain (Pfister et al., 2003). Moisture-stressed trees were used in some successful hydro-climatic reconstructions of variables such as streamflow and precipitation (Woodhouse et al., 2006). Touchan et al. (2005) simulated precipitation from May to August in the northeastern Mediterranean region, which includes Cyprus, using conifer species such as *P. brutia*. Kienast et al. (1987) showed that variability in tree growth due to climate is related to elevation changes; these elevation changes impact precipitation, temperature, soil depth and moisture access. Stella et al. (2011) evaluated the effects of climate and groundwater level on the establishment, growth and death of the *P. caldenia* species, which is located in the lowlands and uplands. Their results showed that groundwater levels could induce a diverging sensitivity of the forest growth and survival rates to climatic variability, enhancing growth at optimum depths (2–8 m), but depressing growth or even killing trees when these levels approach the surface (<2 m). Groundwater level changes should be evaluated for forest management and conservation strategy development in semi-arid woodlands. Rising groundwater levels can affect tree growth as they approach the surface (due to an increase in water access); this rise can cause a shift from a positive water supply effect to a negative effect due to water logging (Jobbagy and Jackson, 2004; Nosetto et al., 2009). Groundwater level increases have also simultaneously encouraged tree establishment and growth due to better groundwater access. Therefore, the tree-rings of woody species have been widely used as proxy to reconstruct hydro-climatological data. Nevertheless, the use of tree-rings to detect groundwater level fluctuations (Ferguson and St. George, 2003; Perez-Valdivia and Sauchyn, 2011) and to determine the effect of flooding on wood anatomy has been limited (Eckstein, 2004; Sass-Klaassen and Hanraets, 2006). Watson and Luckman (2005) evaluated streamflow reconstructions, and their results showed that low flows (hydrological droughts) might not be related to the periods of low rainfall that occur during the growing season.

It is important to select suitable tree species for dendrochronology studies. We selected the *Quercus castaneifolia* species for dendrochronology studies in the Fomanat plain, Guilan, northern Iran. *Quercus* is the largest genus in the family Fagaceae with approximately 300–600 species (Soepadmo, 1972); it is the most common genus of Fagaceae in forests of Iran. There are different species of Oaks in the Hyrcanian forests (northern Iran forests).

*Q. castaneifolia* is an important species of Iran's native Oaks that occurs in the Hyrcanian forests in northern Iran, and it is one of the main species of the Hyrcanian forests (Panahi et al., 2011). An Oak tree can grow up to 35 m tall, with a trunk diameter of up to 2.5 m. Oak trees can live for 400–500 years, and sometimes, they live as long as 1000 years. Oak trees are magnificent trees for parks, arboretums and woodlands where there are spaces for its superb crown to mature. Some Oak species are suitable for dendrochronology studies, and they can be used to reconstruct hydrological and climatological parameters. The sensitivity of the Oak species' tree-ring extent to climatologic and water access changes is high. Ferguson and St. George (2003) forecasted temporal fluctuations in the groundwater levels using estimates that were derived from a subset of the moisture-sensitive bur Oak chronologies. Different studies in the application of dendrochronology in climatology and hydrology have been conducted using the Oak species. We refer to Pilcher and Baillie (1980), Terradas and Savé (1992), Corcuera et al. (2004), Rozas (2005), Paton et al. (2006), Tardif and Conciatori (2006), Danek et al. (2007), Griggs et al. (2007), Moreno and Cubera (2008), Friedrichs et al. (2009), Di Filippo et al. (2010), Gea-Izquierdo et al. (2011).

There are different models and methods for modeling different hydrologic processes. An artificial neural network (ANN) is a new and efficient approach to hydrologic studies. ANNs were used for water resources modeling in the early 1990s. Its use has increased significantly over the last decade, leading to a number of studies of its applications (Maier and Dandy, 1998; Dawson and Wilby, 2001; Elshorbagy et al., 2010a,b; Maier et al., 2010; Abrahart et al., 2012; Wu et al., 2014). ANNs provide an appealing way to simulate water resources systems (Maier and Dandy, 2000). Multilayer percepetron (MLP) feed-forward network types have been widely applied to simulate hydrological processes (Isik et al., 2013). A number of studies have evaluated the use of neural networks for groundwater level forecasting (e.g., Coulibaly et al., 2001; Coppola et al., 2005; Daliakopoulos et al., 2005; Lallahem et al., 2005; Nayak et al., 2006; Uddameri, 2007; Krishna et al., 2008; Trichakis et al., 2009; Ghose et al., 2010; Yoon et al., 2011; Adamowski and