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Review of Empirical Equations of Estimating Saturated Hydraulic Conductivity Based on Soil Grain Size Distribution

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ABSTRACT

Knowledge of hydraulic conductivity is essential for many problems involving water flow and pollution transport in soils. A variety of field and laboratory techniques have been developed to directly measure the unsaturated hydraulic conductivity. In this research, 25 set of soil samples with sand texture have been used. The results showed that among seven empirical formulae (Hazen, Kozeny-Carman, Breyer, Slitcher, Terzaghi, USBR and Alyamani & Sen), the Slitcher formula predicted Ks, saturated hydraulic conductivity, better than other formulae with 0.671 R; 6.08 RMSE; 5.06 MAE; 20.75% RE & 1.393 DT and the Breyer formula estimated Ks, with largest prediction error.

KEYWORDS-empirical equations; hydraulic conductivity; soil particle diameter and soil grain size.

I. INTRODUCTION

Saturated hydraulic conductivity of soil (Ks) is one of the most important soil physical characteristics that are very important in ground water studies, water infiltration, leaching, design of drainage systems and hydrological studies. Direct measurement of hydraulic conductivity is costly, difficult and time-consuming either field or laboratory. Therefore, indirect methods as a way to partially solve this problem are presented. The methods of predicting hydraulic conductivity by empirical formulae based on particle-size distribution properties have been developed. Various studies indicate that the hydraulic conductivity is dependent on grain size and the particle size distribution in porous media [1].

Empirical formula is one of the methods that used to estimate hydraulic conductivity that empirical formulas have been developed. Curve of particle size distribution is one of the basic physical properties of soils that usually expressed the cumulative probability distribution of the diameter of the soil particles [2]. In recent years, many studies have been to predict soil hydraulic functions based on soil grain size distribution [3-5]. Several studies have been carried out to quantify soil physical properties such as particle size distribution. Many studies have attempted to estimate soil hydraulic properties [6].

Since hydraulic properties have a high spatial variation, Therefore in order to determine the hydraulic characteristics of each region requires a lot of soil samples. Since measurement of hydraulic conductivity is difficult and costly. Therefore, the empirical formulas have been developed [7-9].

Many different relationships have been developed from particle-size distribution. Research findings showed that USBR and Slitcher equation calculated the amounts of hydraulic conductivity less than the other equations [10]. The research results showed that the Breyer equation is very suitable for soils with low uniformity coefficient [11].

Carrier (2003) noted that the Kozeny-Carman equation calculated hydraulic conductivity with high accuracy compared to Hazen equation [8]. Odong (2007) have been evaluated several empirical equations to prediction hydraulic conductivity [12]. Jarvis et al. (2002) presented the functions based on relative frequency of particle and geometric mean of particles diameter [13]. Huang and Zhang Evaluated soil water retention curve [14].

Heuvelmans et al. (2005) Regional sated the parameters of a hydrological model with artificial neural networks and linear regression model[15]. Regression transport functions are suitable method for modeling of soil hydraulic properties [15 & 16].

Odong (2007) evaluated the various empirical equations that predicted soil hydraulic conductivity and the results showed that the Kozeny-Carman equation was the best estimator among the studied equations. However, some of the equations underestimated or overestimated hydraulic conductivity [12].

Vukovic and Soro (1992) determined Hydraulic Conductivity of Porous Media from Grain-Size Composition and after the studding of previous researches provide the following general equation [17]:

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$$K = \frac{g}{v} \cdot C \cdot f(n) \cdot d_e^2 \quad (1)$$

Where K is hydraulic conductivity; g is gravity acceleration; v is kinematic viscosity; C is coefficient of sorting; f (n) is function of porosity, and d_e, is effective particle diameter.

Hazen (1982) proposed the equation to prediction of saturated hydraulic conductivity by soil particle diameter, $K_S = c(d_{10})^2$, Where Ks is expressed in cm/sec, c is a constant that varies from 1.0 to 1.5, and d_{10} size gives the diameter for which 10% (by mass) of the particles in a soil sample are finer. This equation is obtained for the washed sand clay and silt causes the hydraulic conductivity calculated by hazel formula does not accurate [18 & 19]. Also, Hazen equation is presented in the following form.

$$K = \frac{g}{v} \times 6 \times 10^{-4} [1 + 10(n - 0.26)] d_{10}^2 \quad (2)$$

Kozeny-Carman formula is one of the most applicable equations used for determine of hydraulic conductivity as a function of the soil properties.

$$K = \frac{g}{v} \times 8.3 \times 10^{-3} \left[\frac{n^3}{(1-n)^2} \right] d_{10}^2 \quad (3)$$

Ahuja et al. (1989) predicted Ks by the Kozeny-Carmen equation. This equation is not suitable for clay soils [8]. Breyer presented the following formula [12]:

$$K = \frac{g}{v} \times 6 \times 10^{-4} \log \frac{500}{U} d_{10}^2 \quad (4)$$

Where U is the particle uniformity coefficient:

$$U = \left(\frac{d_{60}}{d_{10}} \right) \quad (5)$$

Where d_{60} and d_{10} size gives the diameter for which 60% and 10% (by mass) of the particles in a soil sample are finer.

In Breyer method, the parameter of porosity been considered and consequently, the porosity function is considered one [12].

The Breyer equation is often applicable and useful for heterogeneous and non-uniform distribution material. Slitcher presented the following formula [12]:

$$K = \frac{g}{v} \times 1 \times 10^{-2} n^{3.287} d_{10}^2 \quad (6)$$

Slitcher formula often can be used for particle sizes between 0.01 to 5 mm [12].

Terzaghi presented the following formula:

$$K = \frac{g}{v} \cdot C_t \cdot \left(\frac{n - 0.13}{\sqrt[3]{1-n}} \right)^2 d_{10}^2 \quad (7)$$

Where the C_t is coefficient of sorting [20].

The following equation presented by U.S. Bureau of Reclamation (USBR) [12]:

$$K = \frac{g}{v} \times 4.8 \times 10^{-4} d_{20}^{0.3} \times d_{20}^2 \quad (8)$$

USBR formula does not depend on porosity and d_{20} size gives the diameter for which 20% (by mass) of the particles in a soil sample are finer [12].

Alyamani and Sen (1993) offered the following formula [21]:

$$K = 1300 [I_o + 0.025 (d_{50} - d_{10})]^2 \quad (9)$$

Where K_s is hydraulic conductivity, I_o is the intercept.

Cronican and Gribb (2004) offered multiple linear regressions based on limited soil data [18].

In this study several empirical equations have been evaluated to calculate hydraulic conductivity by particle size.

II. MATERIALS AND METHODS

In this study in order to prediction hydraulic conductivity by grain size distribution (PSD) used the 25 sets samples of sandy soil texture. Finally parameters of d_{10}, d_{50} and d_{60}determinedwhere d_{10}, d_{50} and d_{60} size gives the diameter for which 10%, 50% and 60% (by mass) of the particles in a soil sample are finer.

The values of parameters of d_{10}, d_{50},d_{60} and saturated hydraulic conductivity are showed in Table 1.

TABLE I. VALUES OF STATISTICS OF d_{10}, d_{50}, d_{60}AND SATURATED HYDRAULIC CONDUCTIVITY

Statistics	Parameters			
	***d*₁₀**[a]	***d*₅₀**	***d*₆₀**	***K*ₛ**
Mean	0.253	0.707	0.936	24.38

Minimum	0.16	0.42	0.61	15.1
Maximum	0.36	1.10	1.38	36.1
Std. Deviation	0.061	0.185	0.248	5.96
Skewness	-0.171	0.179	0.287	0.204

The results were studied by statistics such as Root Mean Square Error (RMSE), Correlation Coefficient (R), Mean Absolute Error (MAE), Relative Error (RE)and Deviation Time (DT) using equation (10), (11), (12) and (13) respectively, where n is the number of the data series and O_i and P_i are observed and estimated, and O_{ave} and P_{ave} are mean values of observed and estimated respectively.

$$R = \left[\frac{\sum_{i=1}^{n}(O_i - O_{ave})(P_i - P_{ave})}{\sqrt{\sum_{i=1}^{n}(O_i - O_{ave})^2 (P_i - P_{ave})^2}} \right]^{0.5} \qquad (10)$$

$$RMSE = \left[\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n} \right]^{0.5} \qquad (11)$$

$$MAE = \sum_{i=1}^{n} \left[|P_i - O_i| / n \right] \qquad (12)$$

$$RE = (MAE / O_{ave}) \times 100$$

$$Log_{10}^{DT} = \left[n^{-1} \sum_{i=1}^{n} [Log_{10}(P_i / O_i)]^2 \right]^{0.5} \qquad (13)$$

Empirical equations including Hazen, Kozeny-Carmen, Breyer, Slitcher, Terzaghi, Alyamani and Senand USBR Equations have been evaluated.

III. RESULTS

The values of different statistics of empirical formula were indicated in Table 2.

TABLE II. VALUES OF STATISTICS OF EMPIRICAL EQUATIONS ESTIMATE TO HYDRAULIC CONDUCTIVITY

Equation	**Statistics**				
	R[a]	***RMSE***	***MAE***	***RE***	***DT***
Hazen	0.656	53.33	47.65	195.50	2.948
Kozeny-Carmen	0.666	41.74	38.13	156.42	2.597
Breyer	0.637	56.19	48.28	198.04	2.948
Slitcher	**0.671**	**6.08**	**5.06**	**20.75**	**1.393**
Terzaghi	0.671	17.17	14.79	60.68	1.667
USBR	0.474	24.77	18.96	77.79	1.889
Alyamani and Sen	0.699	16.72	12.45	51.07	1.625

It is concluded that the slitcher equation was the best model with 0.671 R, 6.08 RMSE, 5.06 MAE, 20.75% RE and 1.393 DT. Also it is concluded that the Breyer equation predicted Ks, saturated hydraulic conductivity with high prediction error with 0.637 R, 56.19 RMSE, 48.28 MAE, 198.04% RE and 2.948 DT. Meanwhile, the high value of DT statistic indicates that the accuracy and efficiency of the model in estimating the saturated hydraulic conductivity is low.

The difference between measured values of saturated hydraulic conductivity with estimated values has been reported by various researchers [12, 21 & 22].

Odong (2007) evaluated the various empirical equations that predicted soil hydraulic conductivity and the results showed that the Kozeny-Carman equation was the best estimator among the studied equations. However, some of the equations underestimated or overestimated hydraulic conductivity [12].

Itis concluded that the values of hydraulic conductivity calculated by the Slitcher equation is lower than the other equations, which is match with the results by Cheng and Chen (2007),Vukovic and Soro (1992) and Odong (2007) [10, 12 & 17].Alyamani and Sen, Terzaghi and USBR equations calculated saturated hydraulic conductivity lower than Breyer, Hazen and Kozeny-Carmen equations.

It is concluded that the accuracy of hydraulic conductivity estimated by the Kozeny-Carmen equation is rather than the Hazen equation, which is consistent with the conclusions by Carrier (2003) [8].

IV. CONCLUSION

In this research varies empirical formula to calculate hydraulic conductivity based on grain size distribution have been evaluated. The results showed that the slitcher equation was the best formula for predicting saturated hydraulic conductivity among studied equations. The results showed that the Breyer formula predicted saturated hydraulic conductivity with high prediction error. It is concluded that the values of hydraulic conductivity calculated by the Slitcher equation is lower than the other equations. Alyamani and Sen, Terzaghi and USBR equations calculated saturated hydraulic conductivity lower than Breyer, Hazen and Kozeny-Carmen equations.

REFERENCES

[1] Freeze, R.A., and Cherry, J. A. Ground water. Prentice Hall Inc., Englewood Cliffs, New Jersey. 1979.

[2] Hwang S., Lee K.P., Lee D.S., and Power E.S. Models for Estimating Soil Particle-Size Distributions. Soil Sci. Soc. Am. J, 2002. 66:1143-1150.

[3] Hwang S.I., Powers S.E., Using Particle-Size Distribution Models to Estimate Soil Hydraulic Properties. Soil Sci. Soc. Am. J. 2003b. 67:1103-1112.

[4] Hwang S.I., and Choi S.I. Use of a lognormal distribution model for estimating soil water retention curves from particle -size distribution data. J. Hydrol. 2006, 323:325-334.

[5] Hwang S.I., and Hong S.P. Estimating relative hydraulic conductivity from lognormally distributed particlesize data. Geoderma, 2006, 133:421-430.

[6] Rieu M and Sposito G, Fractal fragmentation, soil porosity, and soil water properties: II. Applications. Soil Sci Soc Am J, 1991, 55: 1239-1244.

[7] Arya L. M., Leij F. J., Shouse P. J., and van Genuchten M. Th. Relationship between the hydraulic conductivity function and the particle-size distribution. Soil Sci. Soc. Am. J, 1999b, 63:1063-1070.

[8] Carrier, W.D. Goodbye, Hazen; Hello, Kozeny-Carman. Journal of Geotechnical and Geoenvironmental Engineering. 1054. 2003.

[9] Zeleke, T.B., and B.C. Si. Scaling relationships between saturated hydraulic conductivity and soil physical properties. Soil Sci. Soc. Am. J, 2005, 69: 1691-1702.

[10] Cheng, C., and Chen, X. Evaluation of Methods for Determination of Hydraulic Properties in an Aquifer- Aquitard System Hydrologically Connected to River. Hydrogeology Journal, 2007, 15: 669-678

[11] Pinder, G. F., and Celia, M. A. Subsurface Hydrology. John Wiley & Sons Inc., Hoboken, New Jersey, 2006.

[12] Odong, J. Evaluation of empirical formulae for determination of hydraulic conductivity based on grain-size analysis. Journal of American Science, 2007, 3(3), 54-60.

[13] Kozeny, J. Uber Kapillare Leitung Des Wassers in Boden. Sitzungsber Akad. Wiss.Wien Math.Naturwiss.Kl., Abt.2a, , 1927, 136:271-306 (In German).

[14] Huang G. and Zhang R. Evaluation of soil water retention curve with the pore-solid fractal model. Geoderma, 2005, 127:52-61.

[15] Heuvelmans, G., B. Muys1 and J. Feyen. Regionalisationof the parameters of a hydrological model:Comparison of linear regression modelswith artificial neural nets. Journal of hydrology. Article in press, 2005.

[16] Hodnett, M. G. and Tomasella. J. Marked differencesbetween van Genuchten soil water-retention parameters for temperate and tropicalsoils: a new water retention pedotransfer functions developed for tropicalsoils. Geoderma, 2002, 108: 155-180.

[17] 39- Vukovic, M., and Soro, A. Determination of hydraulic conductivity of porous media from grain-size composition. Water Resources Publications, Littleton, Colorado, 1992.

[18] Cronican A. E. and M. M. Gribb. Literature review: Equations for predicting hydraulic conductivity based on grain-size data. Supplement to Technical Note entitled: Hydraulic conductivity prediction for sandy soils. Published in Ground Water, 2004, 42(3): 459-464.

[19] Hazen, A. Some physical properties of sands and gravels. Massachusetts State Board of Health, Annual Report, 1892, 539-556.

[20] Terzaghi,K., and Peck,R.B. Soil Mechanics in Engineering Practice. Wiley, New York, 1964.

[21] Alyamani, M.S. and Z. Sen. Determination of hydraulic conductivity from complete grain-size distribution curves. Ground water 31, no. 4: 551-555, 1993.

[22] Uma, K.O., B.C.E. Egboka, and K.M. Onuoha. New statistical grain-size method for evaluating the hydraulic conductivity of sandy aquifers. Journal of Hydrology, 1989, 108: 343-366.