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Spatial analysis of infiltration in agricultural lands in arid areas of Iran

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ABSTRACT

Infiltration plays an important role in the hydrologic cycle, runoff generation, soil erosion, as well as irrigation. In the current study, we evaluated a variety of infiltration models, in order to determine the model that is best suited to predict infiltration on agricultural lands in arid areas of the Semnan province in Iran. Additionally, we analyzed spatial variability of the infiltration process using scaling parameters. A number of 60 points were determined for the measurement of water infiltration using the conditioned Latin hypercube sampling (cLHS) method. Each infiltration measurement was carried out with a tension infiltrometer apparatus. Several infiltration models, including Philip, Horton, Kostiakov (KO), Modified Kostiakov (MKO) and Revised Modified Kostiakov (RMKO) models, were fitted to the measured infiltration data. Among the mean coefficient of determination (R^2) values, the highest R^2 values were associated with the RMKO, MKO and Horton models, respectively. While base on the Akaike criterion (ACI), the MKO model was slightly better than the RMKO model for prediction of cumulative infiltration. Cumulative infiltration was scaled using Sorptivity (α_S) and transmissivity (α_A) scaling factors. By minimizing the differences of the sum of squares between the scaled and the average infiltration, the optimum scaling factors (α_{opt}) were estimated. Arithmetic, geometric and harmonic means (i.e. α_m, α_G, α_H; respectively) of α_S and α_A scaling factors were calculated and the infiltration data were scaled utilizing the mentioned scaling factors. Our findings indicated that the best result was yielded by α_H. Strong correlations were found for α_G (r = 0.86) and α_H (r = 0.86) with α_{opt}. For defining the relationship between α_{opt} and α_A, α_S, α_m, α_G and α_H data, a regression analysis was performed. According to our results, curves reflecting the relationship between α_{opt} and α_A, α_S, α_m, α_G and α_H were sigmoid. Based on the results of this study, infiltration in agricultural lands in the arid area displays a great spatial variability.

1. Introduction

It has been widely accepted that the hydrologic cycle, runoff generation, soil erosion and irrigation are effected by infiltration (Mirzaee et al., 2014; Dafny and Šimunek, 2016). Precipitation, irrigation, or a contaminated spill water, which enters the soil or creates runoff is determined by infiltration (Radcliffe and Šimunek, 2012; Ghorbani Dashtaki et al., 2009). It also plays a key role in controlling crop yield for designing irrigation systems, increasing the efficiency of water and solute transport in the soil profile and reducing water losses (Hillel, 1998). The amount of infiltrated water into the soil is one of the main parameters for water resources management. The groundwater system sustainability is also dependent on the amount of recharge by infiltrating rainfall (Chen et al., 2005). So far, a large number of modeling approaches for infiltration have been developed by numerous soil and water scientists (e.g., Green and Ampt, 1911; Kostiakov, 1932; Philip, 1957; Mein and Larson, 1973; Argyrokastritis and Kerkides, 2003; Mirzaee et al., 2014). However, only a few of the proposed infiltration models have been successfully applied using field data. Parameter estimation is the principle criterion for preferring one model over another.

The spatial variability of the soil is considered the main problem for modeling infiltration at the watershed scale (Machiwal et al., 2006). Spatial variation of infiltration causes complexity to the management of irrigation at a watershed scale, as well as drainage. Furthermore, in the agricultural lands, a large spatial variability of infiltration is caused by farming practice. Hence, providing an applicable general infiltration equation for a wide range of soil conditions is pivotal. The classification of soil mapping units and the variation coefficient are among the available approaches in determining the spatial soil variability (Warrick and Nielsen, 1980; Jury, 1986; Jury et al., 1987; Beven et al., 1993; Mulla and Mcbratney, 2002). However, considerable variation in soil hydraulic properties have been reported, even in the same soil mapping unit (coefficients of variation greater than 100%) (Nielsen et al., 1973; Comegna and Vitale, 1993). Several geostatistical techniques can be utilized for the estimation of the hydraulic properties of the spatial soil

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variability. However, the main limitation in utilizing geostatistical techniques for its determination is its requirement to numerous measurement points. Scaling is an alternative way for describing the general infiltration equation. Multifractal analysis has been proposed, as the scaling approach for determining the hydraulic properties of the spatial soil variability (Pahlevan et al., 2016). Furthermore, scaling has been applied as a simple method for describing the field spatial variability (Pachepsky et al., 2003; Nielsen et al., 1998; Warrick et al., 1977), alongside with infiltration, drainage rate and available water (Sharma et al., 1980; Rasoulzadeh and Sepaskhah, 2003; Ahuja et al., 2007). By measuring a representative point at different locations in a watershed, soil hydraulic properties can be estimated by applying scaling approach (Williams and Ahuja, 1991; Kozak and Ahuja, 2005). By using scaling method, Philip's quasi-analytical solution was developed by Warrick et al. (1985) for one dimensional infiltration. Rasoulzadeh and Sepaskhah (2003) scaled infiltration using Buckingham's theorem for the dimensional analysis. Warrick and Hussen (1993) scaled Richards' equation in similar soils. More recently Sadeghi et al. (2011, 2012) have developed an additional scale solution for Richards' equation. Despite their dissimilarity, their advantage over Warrick–Hussen method was that they produced invariant solutions for a wider range of soils.

Spatial variability of soil properties in agricultural land could be induced by farmer's practice and/or result from edaphic factors, such as the parent material and soil position in the *catena*. Therefore, spatial variability of soil properties in agriculture lands may be greater for the undisturbed soil. Limited number of studies have characterized the spatial variability of soil hydraulic properties in arid agricultural lands. However, to the best of our knowledge, no study has been carried out for describing the spatial variability of the soil water infiltration in arid areas of Iran. The main objective of this study is to evaluate a variety of infiltration models and to determine the best model for agricultural lands in arid areas of Iran. In addition, we aim to use the scaling approach to analyze the spatial variability of infiltration process.

2. Materials and methods

2.1. Study area and soil sampling

The study was carried out in the agriculture land in Semnan region in the Semnan province located in the central region of Iran, between latitudes of 35° 30′ to 35° 55′ N and longitudes of 53° 21′ to 53° 34′ E (Fig. 1). The total area was approximately 12,000 ha, in which 90% is earmarked for the production of wheat, barley and corn.

The mean annual temperature in the study area is 18.5 °C the precipitation is 138 mm, respectively, (Fig. 2).

Selection of sampling points were based on the conditioned Latin hypercube sampling (cLHS) method (Minasny and Mcbratney, 2006). Sampling of variables from their distributions can be effectively performed by the stratified-random procedure in cLHS. This sampling method has proven to be impractical in locations with accessibility limitations (Roudier et al., 2012; Jeong et al., 2017). However, our study area was flat and easily accessible. The prescribed distribution of variables or auxiliary variables is utilized for determination of the sampling points. In this study, the Landsat 8 satellite image acquired on September 2015, freely available from the NASA server, was used as the auxiliary variable. Auxiliary variables were consisted of four visible bands (bands 1, 2, 3 and 4), NIR (band 5), SWIR (bands 6 and 7). A number of 60 points were determined for the measurement of water infiltration. Each infiltration measurement was triplicated, using a tension infiltrometer apparatus. For determination of the physical and chemical properties in each point, disturbed and undisturbed soil samples were collected from at a depth of 0 to 15 cm. The disturbed soil samples were air dried and passed through a 2 mm sieve. Soil texture was determined by hydrometer (Gee and Bauder, 1986). Later on, soil pH and electrical conductivity (EC at 25 °C) were determined in the extract paste. Finally, soil organic carbon (OC) content was measured by the Walkley–Black method (Walkley and Black, 1934).

2.2. Infiltration measurement

Infiltration data were obtained using a tension infiltrometer with a 20 cm diameter disk (Soil Measurement Systems LLC, Tucson, Arizona). Water infiltration into the initially dry soil was measured at the inlet (upper boundary) with a constant pressure head of 5 cm for all locations. In order to assure a proper contact between disk and soil, moist fine sand (0.10–0.25 mm) was gently placed on the soil surface. Then, the disk was placed on the soil surface and cumulative water infiltration was monitored versus time. For each sample, the infiltration experiments were continued until the infiltration rate reached a constant value. For measuring bulk density (BD), an undisturbed soil sample was collected from the surface (near to the disk place), using a core sampler with 5 cm diameter and 5.1 cm of height (i.e. 100 cm^3).

2.3. Estimation of infiltration model parameters

In this study five infiltration models including Philip, Horton, Kostiakov, Modified Kostiakov and Revised Modified Kostiakov models were selected. For all the studied models, a non-linear regression

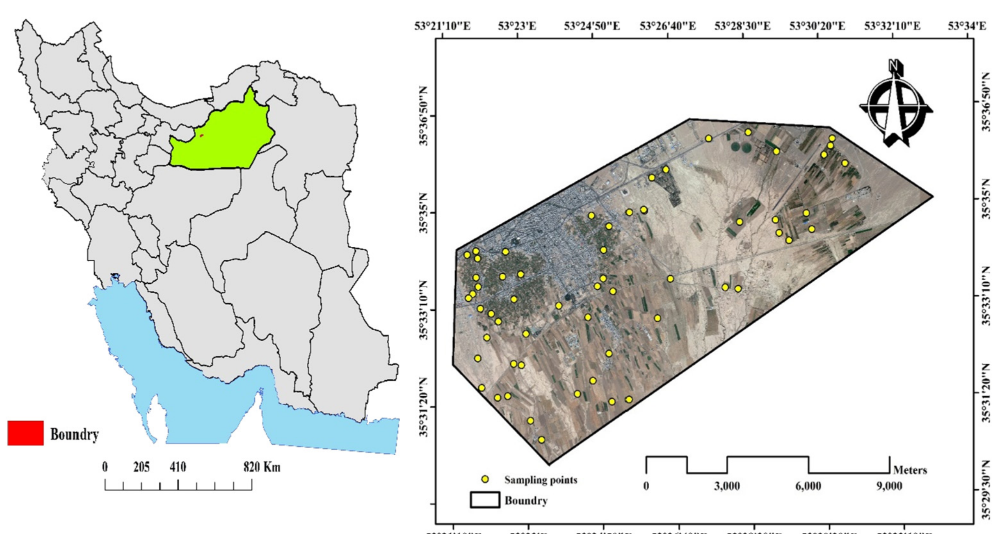

Fig. 1. Position of the study area and distribution of sampling points.

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