A Presentation of an Experimental Model for Unsaturated Hydraulic Conductivity under Affection of Physical Properties of Soil: A Case-by-Case Study of Baghin Plain in Kerman, Iran

Ali Neshat and Mehdi Farhad

Azad University, Kerman Branch, Iran

Abstract: The unsaturated hydraulic conductivity of soil is one of the most principal parameters in the study of water movement in the soil. As the field methods are hard and expensive, they are not desirable among the measurement methods. The principal of Laboratory styles is conducting experiment on the sample of soil from the case region. The aim of this research is to carry out the experiment and required calculation for estimating the most suitable relationship between the unsaturated hydraulic conductivity of soil and soil physical properties in the Baghin region of Kerman. The study also aims to determine the soil general condition with measuring their pH, electrical conductivity, the ratio of existing lime and gypsum in the soil. The next step was to estimate the unsaturated hydraulic conductivityof soil (K_u) by discharging equations in the unit of area, Darcy's law and RETC software and different models of that. By using neural network, SPSS and Curve Expert software and Excel the various models were fitted to the results of the Laboratory .The results showed that the power model from the SPSS software among the different models which were fitted to the results of research, had the maximum coefficient of determination and significant correlation coefficient (r) in the one percent level and the minimum amount of RMSE. Accordingly, this was presented as the best model.

Key words: Unsaturated hydraulic conductivity of soil · Soil physical properties · Neural network · RETC software

INTRODUCTION

Unsaturated hydraulic conductivity is a function of soil moisture and its amount will be decreased with going down the soil moisture. Field methods that are used for measuring the unsaturated hydraulic conductivity are usually time-consuming, hard and expensive, but if they are designed and conducted well, their results will be accurate. Theoretical methods that are used for presenting unsaturated hydraulic conductivity include two groups of experimental equations and mathematical models [1, 2].

The experimental models were concluded from researcher's observation of unsaturated hydraulic conductivity according to the moisture or matric suction of the soil and they have no principal of math. Also, they were justachieved with interaction of measured unsaturated hydraulic conductivity amounts with moisture or matric suction of the soil [3-7].

Moazenzadeh et al. [8] concluded in their evaluation that transitional functions of soil can be called beneficial

and efficiency devices in the estimating of many characteristics of soil, especially hydraulic properties of this porous environment. Also, they explained that the most important point of these functions were avoiding from time and costs which are unavoidable in estimating the direct methods of soil hydraulic properties.

Raoof et al. [5] compared several estimation method of unsaturated hydraulic conductivity of soil in their paper and they used three methods of Van Genuchten, [2], Saxton et al. [9] and Zandeparsa [10] for estimating the unsaturated hydraulic conductivity of soil. Also, against the Van Genuchten method needed the amount of saturated hydraulic conductivity of soil; the amount of unsaturated hydraulic conductivity of soil will be estimated if the amount of saturated hydraulic conductivity is not determined with this method in the different moistures.

Yoosefzadeh et al. [11] presented a new method which included four electrodes moisture method for measuring the moisture in their paper and they introduced

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Corresponding Author: Ali Neshat, Azad University, Kerman Branch, Iran.

a new method for estimating the factor of hydraulic conductivity of unsaturated soil with combination of the correspondence method with Campbell model in determination of theoretical graph of soil moisture.

Farasani *et al*. [12] presented that the size of soil hydraulic properties and their efficiency in the related models to the movement of water in the soil has a principal role in the solution of the majority management problems of water and the unsaturated hydraulic conductivity of soil (k_u) is considered as the most important factor.

Wagner *et al*. [13] evaluated a function from the transitional functions of soil for ascertaining of unsaturated hydraulic conductivity. Also, they had concluded from the statical analysis that the transitional function of soil described the unsaturated hydraulic conductivity of soil better than saturated hydraulic conductivity. Moreover, with evaluating the transitional of soil, they had achieved that the unsaturated hydraulic conductivity of soil depended on the soil texture.

Zhuang *et al*. [14] estimated the unsaturated hydraulic conductivity of soil according to the main characteristics of soil such as density of unsaturated hydraulic conductivity of soil, soil water properties and the distribution of particle sizes.

Setiawan *et al*. [15] conducted Laboratory researches on the two kinds of soil (sand and loam) during the drainage process. Also, they mentioned that Mualem and Burdian models obtained the unsaturated hydraulic conductivity of these two kinds of soil with an acceptable care. Moreover, they presented an equation for these two kinds of soil.

Harvey *et al*. [16] compared different ideas of the layer sands in their paper whose tittle was the effect of unsaturated hydraulic conductivity, for determination of effective hydraulic conductivity amounts on the no same sands with the laboratory results.

Saxton *et al*. [9] studied the unsaturated hydraulic conductivity of soil for ten classifications of different soils. Also, they presented equation by multi nonlinear regression analysis on the texture data of different soils. Van Genuchten [2] presented this equation about the graph of soil moisture with considering the equation of m=1-1/n. Also, he combined his equation with the Mualem equation and presented an equation for unsaturated hydraulic conductivity.

The aim of the present research is to present an equation in the best case of unsaturated hydraulic conductivity of the soil under the impact of soil physical properties.

MATERIALS AND METHODS

The case region is located the six kilometers of the Baghin city in the Kerman Province, this is the height 1754 meters a have see level. Also, it has 105mm annual rainfall. Moreover, evaporation averages is 3021 mm per year in these region.

An extensive land was selected in the study region for conducting the research. To view the status of the soil profile a profile with dimensions of 1*1.5*2 was drilled. The soil structure was massive kind and the soil texture was distinguished loamy type with the touching method. The drilled profile was used in the different depths for removing changed and unchanged samples during the research.

In present research, conducted experiments were classified into two groups. The first group was the evaluation experiments of the soil conditions and they involve measuring of the amount of lime, soil gypsum, determining the status of pH and EC of the soil. The second groups were experiments that evaluate the physical properties of the soil and they were the principal of this research; furthermore, they include soil texture, the amounts of gypsum and lime percent, actual and apparent density of soil, volume moisture of soil, providing graph of soil moisture from determination of Matric potential of soil and determination of saturated hydraulic conductivity of soil. The amounts of gypsum and lime percent, electrical conductivity and pH for profile are presented in Table 1. Soil included five layers whose textures are determined in Table 2. The hydrometer method was used for distinguishing the soil texture.

Four checks with area of lm² were drilled near the drilled profile in the case region for achieving mass moisture, volume moisture, Matricpotential and drawing the graphs of soil moisture. The next step was filling them up with water and on the checks was covered with plastic for preventing the evaporation of the water. After penetrating the water into the checks, a sample was remove from per depth with sampling driller and mass moisture and the volume moisture of per samples were determined by weighting method in Laboratory. Mass moisture, the percent of mass moisture, apparent density, volume moisture and the percent of volume moisture are presented in Table 4.

The used samples were took from the five depths of 0-30, 30-60, 60-90, 90-120 and 120-150cm of soil profile and they were under pressure of 0.3, 0.5, 5 and 15 bar by pressure plates in Laboratory. Also, in per weight level, the soil samples that firstly had reached to saturated case

Table 1: The determination experiment of PH, EC, amount of lime and gypsum soil

The number of sample	depth (cm)	PH	Ec (ds/m)	Lime percent	Gypsum percent
1	0-30	8.52	27.3	14.5	1.94
2	30-60	8.69	20.3	14.25	2.60
3	60-90	8.59	29.1	13.75	4.32
4	90-120	8.51	42.7	16.75	1.14
5	120-150	8.47	39.3	14.75	1.44

Table 2: The determination experiment of soil texture

The number of sample	Depths	Sand%	Silt%	Clay%	Soil texture
1	0-30	39.6	32.4	28	Clay loam
2	30-60	29.6	44.4	26	Loam
3	60-90	51.6	30.4	18	Sandy loam
4	90-120	43.6	22.4	34	Sandy clay loam
5	120-150	31.6	44.4	24	Loam

were measured and the results were recorded. According to Table 5 the graph of soil moisture were drawn for per layer and the equivalent Matric potential with per moisture were achieved according to the corresponding graph.

The Falling head Laboratory method was used for determining the saturated hydraulic conductivity with considering the soil texture. The amounts of saturated hydraulic conductivity for five layers of the soil are presented in Table 6.

The unsaturated hydraulic conductivity was calculated by discharge equations in the unit of area, Darcy law and the corresponding results of experiments.

$$q = \frac{\Delta\theta.D}{T}$$

where

D: Depth of per soil layer, cm
T: Time, day
$\Delta\theta$: Differential moisture
q: Discharge in the unit of area, cm

$$q = k_u \frac{\Delta\Psi}{\Delta z} \Rightarrow k_u = -\frac{q.\Delta z}{\Delta\Psi}$$

where

q: Discharge in the unit of area, $cm.day^{-1}$
Δz: Differential depth between two layers , cm
$\Delta\Psi$: DifferentialMatric potential, cm.
Ku: Hydraulic unsaturated conductivity of soil, $cm.day^{-1}$

Saturated and unsaturated hydraulic conductivity and soil texture for per five layers are presented in Table 7.

The model of soil physic of RETC program was used. The model was performed in the five cases and the unsaturated hydraulic conductivity was estimated.

Table 3: Determination of mass and volume moisture of soil

Number	depths	θ_m Mass moisture	ρ_b Apparent density	ρ_s Actual density	θ_v Volume moisture
1	0-30	0.1163	1.83	2.5	0.2129
2	30-60	0.1220	1.68	2.1	0.2049
3	60-90	.01434	1.71	2.5	0.2451
4	90-120	0.1408	1.80	2.4	0.2534
5	120-150	0.1600	1.86	2.3	0.2977

Table 4: Graph determination of soil moisture in the different layers

Moisture sample, depth sample (cm)

120-150	90-120	60-90	30-60	0-30	Pressure (cm)	Pressure (bar)
20.91	22.42	10.3	17.79	22.61	300	0.3
10.52	13.92	4.71	9.63	10.42	500	0.5
6.61	9.33	3.27	5.96	6.75	5000	5
7.02	8.06	3.18	4.27	5.09	15000	15

Table 5: The final results of determination experiment of saturated hydraulic conductivity of soil

Sample depth	Dry density of soil	Moisture before examination	Time	Length sample	Saturated hydraulic conductivity
0-30	1.83	12.05	1200	7.00	$3.2*10^{-6}$
30-60	1.68	11.86	1800	7.00	$9.5*10^{-6}$
60-90	1.71	18.52	1920	7.00	$6.9*10^{-6}$
90-120	1.80	22.33	1800	7.00	$7.4*10^{-6}$
120-150	1.86	17.87	2700	7.00	$4.9*10^{-6}$

Table 6: The amounts of unsaturated hydraulic conductivity in the different layers

Number	Depths	ρ_b / ρ_s	θv	Ks (cm/day)	Ku (cm/day)
1	0-30	0.73	0.214	0.276	0.248
2	30-60	0.80	0.203	0.821	0.825
3	60-90	0.68	0.246	0.596	5.910
4	90-120	0.75	0.254	0.639	0.514
5	120-150	0.81	0.298	0.423	1.124

Table 7: The evaluation of K_u as depended variable against $\left(\dfrac{K_S.\theta_v.\rho_b}{\rho_S} \right)^{2.49}$ as in-depended variable

Calculated statics of model			Constant coefficients						
Level of being significant	Determination coefficient	Correlation coefficient	d	c	b	a	The math equation	The name of model	Row
0.000	0.236	0.486	-	-	17.824	-1.330	Y=a.x+b	Linear	1
0.001	0.183	0.428	-	-	2.246	6.209	Y=a+b.ln.x	Logarithmic	2
0.008	0.114	0.338	-	-	-0.170	3.369	Y=a+b/x	Inverse	3
0.000	0.278	0.527	-	102.644	-19.979	1.025	Y=a+b.x+c.x2	Quadratic	4
0.000	0.286	0.535	484.30	-174.541	24.915	-0.793	Y=a+b.x+c.x2+d.x3	Cubic	5
0.000	0.490	0.7	-	-	2.416E7	0.016	Y=a.bx	Compound	6
0.000	0.513	0.716	-	-	2.490	41.176	Y=a.xb	Power	7
0.000	0.437	0.661	-	-	-0.221	0.882	Y=e(a/x+b)	S	8
0.000	0.490	0.7	-	-	17.0	-4.165	Y=ea+b.x	Growth	9
0.000	0.490	0.7	-	-	17.0	0.016	Y=a.eb.x	Exponential	10
0.000	0.490	0.7	-	-	8	64.378	Y=l(l/u+a.bx)	Logistic	11

Table 8: The concluded RMSE ERROR of fitting model between K_u and $\left(\dfrac{K_S.\theta_v.\rho_b}{\rho_S} \right)^{2.49}$

RMSE ERROR	Correlation Coefficient	The math equation	The name of model	Row
1.115	0.670	Y=a.xb	Power	1
1.867	0.647	Y=a.eb.x	Exponential	2
1.867	0.647	Y=a.bx	Compound	3
1.838	0.647	Y=ea+b.x	Growth	4
1.655	0.647	Y=l(l/u+a.bx)	Logistic	5

RESULTS AND DISCUSSION

First of all, by principal component three independent variables of saturated hydraulic conductivity, volume moisture and ρ_b/ρ_s were turned into a variable FUC1-1. By SPSS software, unsaturated hydraulic conductivity (dependent variable) that is concluded from weighted and geometric averaging on the amounts of unsaturated hydraulic conductivity of per depth with 13 frequencies, Retc software of Burdine model, Brooks and Corey, Mualem model and Van Genuchten were fitted on FUC1-1 variable by linear regression, quadratic, cubic and reverse models. Finally the unsaturated hydraulic conductivity (dependent variable) that is concluded from the corresponding methods was fitted on independent variables, which include saturated hydraulic conductivity, volume moisture and ρ_b/ρ_s. It is seen that the neural network has

the maximum coefficient of determination and the best forecasting due to amounts of Burdine model, Brooks and Corey and it is the best relationship between unsaturated hydraulic conductivity of the soil such as apparent density (ρ_b), actual density (ρ_s), saturated hydraulic conductivity of soil (Ks) and volume moisture of soil (θ_v).

All of the models are evaluated in Table 8. According to Table 8 Power, Compound, Growth, Exponential and Logistic model that have the determination coefficient of 0.513, 0.490, 0490, 0.49 and 490 respectively have the highest correlation coefficient (r) in the one percent level. Also, for accessing to the best-fitted model among the corresponding models RMSE errors are shown in Table 9. The RMSE error presents the error that concluded from difference between main digits and digits, which resulted from fitting of model.

With considering the results of Excel and curve expert software, the power equation was selected as the best equation:

$$Y = 41.176 X^{2.49}$$

With replacing the variables, which are related to Y and X, the following equation was achieved:

$$K_u = 41.176 \left(\frac{K_s . \theta v . \rho_b}{\rho_s} \right)^{2.49}$$

CONCLUSIONS

- As Kerman is a dry place, an applied equation is needed for the moving of water in the unsaturated soil in order to prevent of water waste.
- The unsaturated hydraulic conductivity has direct relation with saturated hydraulic conductivity, volume moisture and apparent density, but it has reserve equation will actual density.
- The corresponding equation was determined by saturated and unsaturated hydraulic conductivity and soil physical parameters of Baghin region, so it should be reformed and calibrated.

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