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Developing Pedo Transfer Functions to Predict Infiltration Rate in Flood Spreading Stations of Iran

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Abstract: Since, measuring infiltration rate directly is time consuming and expensive, the Pedo Transfer Functions (PTFs) were developed to estimate soil infiltration rate using soil physical data of the flood spreading stations in Iran. Infiltration rate was measured in the flooded areas by double ring method. Selected soil physical properties used as input variables were sand, silts, clay percentage, bulk density, field capacity and wilting point. Soils studied were classified as Entisols. All stations were classified into three groups using Principal Component Analysis (PCA). Linear and nonlinear PTFs were developed to estimate infiltration rate. For one variable linear regression, the PTFs at 0.95 confidence interval were obtained. Nonlinear regression developed as PTFs using gravel, sand, silt and clay percent. There were also developed the multi variable functions based on the gravel, sand, silt and clay percent, so it is possible that developing the related functions to estimate infiltration rate by easily measured soil parameters. Most of the developed functions were cubic. Changes in PTFs have wide variation and developed PTFs vary based on the number of parameters formed them.

Key words: Flood, infiltration, regression, soil properties, water spreading

INTRODUCTION

Presently, the flood spreading systems are using in some regions of Iran to control flood damages and aquifers recharge. By spreading a large volume of floods containing suspension load on the spreading network, it may lead to some differences in soil infiltration. Soil infiltration rate is an important parameter for quantifying runoff, soil water and solute movement and for modeling hydro geologic processes. General idea is that due to the existence of solute and suspended materials in flood water, soil infiltration rate may gradually reduce. Since, direct measurement of soil infiltration is time consuming and expensive, an alternative approach to estimate soil infiltration has been a subject of research efforts and an indirect estimation method which is often regarded as Pedo-Transfer Function (PTF) approach has been developed. In the PTF method, soil properties such as infiltration rate can be estimated in terms of easily measurable soil physical and chemical properties.

Pedo-transfer functions have been used for a wide range of non cultivated soils, amongst other US soil (Pachepsky *et al*., 2006) and Danish soils (Borgesen and Schaap, 2005). Mateosa and Giráldeza (2005) showed that the total sediment load decreases with successive irrigations and increases as it

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moves downstream, while the bed load decreases. If it is not pay attention to sedimentation of spreading channels, land and plant cover will degrade, decrease infiltration and increase soil salinity. Wagner *et al.* (2001) evaluated eight well-known PTFs used for estimation of soil hydraulic conductivity using detailed measurements of 63 German soil horizons and found that the developed PTF performed the best for predicting unsaturated hydraulic conductivity. Krogh *et al.* (2000) tested 1643 soil samples and showed the clay and organic matter of soil can explain 90% of Cation Exchangeable Capacity (CEC) differences by improving of some functions.

Tomessla *et al.* (2000) used PTFs to estimate moisture curve of Brazilian soil and showed the improved functions have the minimum error compared to other common functions. Khodaverdilu and Homaee (2002) studied 27 soil samples of Karaj series with loamy texture and showed that the improved PTFs can estimate soil moisture content by 93% correlation coefficient. To estimate soil water content, Jarvis *et al.* (2002) developed PTFs on the arable lands that can explain more accurate than non arable lands, so that the correlation coefficient increased from 15 to 35%. Soil Water Characteristic Curve (SWCC) of a silty soil was studied indirectly using the estimation algorithms known as pedo-transfer functions. The study reveals that the PTFs developed previously to estimate SWCCs match very well with the experimental results (Thakur *et al.*, 2007). McBratney *et al.* (2002) suggest that this problem can be overcome by using Monte Carlo methods to choose the results from the Pedotransfer function which gives the least variance.

Ghorbani Dashtaki and Homaee (2004) by improving PTFs showed that the mean soil particle size, standard error and special gravity of soil are suitable parameters to estimate soil moisture content. Haung and Zhang (2005) used the soil particle size as an easily measurable soil property to improve PTFs for estimation soil moisture curve. Pachepsky *et al.* (2006) used the soil structure in PTFs for estimation of soil hydraulic conductivity. Sten *et al.* (2001) reviewed the current status of PTF development, methods to develop PTFs and the accuracy and uncertainty of various PTFs. Because every PTF is developed on the basis of a limited database, it exist a lot of uncertainty in applying PTF to different soil conditions from the soil conditions under which PTFs are developed. Thus, there is a need to understand the accuracy and the limit of the PTFs developed in other places in order to apply for soil conditions.

The aim of the present research was to develop the PTFs for estimating soil infiltration rate by the linear and nonlinear regression methods using soil physical data of flood spreading stations of Iran.

MATERIALS AND METHODS

The study area, Iran covers an area of 1,648,000 km^2 (636,296 mi^2) and extends about 2,250 km (1,398 mi) SE-NW and 1,400 km (870 mi) NE-SW. Iran has a variable climate. In the Northwest, winters are cold with heavy snowfall and subfreezing temperatures during December and January. Spring and fall are relatively mild, while summers are dry and hot. In the South, winters are mild and the summers are very hot, having average daily temperatures in July exceeding 38°C. On the Khuzestan plain, summer heat is accompanied by high humidity. In general, Iran has an arid climate in which most of the relatively scant annual precipitation falls from October through April. In most of the country, yearly precipitation averages 25 cm or less. The major exceptions are the higher mountain valleys of the Zagros and the Caspian coastal plain, where precipitation averages at least 50 cm annually. In the western part of the caspian, rainfall exceeds 100 cm annually and is distributed relatively evenly throughout the year. This contrasts with some basins of the central plateau that receive 10 cm or less of precipitation annually.

Thirteen flood spreading stations were selected in the country which infiltration rate was measured during 5 years (Fig. 1). The regional soils are classified as Entisols with high percent of gravel and belong to main subgroup of xeroflovents.

Infiltration rate (mm h^{-1}) was measured in spreading stations during five years after construction by double ring method (ASTM D5093-02, 2008) in flood spreading lines (Fig. 2).

Fig. 1: Location of the flood spreading stations

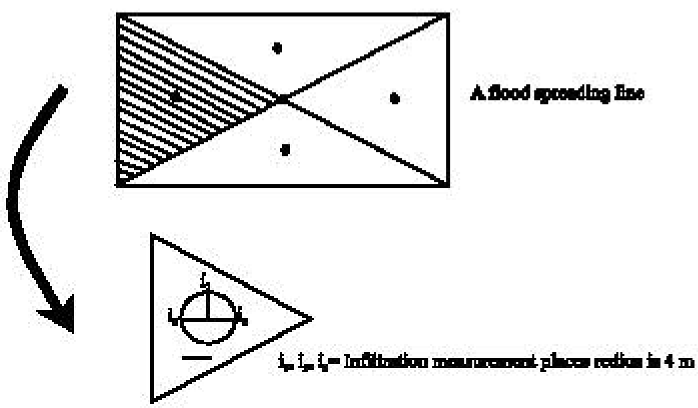

Fig. 2: Measurement of infiltration rate in a singular point

Totally, 585 measurements of infiltration rate were investigated. The Kolmogorov-Smirnov test (Stephens, 1974) was used to determine the normality of data obtained. Selected soil properties used as input variables for estimation of infiltration rate were silt, sand, clay percentage, bulk density, field capacity and wilting point measured based on NRCS (1992) of USDA standards.

All stations were classified by Principal Component Analysis (Levesque, 2007) using soil physical data mentioned above. Linear and nonlinear pedo transfer functions were developed to estimate infiltration rate.

Pedo-Transfer Function Approach

To develop the Pedo-Transfer Functions (PTFs) approach to estimate infiltration rate, this parameter was indirectly estimated from the easily measured soil properties. Stepwise regression method (Levesque, 2007) was used to establish the prediction equation for PTFs with $\alpha = 0.05$.

PTF for Soil Infiltration Rate

The PTFs for soil infiltration rate were explained as below (Eq. 1, 2):

$$I = b_0 + b_1 t + b_2 t^2 + b_3 t^3 \quad (1)$$

$$I = b_0 b_1^{\,t} \quad (2)$$

Where:
I: Soil infiltration rate
t: Given variable
b: Relation coefficients

RESULTS

The soil infiltration rate values evaluated and classified into three classes by the application of the cluster and principal component analysis (Fig. 3).

As Fig. 3 and Table 1, the results showed that factor 1 can explain 42.2% of variance. While factors 2 and 3 explain 14.3 and 10.8%, respectively of variance of the soil physical properties of flood

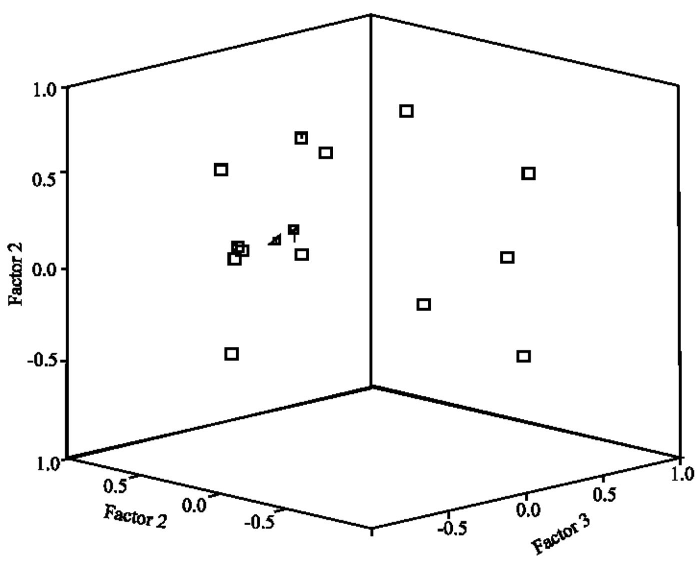

Fig. 3: Recognizable classes based on eigenvalue of correlation matrix above 1

Table 1: Eigenvalue of correlation matrix

	Eigenvalue of correlation matrix above 1	
Factors	Percent of variance	Cumulative percent
1	47.15	47.15
2	14.30	61.45
3	10.78	72.23

Table 2: Grouping flood spreading stations based on cluster analysis

Groups	Stations
1	East Azarbaijan, West Azarbaijan, Sabzevar, Yazd, Gonabad, Birjand, Ilam, Hormozgan
2	Kerman, Mazandaran, Fars
3	Balochestan, Bosher

Table 3: Normalization of functions for independent variables of stations group 1

Normalization functions	Variables
$(\text{Sand})^2$	Sand
In(1+Silt)	Silt
In(1+Clay)	Clay
$(\text{Gravel})^{0.7}$	Gravel
$\text{In}(\text{SP})^{0.4}$	SP
$\text{Bd}^{0.9}$	Bd
$\text{PWP}^{0.9}$	PWP

Table 4: Coefficients of PTFs to predict infiltration rate in stations group 2

Model		B	SE	t-value	Sig.
1	(Constant)	60.966	16.483	3.699	0.014
	Sand	-0.578	0.164	-3.530	0.017
	Silt	-0.868	0.288	-3.010	0.030
	FC	-1.574	0.502	-3.139	0.026

Table 5: Improved PTFs for predicting infiltration rate in groups

Groups	PTFs	R^2
1	$I = 2.894\text{-}0.00003\times\text{sand}^2$	1.00
	$I = 2.869\text{-}0.00003\times\text{sand}^2\text{-}0.002\times\text{PWP}^{0.9}$	1.00
2	$I = 60.966\text{-}0.578\times\ln(\text{sand})\text{-}0.868\times\ln(\text{silt})\text{-}1.574\times\ln(\text{FC})$	0.74
3	$I = 7.587\text{-}0.062\times\text{sand}^{0.9}$	0.60

It should be used the actual value of variables in functions

spreading stations. Table 2 shows the result of classification flood spreading stations into three groups based on clustering. There are 8 stations lay in group 1, 3 in group 2 and 2 in group 3.

The results of the Kolmogorov-Smirnov test (Stephens, 1974) showed all data of soil physical properties are abnormal because the test coefficient was less than 0.05. Table 3 shows the results of normalization of data for station group 1 for example. Logarithmic and power functions used for normalization of data.

Linear PTFs

Two models of PTFs for predicting infiltration rate were improved in stations group 1 based on sand percent and permanent wilting point. To predict infiltration rate in stations group 2, one model was improved based on silt, sand and field capacity. An example for group 2 was showed in Table 4.

For stations group 3 another model also developed based on sand. Resulted PTFs for three groups of flood spreading stations were showed in Table 5. These functions are power models in groups 1 and 3, whereas resulted equation for groups 2 is logarithmic.

Nonlinear PTFs

For stations group 1, two models of nonlinear PTFs with one variable improved based on gravel and sand with R^2 of 0.14 and 0.16 as Table 6 and related equations were demonstrated in Fig. 4 and 5.

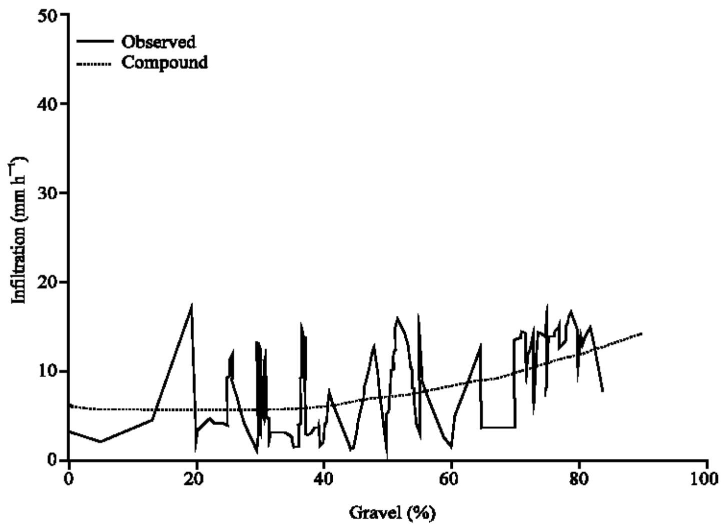

Fig. 4: Non linear relation between Infiltration rate and gravel percent for stations group 1

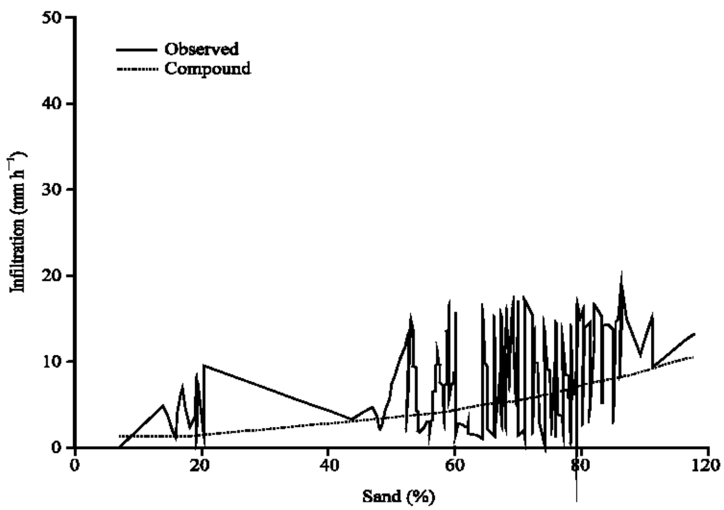

Fig. 5: Non linear relation between Infiltration rate and sand percent for stations group 1

Table 6: Nonlinear models developed for estimating infiltration rate in stations group 1

Groups	Independent variables	Model	R^2	Sig.	b_0	b_1	b_2	b_3
1	Gravel	Cubic	0.14	0.00	6.1767	-0.0545	0.00120	4.10E-06
1	Sand	Compound	0.16	0.00	1.1213	1.0235	-	-
2	Sand	Cubic	0.40	0.00	0.9096	0.0024	-5.00E-05	3.20E-07
2	Silt	Cubic	0.60	0.00	0.9755	-0.0038	0.000100	-2.00E-06
2	Clay	Cubic	0.29	0.01	0.9487	0.0017	-0.000100	2.10E-06
3	Sand	Cubid	0.13	0.03	-13.5840	1.5103	-0.035600	0.000300
3	Silt	Cubic	0.12	0.05	13.4271	-0.8296	0.020200	-0.000100

There are also three nonlinear PTFs developed for stations group 2 that have been made from sand, silt and clay factors (Table 6). For stations group 3 there are developed 2 PTFs with independent variables of sand for the first equation and silt for the second one.

Table 7: Multivariable PTFs to estimate infiltration in the groups

Groups	PTFs	R^2
1	$I = 3.705+0.0000007\times sand^{2.325}+0.00000003\times gravel^{4.105}$	0.236
2	$I = -221.131+0.43\times sand^{1.364} + 14.911\times gravel^{-5.698}+8.183\times silt$	0.997

Multivariable PTFs

Multivariable PTFs were developed to estimate infiltration rate using independent variables of sand and gravel for group 1 and sand, gravel and silt for group 2 (Table 7). Resulted equations were power models and showed that soil textural fractions of sand and silt in addition to gravel can affect the infiltration rate.

DISCUSSION

Although, the literature review showed there were many researches on PTFs, but their emphasis are generally focused on soil hydraulic conductivity (Pachepsky *et al*., 2006; Wagner *et al*., 2001) and soil moisture curve (Haung and Zhang, 2005; Ghorbani Dashtaki and Homaee, 2004; Tomesla *et al*., 2000) and there are little researches to predict soil infiltration rate. So, developing the related functions to estimate infiltration rate by easily measured soil parameters has a special importance.

Determining coefficients of developed PTFs showed they can not explain all variance of changes which may be due to the following reasons: Firstly, infiltration is a complex process and has high variance; secondly there is not a parameter that can show the effect of soil structure and pores on infiltration rate. This is in agreement with Sten *et al*. (2001) that mentioned there is a lot of uncertainty in applying PTF to different soil conditions.

Resulted regression coefficients at assumed confidence interval of 0.95 obtained in this research vary 0.16 to 1.00, so the changes have wide variation. It seems the different properties of flooded surface and flood quality is the reason. Khodaverdilu and Homaee (2002) obtained 93% correlation coefficient and Jarvis *et al*. (2002) calculated 15 to 35%.

The PTFs obtained were mostly based on soil texture. Ghorbani and Homaee (2004) and Haung and Zhang (2005) used the soil particle size and Pachepsky *et al*. (2006) used the soil structure as an easily measurable soil property to improve PTFs.

CONCLUSION

In this study, developed PTFs vary based on the number of parameters formed them. Most of the developed functions are cubic and one of them is compound. The PTF approach estimates soil infiltration rate parameters indirectly based on the input variables of soil texture and is very efficient way of estimating soil infiltration rate. Determining coefficients of developed PTFs showed they can not explain all variance of changes. It may caused by two reason. Firstly, infiltration is a complex process and has high variance; secondly there is not a parameter that can show the effect of soil structure and pores on infiltration rate.

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