EVALUATION OF PEDOTRANSFER FUNCTIONS FOR ESTIMATING SOIL MOISTURE CONSTANTS: A STUDY ON SOILS IN DRY ZONE OF TROPICAL SRI LANKA

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Abstract - Soil hydraulic parameters often play a key role in resource planning and management in agriculture and environment. Hence, lack of reliable data on soil hydraulic parameters is one of the major drawbacks in resource planning in tropical countries. Pedotransfer functions (PTF) can play a significant role in filling this data gap. Therefore, this study aimed to evaluate the existing PTF developed for tropical soils to identify the potential use for dry zone soils of Sri Lanka. Twenty two PTF developed by 9 research works were selected to find out the applicability of PTF to predict volumetric water content (VWC) at -10, -33 and -1500 kPa for tropical soils in dry zone Sri Lanka. Further this study aimed to identify the potential predictors to develop PTF for dry zone soils of tropical Sri Lanka. Out of the selected 22 PTF, three PTF developed by Botula et al. (2013) showed better performances compared to other PTF. Sand and bulk density were identified as the probable predictors to predict VWC at -10 and -33 kPa while Clay was identified as a probable predictor to predict VWC at -1500 kPa.

Keywords - Pedotransfer functions, Sri Lanka, tropical soils, volumetric water content.

I. INTRODUCTION

Agricultural environment in tropical countries are threatened by the climate change, environmental pollution due to unsustainable agricultural practices, limiting fresh water availability for irrigation and increasing energy prices etc. Therefore, urgent attention required to increase irrigation efficiency and pollution control of available water resources. Since soil hydraulic parameters are key factors determining the irrigation schedules and water movements, better understanding about soil hydraulic parameters are essential. Further crop and environmental modeling are increasingly applied for decision making of agriculture and environment, the demand for knowing of soil hydraulic parameters are dramatically increasing at present. However the availability of reliable data on soil hydraulic parameters is limited in tropical countries due to limited laboratory facilities and financial conditions. Since, determination of soil hydraulic parameters are laborious, an alternative indirect ways are required to estimate soil hydrological properties using easily measurable soil parameters.

Pedotransfer functions (PTF) are predictive functions which used estimate soil parameters which are difficult to determine using some easily measurable soil parameters [1]. PTF are already developed for most of the temperate soils but rarely for tropical soils [2]. Although it is not advisable to extrapolate PTF, those PTF developed for temperate soils are using in some software and are extensively using in worldwide irrespective to the climatic region due the data unavailability [3]. Despite of being a tropical country, most of the studies in Sri Lanka are also using those functions developed for temperate soils due to unavailability of reliable data. No any attempts were taken to develop PTF to Sri Lankan soils yet. Although few attempts were taken to develop pedotransfer functions for soils in other tropical countries [1], no evaluation was conducted to check the applicability of those PTF to Sri Lankan soils. Therefore this study aimed to evaluate the applicability of available PTF developed for tropical soils to estimate field capacity and permanent wilting point of tropical soils in dry zone of Sri Lanka. Further this study also aimed to identify the possible predictor variables to develop PTF for Sri Lankan tropical soils. Procedure for Paper Submission

II. MATERIALS AND METHODS

A. Study Area

This study was based on dataset of soil samples collected during the soil survey of dry zone Sri Lanka conducted under the SRICANSOL project [4]. The entire soil survey was covered almost all the soil series presence in dry zone of Sri Lanka by 51 soil profiles considering all sub divisions separately. The samples had been analyzed to cover wide range soil physical and chemical parameters. After removing soil profiles and/or sub horizons with missing data of volumetric water content (VWC), 142 data points were selected for this study. Important parameters of selected observation points are summarized and shown in Table 1. Selected data were used to evaluate the selected PTF which is properly documented as

developed for tropical soils.

B. Pedotransfer functions

PTF can be classified as parametric PTF and point PTF [5]. In this study point PTF developed for tropical soils were selected (Table 2) to study the applicability of available PTF to estimate VWC at -10, -33 and -1500 kPa of tropical soils in dry zone of Sri Lanka. When selecting PTF for this study, data availability of the existing data set and region of PTF developed were considered. All PTF were readjusted to obtain VWC in same units (mm/mm) Gravimetric water contents were converted in to volumetric water content for fair comparison among all the PTF selected.

	Sand (%)	Silt (%)	Clay (%)	BD (g/cm^3)	OC (%)	$\theta_{-10\ kPa}$	$\theta_{-33\ kPa}$	$\theta_{-1500\ kPa}$
Minimum	19.0	0.0	1.0	1.2	0.0	0.08	0.04	0.03
Maximum	99.0	37.0	61.0	1.8	2.6	0.47	0.43	0.35
Mean	68.5	12.4	19.0	1.5	0.4	0.23	0.20	0.14
SD	16.4	7.3	12.2	0.1	0.4	0.08	0.08	0.06

BD – Bulk density, OC – Organic carbon, $\theta_{-x\ kPa}$ - Volumetric water content at -10, -33 and -1500 kPa, SD – Standard deviation

Table 1. Summary statistics of soil data set of Dry zone Sri Lanka

Source	PTF	PTF name
Lal (1979) [7]	$\theta_{10} = 0.102 + 0.003Cl$	L10
	$\theta_{33} = 0.065 + 0.004Cl$	L33
	$\theta_{1500} = 0.06 + 0.003Cl$	L1500
Aina and Periaswamy (1985) [8]	$\theta_{33} = 0.6788 – 0.0055Sa$ -0.0013($Sa.BD$)	AP33
	$\theta_{1500} = 0.0213 + 0.0031Cl$	AP1500
Dijkerman (1988) [9]	$w_{33} = 0.3697 – 0.0035Sa$	D33
	$w_{1500} = 0.0074 + 0.0039Cl$	D1500
van den Berg et al. (1997) [10]	$\theta_{10} = 0.1088 + 0.00347Cl + 0.00211Si$ +0.0 1756OC	V10
	$\theta_{1500} = 0.00334Cl/BD + 0.00104Si/BD$	V1500
Gaiser et al. (2000)[11]	θ_{33}= 0.00208TOC + 0.006Cl + 0.00166Si	G10
	θ_{1500} = 0.00088TOC + 0.00340Cl + 0.00057Si	G1500
Adhikary et al. (2008)[12]	θ_{33} =0.5637 –0.0051Sa –0.0027Si	A33
	θ_{1500} =0.0071+ 0.0044Cl	A1500
Minasny and Hartemink (2011)[13]	θ_{10} = 0.599−0.0878BD−0.0031Sa	MH10
	θ_{33}= 0.565−0.0749BD−0.0034Sa	MH33
	θ_{1500} =0.0795 + 0.0086OC + 0.004Cl −0.00004(Cl−0.377)^2	MH1500
Botula et al. (2013)[14]	θ_{10} = 0.43520 - 0.00296Sa	B10
	θ_{33} = 0.41929 - 0.00349Sa	B33
	θ_{1500} = 0.21046 - 0.00170Sa + *0.00175*Cl	B1500
Mdemu (2015)[15]	θ_{10} = -0.0437 +0.0032Cl + 0.0516OC + 0.1184BD	M10
	θ_{33} =-0.1233 + 0.0031Cl +0.0552OC + 0.1533BD	M33
	θ_{1500} =-0.2360 + 0.0041Cl + 0.0003Si +0.0125OC + 0.1615BD	M1500

θ_x = volumetric water content at a specific matric potential (mm/mm), w_x = gravimetric water content at a specific matric potential (g/g), Cl = clay (%), Si = silt (%), Sa = sand (%), BD = bulk density (Mg m-3), OC = organic carbon (%), TOC = total organic carbon (g/kg)

Table 2: Selected PTF to find out the applicability to use for soils in dry zone of Sri Lanka

C. Model evaluation

Since a single model evaluation index may not useful to proper evaluation of PTF, several model evaluation indices such as mean error (ME), root mean square error (RMSE), modeling efficiency (EF) and coefficient of determination (R2) were used to evaluate model predictions [6]. In a perfect prediction ME and RMSE values should be equal to 0 and EF and R2 value should be equal to 1. Objective function (OBF) was developed combining ME, RMSE, EF and R2 to evaluate the performance of PTF (equation 1). The methods scored the least values for OBF were selected as the best methods to predict VWC at −10, −33 and −1500 kPa.

$$OBF = \sqrt{RMSE^2 + ME^2 + (1 - R^2) + (1 - EF)^2} \quad (1)$$

III. RESULTS AND DISCUSSION

Model evaluation index	PTF								
	L10	**-**	**-**	**V10**	**-**	**-**	**MH10**	**B10**	**M10**
ME	-0.07	-	-	-0.02	-	-	0.03	0.00	-0.01
RMSE	0.10	-	-	0.07	-	-	0.07	0.06	0.06
NSE	-0.69	-	-	0.21	-	-	0.15	0.31	0.23
R^2	0.21	-	-	0.30	-	-	0.31	0.32	0.24
OBF	1.87			1.06			1.10	0.97	1.08
	L33	**AP33**	**D33**	**-**	**G33**	**A33**	**MH33**	**B33**	**M33**
ME	-0.06	0.11	0.00	-	-0.05	-0.02	0.02	-0.02	0.00
RMSE	0.09	0.13	0.07	-	0.09	0.07	0.06	0.06	0.06
NSE	-0.28	-1.87	0.17	-	-0.34	0.21	0.29	0.33	0.28
R^2	0.28	0.43	0.40	-	0.35	0.36	0.41	0.40	0.28
OBF	1.47	2.93	1.03	-	1.49	1.02	0.93	0.90	1.02
	L1500	**AP1500**	**D1500**	**V1500**	**G1500**	**A1500**	**MH1500**	**B1500**	**M1500**
ME	-0.08	-0.06	-0.01	-0.09	-0.06	-0.05	0.00	0.00	-0.04
RMSE	0.09	0.08	0.06	0.10	0.08	0.07	0.05	0.05	0.07
NSE	-1.13	-0.54	-0.13	-1.62	-0.64	-0.32	0.24	0.38	-0.20
R^2	0.35	0.35	0.31	0.44	0.40	0.35	0.39	0.42	0.30
OBF	2.23	1.67	1.33	2.68	1.75	1.47	0.98	0.85	1.39

Table 3. Model performance based on selected model evaluation indices

A. PERFORMANCES OF SELECTED PTF

The performances of the selected PTF to predict VWC at −10, −33 and −1500 kPa were assessed. Prediction performances of selected methods are shown in Table 3. According to the OBF values, PTF B10, B33 and B1500 showed best performances to estimate VWC at −10, −33 and −1500 kPa respectively. PTF V10, M10 and MH10 also showed comparatively better results to estimate VWC at -10 kPa while PTF MH33, M33 and A33 showed comparatively better results to predict VWC at -33 kPa. PTF MH1500, D1500 and M1500 showed better performances to predict VWC at -1500 kPa. Therefore aforesaid 12 PTF (3 VWC levels x best 4 method at each VWC level) were selected for further assessment. Based on the input predictor variables, selected 12 PTF were categorized in to 4 groups as shown in Table 4.

B. POTENTIAL PREDICTORS

Table 3 and Figure 1 show that, PTF L10, L33, AP1500 and A1500 underestimated the VWC. All these PTF used only Clay to predict VWC. PTF V1500 (used Clay, Silt and BD as predictors) and G1500 (used Clay, Silt and BD as predictors) also showed underestimation compared to the observed values. However D1500 (used Clay and BD as predictors) and MH1500 (used Clay and OC as predictors) able to show fair estimation compared to the observed values. AP33 (used Sand and BD as predictors) showed over estimation compared to the observations. However, D33 (used Sand as a predictor and BD used to convert GWC to VWC) showed relatively better results using same predictors. All selected PTF showed low values as EF, hence poor modeling ability. The worst EF values were recorded by L10, L33, AP33, G33, L1500, AP1500, D1500, G1500, A1500 and M1500 irrespective to the used predictor variable/s. However, all the PTF (except AP33) did not consider Sand as a predictor variable in their PTF. Two PTF (B10 and B33) of selected 12 PTF (Table 4) did fair prediction only using Sand, while two other PTF able to do fair prediction using Sand and Clay or Silt as the predictor variable. Further two more PTF did fair prediction using Sand and BD as predictor variables. Most success PTF to predict VWC at -10 and -33 kPa used Sand and/or BD as predictor variable to predict VWC (except V10). All success PTF to predict VWC at -1500 kPa used Clay as predictor variable combining with other selected predictor variables. These results show that Sand and BD are important predictor variables to predict VWC at -10 and -33 kPa while Clay is important in predicting VWC at -1500 kPa.

However, results of Pearson's correlation analysis (Table 5) showed highly significant relationships between sand, silt and clay percentages with VWC at -10, -33 and -1500 kPa. Further, VWC at -10, -33 and -1500 kPa showed significant correlations with organic carbon content. Surprisingly Bulk density of the soil showed significant relationship with only VWC at -1500 kPa. However BD is used in 4 successful PTF developed to predict VWC at -10 and -33 kPa (Table 4).

Input Predictor types	Used predictor variables to predict VWC at		
	-10 kPa	-33 kPa	-1500 kPa
Texture only	Sa (B10)	Sa (B33) Sa, Si (A33)	Sa, Cl (B1500)
Texture and BD only	Sa, BD (MH10)	Sa, BD (MH33)	Cl, BD (1500)
Texture and OC only	Si, Cl, OC (V10)	-	Cl, OC (MH1500)
Texture, BD and OC	Cl, BD, OC (M10)	Cl, BD, OC (M33)	Cl, Si, BD, OC (M1500)

Table 4. Groups of selected PTF based on input predictor variable types

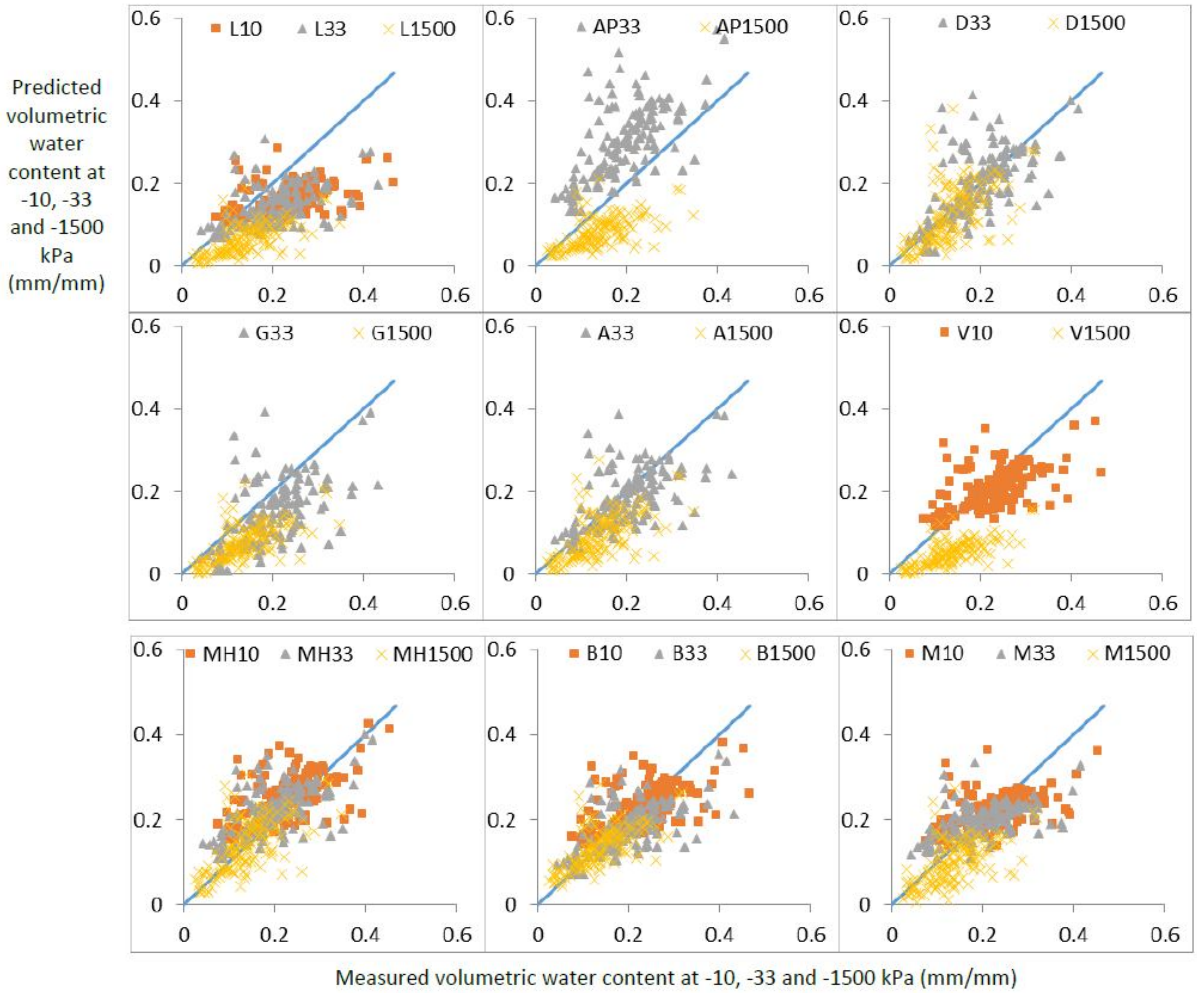


Figure 1. Measured and predicted volumetric water contents at -10, -33 and -1500 kPa of dry zone soils of tropical Sri Lanka

	Sand(%)	Silt(%)	Clay(%)	BD	OC	θ_{-10}	θ_{-33}	θ_{-1500}
Sand(%)		***	***	***	*	***	***	***
Silt(%)	-0.72		***	***	***	***	***	***
Clay(%)	-0.91	0.37				***	***	***
BD	0.33	-0.48	-0.16		***		*	**
OC	-0.16	0.39	-0.01	-0.37		**	***	**

θ_{-10}	-0.58	0.55	0.46	-0.11	0.22		***	***
θ_{-33}	-0.65	0.58	0.53	-0.17	0.23	0.97		***
θ_{-1500}	-0.7	0.58	0.6	-0.21	0.21	0.92	0.96	

BD – Bulk density, OC – Organic carbon, $\theta_{-x\ kPa}$ - Volumetric water content at -10, -33 and -1500 kPa, *, ** and ***: significant at $p<0.1$, $p<0.05$ and $p<0.01$

Table 5. Pearson's correlation matrix between soil properties of dry zone soils in Sri Lanka

CONCLUSIONS

Pedotransfer functions developed by Botula et al. (2013) can be used to estimate volumetric water content at -10, -33 and -1500 kPa of dry zone soils of Sri Lanka. However, PTF need to be developed for Sri Lankan soils as the selection also shows low reliability on prediction results.

Sand and bulk density could be identified as better predictor variables to predict volumetric water content at -10 and -33 kPa of dry zone soils of Sri Lanka, while clay could be identified as better predictor variable to predict volumetric water content at -1500 kPa of dry zone soils of Sri Lanka.

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REFERENCES

[1] J.H.M. Wösten, Y. A. Pachepsky and W. J. Rawls, "Pedotransfer functions: bridging the gap between available basic soil data and missing soil hydraulic characteristics", Journal of Hydrology, 251, 3–4, pp 123–150, 2001.

[2] J. Tomasella and M. Hodnet, "Pedotransfer functions for tropical soils" in Development of Pedotransfer functions in Soil hydrology, edited ; Y. Pachepsky and W.J. Rawals, Elseveir B.V. pp 415-429, 2004.

[3] Y.D. Botula, W.M. Cornelis, G. Baert, and E. Van Ranst, "Evaluation of pedotransfer functions for predicting water retention of soils in Lower Congo (DR Congo), Agricultural water management, 111, pp 1-10, 2012.

[4] A.R. Dassanayake, G.G.R. de Silva, R.B. Mapa and D. Kumaragamage, "Benchmark Soils of the Dry Zone of Sri Lanka -Fact Sheets" Publication of SRICANSOL project, Soil Science Society of Sri Lanka, pp 1-112, 2005.

[5] H. Vereecken, M. Weynants, M. Javaux, Y. Pachepsky, M.G. Schaap and M. van Genuchten, "Using pedotransfer functions to estimate the van Genuchten-Mualem soil hydraulic properties: A review", Vadose zone Journal, 9, pp 1-26, 2010.

[6] Rustanto, M. J. Booij, H. Wösten, A. Y. Hoekstra, "Application and recalibration of soil water retention pedotransfer functions in a tropical upstream catchment: case study in Bengawan Solo, Indonesia", Journal of Hydrology and Hydromechanics, 65 (3), pp 307–320, 2017.

[7] R. Lal, "Physical properties and moisture retention characteristics of some Nigerian soils", Geoderma, 21, pp 209-223, 1979.

[8] P. O. Aina and P. Periaswamy, "Estimating available water holding capacity of Western Nigerian soils from soil texture and bulk density, using core and sieved samples", Soil Science 140 (1), pp 55-58, 1985.

[9] J.C.Dijkerman, "An Ustult-Aqualt-Tropept catena in Sierra Leone, West Africa, II. Land qualities and land evaluation", Geoderma 42 (1) pp 29-49, 1988.

[10] M. van den Berg, E. Klamt , L.P. van Reeuwijk and W.G. Sombroek, "Pedotransfer functions for the estimation of moisture retention characteristics of Ferralsols and related soils, Geoderma 78, pp 161-180, 1997.

[11] T. Gaiser, F. Graef, and J. C. Cordeiro "Water retention characteristics of soils with contrasting clay mineral composition in semi-arid tropical regions", Australian Journal of Soil Research, 38, pp 523-536, 2000.

[12] P. P. Adhikary, D. Chakraborty, N. Kalra, C. B. Sachdev, A. K. Patra, S. Kumar, R. K. Tomar, P. Chandna, D. Raghav, K. Agrawal, and M. Sehgal, "Pedotransfer functions for predicting the hydraulic properties of Indian soils", Australian Journal of Soil Research, 46, pp 476–484, 2008.

[13] B. Minasny and A. E. Hartemink, "Predicting soil properties in the tropics", Earth-Science Reviews 106, pp 52–62, 2011.

[14] Y. D. Botula," Hierarchical pedotransfer functions to predict water retention of soils in Lower Congo" in Indirect methods to predict hydrophysical properties of soils of Lower Congo, Ghent University, Ghent, pp 152, 2013.

[15] M. V. Mdemu, "Evaluation and Development of Pedotransfer Functions for Estimating Soil Water Holding Capacity in the Tropics: The Case of Sokoine University of Agriculture Farm in Morogoro, Tanzania", Journal of Geography and Geology, 7 (1), pp 1-9, 2015.

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