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Evaluation of Pedotransfer Functions for Predicting Saturated Hydraulic Conductivity of Rainfed Soils from Shirala Nemane Watershed

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ABSTRACT

A study was carried out to evaluate applicability of four different pedotransfer functions (Rosetta, Jabro, Puckett and Campbell) in estimating saturated hydraulic conductivity (Ks) of soils from Shirala Nemane watershed with geographical area of 22,400 ha. in Buldhana district of Maharashtra state. Eighty seven sampling points were marked at a grid of 2 km x 2 km using Global Positioning System. Soil samples were collected from each sampling point at a depth of 0-30 cm. The measured and estimated Ks were compared with one to one correspondence using statistical indices such as root mean square error (RMSE), mean error (ME), mean absolute error (MAE), degree of agreement (d) and coefficient of determination (R^2). The lowest RMSE value (0.6921 cm/hr) and highest R^2 value (0.0702) was observed in estimation of Ks using generic pedotransfer function- Rosetta. Prediction of Ks using Rosetta had lower errors than Jabro, Puckett and Campbell parametric pedotransfer function.

Key words *Saturated hydraulic conductivity, Pedotransfer function, Rosetta etc.*

A soil hydraulic property that is often a required input to simulation models is the saturated hydraulic conductivity, Ks. It is one of the most important soil physical properties for determining infiltration rate and other hydrological processes (Gulser *et al.* 2008). In general, the Ks refers to the capacity of the soil to drain water and gives information about the presence of disruptive soil strata, and the correlation between the permeability and other soil characteristics. The geometry of the complex pores that depend on texture, structure, viscosity and density, determine the Ks. In hydrologic models, this is a sensitive input parameter and is one of the most problematic measurements at field-scale in regard to variability and uncertainty (Carpena *et al.* 2002). The Ks is known to be one of the most variable of all soil physical properties, varying up to 10 orders of magnitude for different geo-materials (Mbonimpa *et al.* 2002). Although the soil hydraulic properties can be measured directly, this practice is both costly and time-consuming, and sometimes results obtained are unreliable because of the associated soil heterogeneity and experimental errors. When large areas of land are under study, it is virtually impossible to perform enough measurements to be meaningful, indicating the need for an inexpensive and rapid way to determine soil hydraulic properties. Many indirect methods such as pedotransfer functions (PTFs) have been developed to reduce the effort and cost. These PTFs are predictive functions of certain soil properties estimated from other simpler measured soil properties (McBratney et al. 2002). They can be used as inputs to models in order to reduce costs and accelerate the investigations. A detailed review of PTFs is given by Wösten et al. 2001 and scaling of soil physical properties in relation to models is given by Pachepsky et al. 2004. The objective of this study was to evaluate the applicability of the four widely used pedotransfer function viz. Rosetta, Jabro, Puckett and Campbell to calculate saturated hydraulic Conductivity (Ks) for rainfed soils from the Shirala Nemane watershed, Buldhana District of Maharashtra State.

MATERIAL AND METHODS

Location, topography and climate of study watershed

Shirala Nemane watershed is located between 76^{0}19'23.72"E- 76^{0}42'55.32"E longitude and 20^{0}17'32.48" N – 20^{0}30'23.42" N latitude. The watershed has an area of 224 km^2 located in the Buldhana District of Maharashtra state. The watershed has shallow, gravely and stony reddish soils. The soil over the piedmont deposits is coarse, highly friable and is locally known as malli soil and is well suited for horticulture. The climate of the district is characterized by a hot summer and general dryness throughout the year except during the south-west monsoon season. The mean minimum temperature is 13^{o}C and mean maximum temperature is 43.3^{o}C. The normal annual rainfall over the watershed ranges from 711 mm to 911 mm.

Collection of the soil samples and Soil analysis

Total eighty Seven sampling points were marked at a grid of 2km x 2km using Geographical Positioning System (GPS). Soil samples were collected from each sampling point at a depth of 0-30 cm. Soil samples were air-dried and grinded to pass through a 2-mm sieve. The soil samples so collected were analysed in laboratory for various physical and chemical soil properties such as bulk density using Clod Coating method (Black, et al. 1965), particle size distribution using Bouyoucos hydrometer method and saturated hydraulic conductivity using constant head permeameter method.

Description of the software used

Some PTFs have been developed as standalone computer programs like ROSETTA (Schaap et al., 2001) and SOILPAR (Acutis and Donatelli, 2003). ROSETTA uses a neural network and bootstrap approach for parameter prediction and uncertainty analysis respectively while SOILPAR provides 15 PTF procedures, classified as point and function PTFs for parameter estimation.

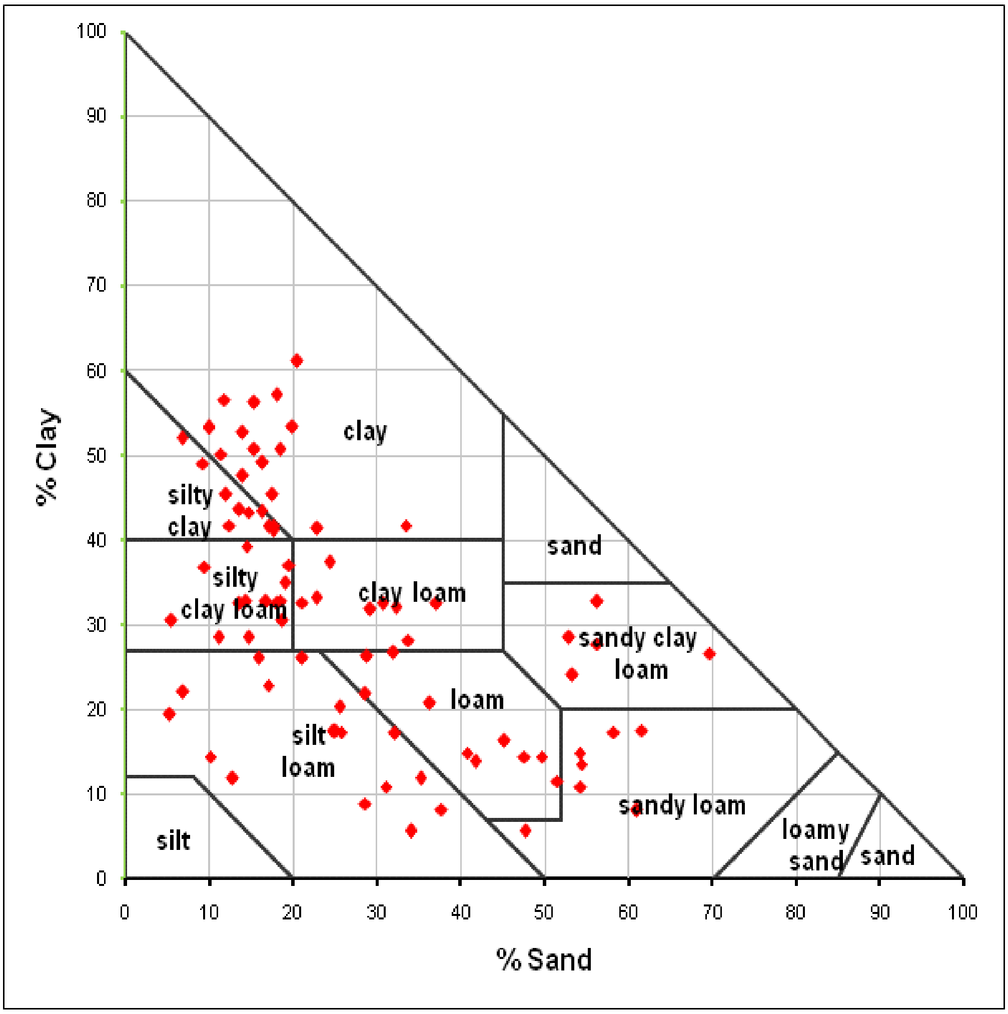

Fig. 1. Particle size distribution of soil samples on textural triangle.

Rosetta

Generic PTF Rosetta offers five models that allow the prediction of the hydraulic properties with limited or more extended sets of input data. This hierarchical approach is of a great practical use because it permits optimal use of available input data. The first model (H_1) is a class PTF, consisting of lookup table that provides parameter averages for each USDA textural class. The second model (H_2) uses sand, silt and clay as input (SSC). The third model (H_3) includes bulk density as predictor in addition to the input variables of the second model (SSCBD). Model (H_1) is simple table with average hydraulic parameters for each textural class. This model was therefore discarded as it does not consider any soil forming factors or the total empirical relations between soil and its properties. The model H_2 and model H_3 were attempted in the study.

SOILPAR 2.0

SOILPAR 2.0 is a program for estimating soil parameters (Stokles et. al., 2003). It allows: (1) storing soil data in a georeferenced database, (2) computing estimates of soil hydrological parameters, (3) comparing the estimates with measured data using both statistical indices and graphics, and (4) Creating maps using the ESRI format. The point PTFs currently implemented in SOILPAR are, Baumer, Brakensiek-Rawls, BSS subsoil and topsoil, EPIC, Hutson, Manrique, Rawls, Jabro, Puckett and Jaynes-Tyler method. The estimates of Ks are provided by Jabro, Puckett and Campbell method.

Performance evaluation

In this study performance of the Generic Pedotransfer Function 'Rosetta' was evaluated based on one to one correspondence between measured and predicted values of FC, PWP, AWC and K_s using statistical indices such as, Root Mean Square Error (RMSE), Index of Agreement (d), Maximum Absolute Error (ME), Mean Absolute Error (MAE). The mathematical expressions for statistical indices used in this study are give bellow,

Root Mean Square Error

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Ei-Mi)^2}{n}} \quad \dots(1)$$

Index of Agreement

$$d = 1 - \frac{\sum_{i=1}^{n}(Ei-Mi)^2}{\sum_{i=1}^{n}(|Ei-\bar{M}|+|Mi-\bar{M}|)^2} \quad \dots(2)$$

Table 1. Descriptive statistics of laboratory measure soil properties

Statistical Parameter	Sand	Silt	Clay	BD	OC	Ks
	(%)	(%)	(%)	(gm/cc)	(%)	(cm/hr)
Mean	26.80	42.74	30.46	1.34	0.50	0.95
S.E.M.	1.70	1.50	1.57	0.01	0.02	0.11
S.D.	15.87	14.02	14.68	0.11	0.21	1.01
Variance	251.76	196.5	215.5	0.01	0.05	1.03
C.V.	0.59	0.33	0.48	0.09	0.43	1.06
Minimum	5.33	3.74	5.72	1.18	0.14	0.15
Maximum	69.59	75.45	61.17	1.66	1.07	4.25
N	87	87	87	87	87	87

Maximum Absolute Error

$$ME = Max|Ei - Mi)| \quad \dots (3)$$

Mean Absolute Error

$$MAE = \sum_{i=1}^{n} \frac{|Ei - Mi|}{n} \quad \dots (4)$$

where, n represents the number of data used for modeling and E_i and M_i represent measured and computed value respectively. $\overline{M}$ represent mean of measured values.

We considered RMSE as a primary indicator in evaluation as it is the most commonly reported indicator in the literature (Wosten *et al.* 2001). Earlier research reports (Wosten *et. al.,* 2001) indicated that, the RMSE value in prediction of soil water retention properties normally are less than 0.05 m^3/m^3 but for saturated hydraulic conductivity, there is no such threshold value of RMSE is reported, hence it is considered double of standard error in measurement (SEM). The SEM for saturated hydraulic conductivity was found to 0.11 cm/hr, hence threshold value of RMSE for rejecting or accepting prediction is taken as 0.22 cm/hr.

RESULTS AND DISCUSSION

From the measured soil textural properties of the collected samples in the study area, eight different textural classes viz. Sandy loam Sandy clay loam, Loam, Silt loam, Silty clay loam, Silty clay, Clay loam and Clay were observed. The textural triangle showing textural distribution of soil samples collected from study watershed is shown in Fig. 1. The hydraulic properties of the soil samples varied greatly with soil texture. The sand content varied from 5.72 to 69.59%, while silt and clay varied from 3.74 to 75.45% and 5.72 to 61.17% respectively. Saturated hydraulic conductivity of all samples varied from 0.15 to 4.25 cm/hr. Descriptive statistics of all measured soil properties are presented in the Table 1.

The comparison of measured and estimated saturated hydraulic conductivity (Ks) was carried out using different statistical indices as described earlier. Evaluation indices of one to one comparison between measured and estimated saturated hydraulic conductivity (Ks) using Rosetta (H2), Rosetta (H3), Jabro point PTF, Puckett point PTF and Campbell parametric PTF are presented in the following Table.

As stated earlier, double of standard error in measurement (SEM) was considered as criteria in acceptance and rejection of prediction using PTFs. The SEM for K_S was found to be 0.11 cm/hr, hence threshold value of RMSE for rejecting or accepting prediction is taken as 0.22 cm/hr. From Table- 2 it could be concluded that estimation of K_S through all the methods were not acceptable as the RMSE values found much higher than threshold value of 0.22 cm/hr. Other statistical indices also indicated disagreement. However, estimation of saturated hydraulic conductivity using Rosetta (H2) model observed least errors compared to other approaches used in this study.

CONCLUSION

An objective of this study was to evaluate applicability of four different pedotransfer functions (Rosetta, Jabro, Puckett and Campbell) in estimating saturated hydraulic conductivity (Ks) of soils from Shirala Nemane watershed with geographical area of 22,400 ha. in Buldhana district of Maharashtra state. On the basis of statistical evaluation indices, it can be concluded that, the generic PTF Rosetta can be used for estimation of saturated hydraulic conductivity of Rainfed soils from Shirala Nemane Watershed, Maharashtra with reasonable accuracy.

Table 2. Statistical Indices for Estimation of saturated hydraulic conductivity (Ks)

Pedotransfer Function (PTF)	RMSE	D	ME	MAE	R^2	N
Rosetta (H2)	0.6921	0.7775	2.2077	0.5097	0.702	87
Rosetta (H3)	1.042	0.1922	3.1914	0.7932	0.001	87
Jabro point PTF	4.2332	0.0391	11.49	3.4754	0.407	87
Puckett Point PTF	10.7906	0.2597	46.85	4.4778	0.070	87
Campbell parametric PTF	1.165	0.3976	3.91	0.6979	0.002	87

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