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ORIGINAL ARTICLE

Pedotransfer Functions for Estimating Soil particle-size Distribution curve

Hamid Reza Fooladmand
Department of Water Engineering, College of Agriculture, Marvdasht Branch, Islamic Azad University, Marvdasht, Iran
Email: hrfoolad@yahoo.com

ABSTRACT

Many models are existed for representation and estimation of the particle-size distribution (PSD) curve. In this study four models were used: the model of Haverkamp and Parlange (1986) in two conditions, the model of Assouline et al. (1998), and the model of Fredlund et al. (2000). All mentioned models contain different parameters, and by knowing the parameters of each model, the estimation of PSD curve can be done. In this study, some equations have been derived for estimating the parameters of the model of Haverkamp and Parlange (1986) in two conditions and the model of Assouline et al. (1998), and used the equations for estimating the parameters of the model of Fredlund et al. (2000) which has been obtained by Fooladmand and Mansuri (2013). After estimating the parameters of selected models, the PSD curve can be estimated easily. All estimated equations for the model parameters have been obtained only based on soil textural data which are available easily for most soil samples data. In this study, 30 soils were collected from different locations in Fars Province, south of Iran to calibrate the equation, and 10 soils in this area plus 30 soils of UNSODA soil data bases were used to validate the obtained results. 40 soils used in validation stage have been divided into three groups containing fine, medium and course textures. The results indicated that the model of Fredlund et al. (2000) was appropriate for soils with fine and course textures, and the model of Assouline et al. (1998) was appropriate for soils with medium texture.
Keywords: *Particle-size distribution, Pedotransfer function, Fars province, UNSODA*

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INTRODUCTION

The particle-size distribution (PSD) curve affects many important soil attributes. This curve for example can be used for indirect estimation of soil hydraulic properties such as the soil water characteristic curve, therefore selecting the most appropriate model to represent the PSD curve is important for more precise estimation of other soil hydraulic properties. Different models have been proposed by many investigators for representation and estimation of the PSD curve [1-16]. The PSD curve of each soil can be measured with a combination of the hydrometer and the wet sieving methods as described by Gee and Bauder [17]. However, direct measurement of this curve may be time-consuming. On the other hand, many soil data bases contain only the percentages of clay, silt and sand. The proposed model by Skaggs et al. [15] which has been modified by Fooladmand and Sepaskhak [6] can be estimated the PSD curve with these soil textural data. Furthermore, an alternative to measurement the PSD curve is its estimation using more easily available soil properties which can be called pedotransfer functions (PTFs). However, since PTFs are often developed empirically, their applicability may be limited to the data set used to define the method [18]. Moreover, the available PTFs can produce substantially different estimates. Thus, users have a difficult task in selecting a more appropriate PTFs for their application [19]. On the other hand, PTFs are scarce for estimating PSD curve. Also, function pedotransfer must be used to estimate PSD curve. Function pedotransfer predicts the parameters of a closed-form analytical equation of PSD curve [7, 20, 20]. For example, Fooladmand and Mansuri [5] obtained the equations for estimating the parameters of the model of Fredlund et al. [7] based on the values of caly, silt, sand and the values of geometric mean and geometric standard deviation of the particle-size diameter which have been defined by Shirazi and Boersma [22]. The objective of this study was: 1) Obtain the PTFs for estimating the parameters of the models of Assouline et al. [20] and Haverkamp and Parlange [21] to estimate PSD curve, and 2) Compare the obtained results with the derived equations for estimating the parameters of the model of Fredlund et al. [7] by Fooladmand and Mansuri [5] for estimating PSD curve.

MATERIAL AND METHODS

For this study, fourty soils were collected in depths of 0-30 cm from different locations in Fars Province, south of Iran. The PSD curve of each soil was measured with a combination of the hydrometer and the wet sieving methods [17], and then the percentages of clay, silt and sand of each soil were determined according to the USDA system for particle size range (clay < 0-0.002 mm; silt: 0.002-0.05 mm; and sand: 0.05-2 mm), and the texture of each soil was determined. Thirty of collected soils were used to calibrate the equations for estimating PSD curve, and remained ten soils plus thirty soils of UNSODA soil data bases [23] were used to validate the obtained results. Fourty soils used in validation stage have been divided into three groups containing fine (Clay, Silty clay and Silty clay loam), medium (Loam, Silt loam and Clay loam) and course (Sandy loam and Loamy sand) textures. Statistical information of selected soils in calibration and validation stages are presented in Tables 1 and 2, respectively.

Table 1. Statistical information of selected soils (30 sample) in calibration stage.

	Minimum	Maximum	Average	Standard deviation
Clay (%)	1.2	46.0	19.4	11.7
Silt (%)	17.0	62.0	47.0	12.7
Sand (%)	4.0	79.0	33.5	22.6

Table 2. Statistical information of selected soils in validation stage.

Texture group	Number of samples		Minimum	Maximum	Average	Standard deviation
Fine	13	Clay (%)	28.0	58.0	46.1	10.6
		Silt (%)	34.0	62.0	42.1	8.9
		Sand (%)	3.5	20.5	11.8	5.3
Medium	18	Clay (%)	11.0	36.0	21.4	7.7
		Silt (%)	28.1	56.6	42.2	7.7
		Sand (%)	21.3	46.3	36.5	8.5
Course	9	Clay (%)	4.0	18.6	11.1	5.1
		Silt (%)	16.0	40.2	28.1	6.5
		Sand (%)	52.5	80.0	60.8	8.3

In this study, three models have been selected for representation of the measured PSD curve as follows:

1- The model of Haverkamp and Parlange [21]: This model for representation the PSD curve was derived from the model of van Genuchten [24] for representation of the soil moisture retention curve. This model is as follows:

$$P(d) = \left[1 + \left(\frac{d_a}{d}\right)^n\right]^{-m} \quad (1)$$

where P(d) is the mass fraction of particles passing particular soil diameter (g g^{-1}), d is the soil particle diameter (mm), and m and n are the parameters of the model. Two relationships have been proposed between the paremeters of m and n as follows [21]:

$$m = 1 - \frac{1}{n} \quad (2)$$

$$m = 1 - \frac{2}{n} \quad (3)$$

According to the equations (2) and (3), the model of Haverkamp and Parlange [21] are called HP1 model and HP2 model in this study.

2- The model of Assouline et al. [20]: This model for representation the PSD curve is as follows:

$$P(d) = c + (1-c)\left[1 - \exp(-aD^b)\right] \quad (4)$$

where P(d) and d has been defined before, and a, b and c are the parameters of the model. Also, the parameter of D is obtained from the following equation [20]:

$$D = \frac{d - 0.002}{2 - 0.002} \quad (5)$$

In this study the model of Assouline et al. [20] is called A model.

3- The model of Fredlund et al. [7]: This model for representation the PSD curve is as follows:

$$P(d)=\frac{1}{\left\{Ln\left[\exp(1)+(\frac{q}{d})^{s}\right]\right\}^{r}}\left\{1-\left[\frac{Ln(1+\frac{d_r}{d})}{Ln(1+\frac{d_r}{d_m})}\right]^{7}\right\} \quad (6)$$

where P(d) and d has been defined before, d_m is equal to 0.0001 mm, and q, r, s and d_r are the parameters of the model. In this study the model of Fredlund et al. [7] is called F model. The parameters of HP1, HP2, A and F models must be available to estimate the PSD curve. In this study, these parameters were obtained by using the PSD curve measurements by considering minimum differences between measured and estimated PSD curve by using the Solver menu of Microsoft Excel. After that, new equations were derived for the estimation of each parameter based on soil textural data such as the percentages of clay, silt and sand, and the values of the geometric mean particle-size diameter (d_g), and geometric standard deviation of the particle-size diameter (δ_g). The values of d_g and δ_g are calculated as follows [22]:

$$k=0.01(f_c Ln0.001+f_{si}Ln0.026+f_{sa}Ln1.025) \quad (7)$$

$$d_g=\exp(k) \quad (8)$$

$$t^2=0.01\left\{f_c(Ln0.001)^2+f_{si}(Ln0.026)^2+f_{sa}(Ln1.025)^2\right\}-k^2 \quad (9)$$

$$\delta_g=\exp(t) \quad (10)$$

Where d_g is in mm, and f_c, f_{si} and f_{sa} are the clay, silt and sand fractions of soil (%), respectively.

In this study, thirty soils of total investigated soils in Fars province, south of Iran were selected for deriving the equations of the selected models in calibration stage, and the other ten remained soils plus thirty soils of UNSODA were used for the validation of the obtained results. The equations for estimating the parameters of HP1, HP2 and A models have been derived in this study. Also, with mentioned procedure, Fooladmand and Mansuri [5] supposed the value of 1000 for the parameter of d_r in the F model, and derived the following equations for the other parameters of this model:

$$q=0.18612+0.00088Clay-0.00265Silt+0.00393\delta_g \quad (11)$$

$$r=0.52961+0.01728Sand-1.63977d_g-0.04897\delta_g \quad (12)$$

$$s=3.72\exp(-0.03Clay) \quad (13)$$

Where Clay, Silt and Sand are in percent, and d_g and δ_g have been defined before.

To evaluate the obtained results in the validation stage, the root mean square error (RMSE), geometric mean error ratio (GMER) and geometric standard deviation of the error ratio (GSDER) have beeb used as follows [25]:

$$RMSE=\left[\frac{\sum_{i=1}^{N}(P_m-P_e)^2}{N}\right]^{0.5} \quad (14)$$

$$e=\frac{P_e}{P_m} \quad (15)$$

$$GMER=\exp\left(\frac{1}{N}\sum Ln(e_i)\right) \quad (16)$$

$$GSDER=\exp\left[\left(\frac{1}{N-1}\sum\left[Ln(e_i)-Ln(GMER)\right]^2\right)^{0.5}\right] \quad (17)$$

where P_m and P_e are the measured and estimated mass fraction of soil particles, and N is the number of segments in particle-size distribution in each soil sample. A GMER value equal to one corresponds to an exact matching between measured and estimated data; GMER less than one indicate that estimated values are generally underestimated, and GMER greater than one points to a general over-estimation. GSDER equal to one corresponds to a perfect matching and it grows with deviation from measured data. The best model will, therefore, give a GMER close to one and a small GSDER [26]. Also, the lower RMSE value show better agreement between measured and estimated PSD curve.

RESULTS AND DISCUSSION

The best derived equations for estimating the parameters of HP1, HP2 and A model in calibration stage are as follows:

HP1 model:

$$d_a = 0.0021\delta_g + 0.00015Clay + 0.0017Sand \quad (18)$$

$$n = 10.837d_g + 0.04Clay \quad (19)$$

HP2 model:

$$d_a = 0.0046\delta_g + 0.0021Sand \quad (20)$$

$$n = 0.0506Clay + 0.0516Sand \quad (21)$$

A model:

$$a = -2103.83d_g + 14.46Sand \quad (22)$$

$$b = -3.68d_g + 0.043Sand + 0.0152Clay \quad (23)$$

$$c = 0.96d_g + 0.024\delta_g + 0.0048Clay - 0.0055Sand \quad (24)$$

The parameters of above equations are similar to equations (11) to (13). Also, the R^2 value of the equations (18) to (24) are 0.89, 0.79, 0.87, 0.88, 0.72, 0.97 and 0.97, respectively and all mentioned quations are significant in 5 % probability.

After that, by using the obtained results in this study and by considering the reported results by Fooladmand and Mansuri [5] for the F model, PSD curve of fourty soils in validation stage have been estimated with HP1, HP2, A and F model, and the results have been compared with the measured PSD curve of these soils. To compare the results, the values of RMSE, GSDER and GMER were computed. The maen values of mentioned statistical paremeters for three texture groups (fine, medium and course) are presented in Tables 3 to 5, separately.

Table 3. The mean values of RMSE for different texture groups by using different models.

Texture groups Models	Fine	Medium	Course
HP1	0.235	0.125	0.117
HP2	0.275	0.181	0.181
A	0.090	0.088	0.115
F	0.067	0.098	0.081

Table 4. The mean values of GSDER for different texture groups by using different models.

Texture groups Models	Fine	Medium	Course
HP1	2.603	1.410	3.065
HP2	3.473	3.545	8.140
A	1.122	1.139	1.293
F	1.104	1.208	1.158

Table 5. The mean values of GMER for different texture groups by using different models.

Texture groups Models	Fine	Medium	Course
HP1	0.629	1.072	0.561
HP2	0.512	0.574	0.250
A	0.983	1.043	1.070
F	1.045	1.177	1.179

As shown in these tables, F model was the best for fine and course texture groups according to the mean values of RMSE and GDSER. Also, according to the maen value of GMER, the F model tends to over-estimation in fine and course texture groups. Therefore, the results demonstrated that assuming the value of 1000 for d_r in F model which has been proposed by Fooladmand and Mansuri [5] is appropriate.

Furthermore, Fooladmand and Mansuri [5] reported the appropriatness of the F model for fine textures such as silty clay and silty clay loam which was in agreement with the obtained results in this study. On the other hand, A model was the best for medium texture group according to the mean values of RMSE and GDSER. Also, according to the maen value of GMER, the A model tends to over-estimation in medium texture group. However, the mean values of GMER in medium texture groups is vely close to one, i.e. between measured and estimated results are a very good matching.

For example, the measured and estimated PSD curve for the best model for one soil in each texture group (fine, medium and course) have been presented in Figure 1 to 3.

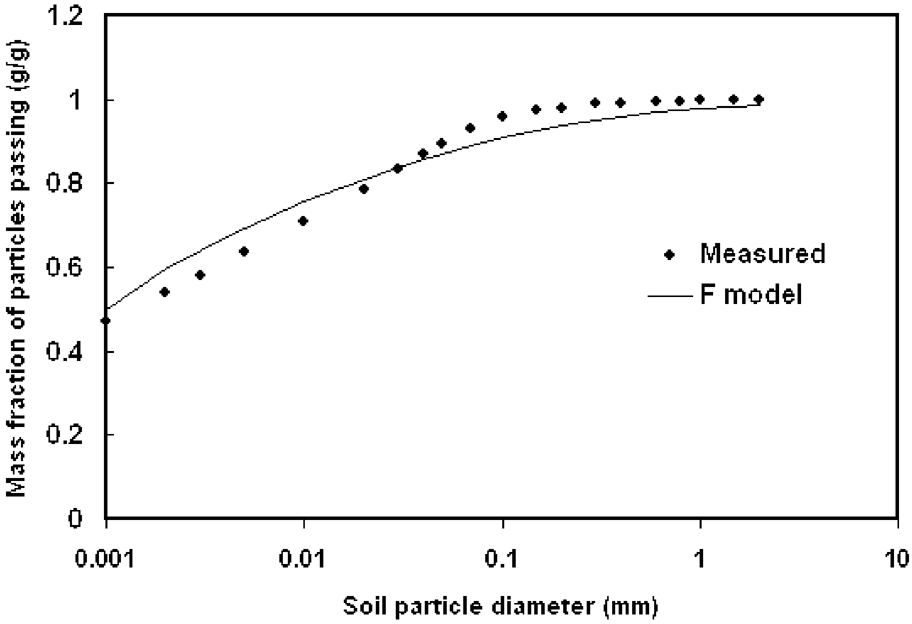

Figure 1. Measured and estimated PSD curve with F model in a fine texture soil.

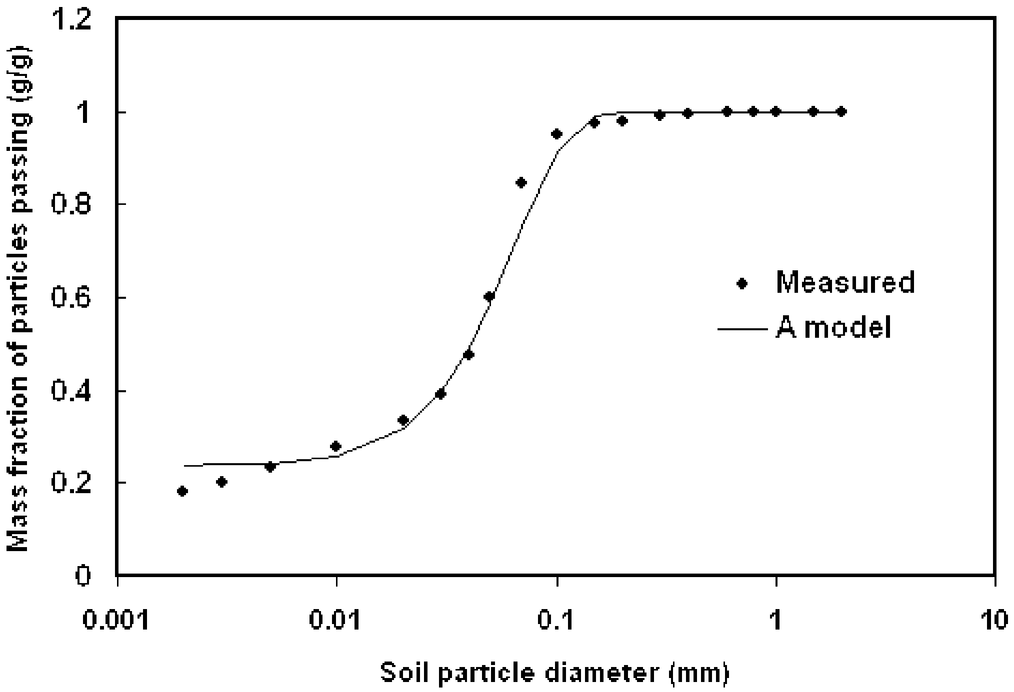

Figure 2. Measured and estimated PSD curve with A model in a medium texture soil.

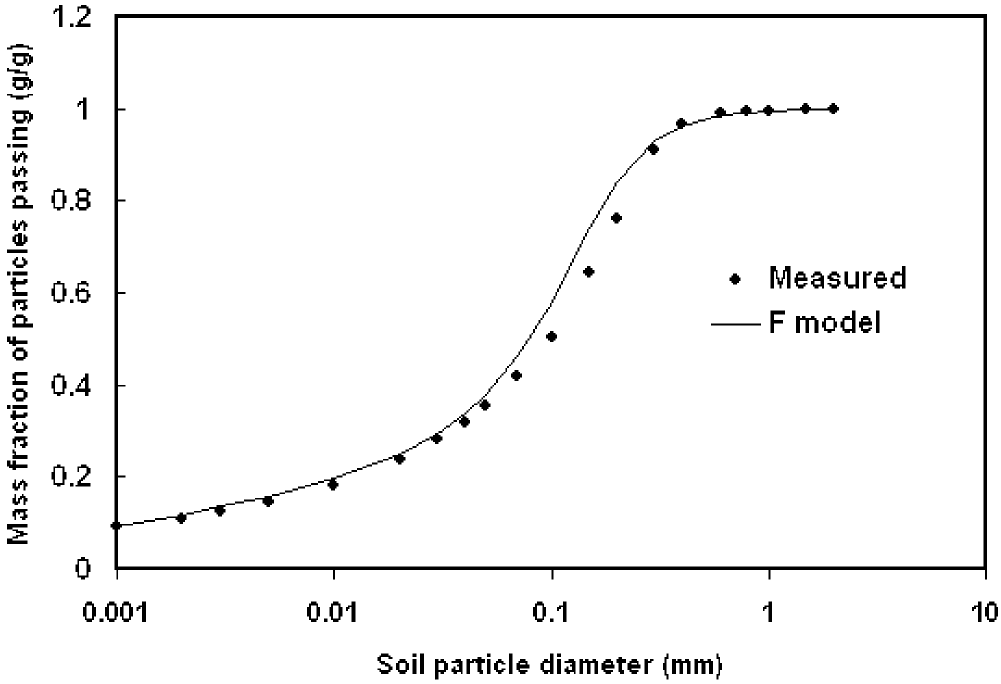

Figure 3. Measured and estimated PSD curve with F model in a course texture soil.

Also, the results of this study indicated that the HP1 and HP2 models are not appropriate for estimating the PSD curve, althogh these models derived from the model of van Genuchten [24] for representation of the soil moisture retention curve which was the best and the most common model for this curve.

CONCLUSION

Different models can be used for estimating the PSD curve. In this study, four models have been selected, and new equations have been drived for estimating the paremeters of the selected models. The results indicated that the model of Fredlund et al. [7] by using the equations for its parameter which has been derived by Fooladmand and Mansuri [5] was appropriate for fine and course texture groups which was in agreement with the obtained results by Fooladmand and Mansuri [5]. Also, the results showed that the model of Assouline et al. [20] by using the equations for its parameter which has been derived in this study was appropriate for medium texture group. Furthermore, the results indicated that two conditions of the model of Haverkamp and Parlange [21] were not appropriate for estimating the PSD cure. Further research should be undertaken to calibrate and validate the parametric models of representation PSD curve in other soil samples in different locations of the world to complete the obtained results in this study.

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