4. Pedotransfer Functions of Soil Water Retention Characteristic

4.1 Pedotransfer Function

While measurements permit an exact determination of soil hydraulic properties, they are time consuming and expensive. Moreover, many studies are concerned with large areas of land that may exhibit substantial spatial variability in soil hydraulic properties. The cost effectiveness of obtaining soil hydraulic properties can be improved by using indirect methods, which allow the prediction of hydraulic properties from more easily measurable properties. Pedotransfer functions (PTFs) are one of the most commonly used indirect methods, which allow easily measurable soil properties such as particle size distributions and bulk density to be used to predict soil hydraulic properties (Arya and Paris, 1981; Campbell, 1985; Scheinost *et al*, 1997).

In this study, saturated hydraulic conductivity data showed poor correlation with other soil properties. Therefore, it is not considered for the development of PTFs. However, soil water retention data showed good correlation with soil properties such as soil particle distribution and bulk density. Therefore, PTFs were developed for water retention characteristic of soils in the SIR.

The closed form of van Genuchten model (1980) was used in the estimation of PTF. It yields a continuous function of θ(h) relationship.

$$\theta(h) = \theta_r + \frac{(\theta_s - \theta_r)}{\left[1 + (\alpha\, h)^N\right]^{(1-1/N)}} \tag{7}$$

where θ(h) is volumetric water content ($cm^3\ cm^{-3}$) at suction h (cm), parameters θ_r and θ_s are residual and saturated water contents, respectively, ($cm^3\ cm^{-3}$), α is a scaling parameter (>0, in cm^{-1}) related to the inverse of the air entry suction, and N (>1) is a curve shape parameter, a measure of the pore size distribution (van Genuchten, 1980).

Scheinost *et al* (1997) proposed the following expressions for relating the parameters of the van Genuchten Equation (7) such as θ_s, θ_r, α, and N with soil physical properties:

$$\theta_s = b_1\,(1 - BD/2.65) + b_2 \quad \text{or} \quad \theta_s = s_1\, c + s_2\, BD + s_3 \tag{8}$$

$$\theta_r = r_1\, c + r_2\, s + r_3 \tag{9}$$

$$\alpha = a_1 + a_2\, d_g \tag{10}$$

$$N = n_1 + n_2\, \sigma_g \tag{11}$$

where c is clay percentage, s is sand percentage, BD is bulk density in g cm^{-3}, d_g (mm) is geometric mean diameter, and σ_g is geometric standard deviation, b_1, b_2, s_1, s_2, s_3, r_1, r_2, r_3, a_1, a_2, n_1 and n_2 are empirical parameters.

The parameters d_g and σ_g were calculated from particle size fractions (m_1, m_2, m_3 are clay, silt and sand mass fractions respectively) as:

$$d_g = \exp \sum_{i=1}^{3} m_i \ln d_i \tag{12}$$

$$\sigma_g = \exp\left[\sum_{i=1}^{3} m_i \left(\ln d_i\right)^2 \quad \left(\sum_{i=1}^{3} m_i \left(\ln d_i\right) \right)^2 \right]^{0.5} \tag{13}$$

where m_i is the mass fraction and d_i is the mean particle size diameter of the i^{th} mass fraction class.

4.2 Parameter Estimation

4.2.1 Soil Property Data

The measured soil hydraulic and soil properties of all sampling points in the SIR was arranged in a tabular form. It contains measured data of soil water retention characteristic and soil properties such as particle size distribution and bulk density Horizons A and B1. Sampling points containing data of both soil physical properties and water retention characteristic were used to develop pedotransfer functions. The soil properties used were:

(i) particle size fractions of clay (<2 µm), silt (5–50 µm) and sand (50–2000 µm)

(ii) bulk density (BD) in g cm^{-3}

(iii) measured soil water contents at water suctions of 0, 1, 5, 8, 10, 60, 80, 200 and 1500 kPa

(iv) geometric mean particle size diameter d_g (mm) and geometric standard deviation σ_g (mm)

4.2.2 Fitting Parameters

The parameters θ_s , θ_r , α, and N of the van Genuchten Equation (7) are replaced with Equations (8), (9), (10), and (11), which results in the following equation:

$$\theta(h) = r_1 c + r_2 s + r_3 + \frac{\left[s_1 (1 - BD/2.65) + s_2 - r_1 c - r_2 s - r_3 \right]}{\left[1 + \left((a_1 + a_2 d_g) h \right)^{(n_1 + n_2 \sigma_g)} \right]^{(1 - 1/(n_1 + n_2 \sigma_g))}} \tag{14}$$

Nonlinear regression analysis was used to fit the parameters of the PTF Equation (14) from measured data by minimising sum of squared residuals of measured θ and predicted $\hat{\theta}$. The parameters of PTFs of soil water retention characteristic for Horizons A and B1 are presented in Tables 31.1 and 31.2.

4.3 Evaluation Criteria

The performance of PTFs was analysed comparing the quality of the estimation when applied on a particular soil data set. The following indicators were used to evaluate the performance of PTFs.

(1) Root Mean Squares of Residuals

Root mean squares of residuals (RMSR) calculates the mean accuracy of prediction, which represents the expected magnitude of error.

$$RMSR = \left[\frac{1}{M} \sum_{i=1}^{M} \left(\hat{\theta}_i - \theta_i \right)^2 \right]^{\frac{1}{2}} \tag{15}$$

where M is the number of data points, and θ and $\hat{\theta}$ are measured and predicted water contents, respectively.

(2) Coefficient of Determination (R^2)

Coefficient of determination (R^2) measures the percent of variation in the dependent variable explained by variation in the independent variable(s). R^2 varies from 0 (0 percent variation explained) to 1 (100 percent variation explained).

$$R^2 = 1 - \frac{\sum_{i=1}^{M} \left(\hat{\theta}_i - \theta_i \right)^2}{\sum_{i=1}^{M} \left(\theta_i - \bar{\theta} \right)^2} \tag{16}$$

where $\bar{\theta}$ is the mean of measured θ values.

(3) Mean Deviation

Tietje and Tapkenhinrichs (1993) proposed the use of mean deviations (MD) as a measure of how well the PTFs fit to the retention curve. It is the sum of the area difference between the observed and predicted water retention curves. MD indicates whether the PTFs over or underestimate the observed data. MD for K number of water retention curves was calculated as:

$$MD = \frac{1}{K} \sum_{i=1}^{K} \left[\frac{1}{b-a} \int_a^b \left[\hat{\theta} - \theta \right] d(\log_{10} h) \right] \tag{17}$$

To allow for the log normal distribution of h, the MDs were calculated using $\log_{10}(h)$. The integration boundaries a and b were set to a = $\log_{10}$(0.1 kPa) and b = $\log_{10}$(1500 kPa). The integration was done numerically by calculating the area under the curves using water contents at measured suctions (Budiman, 2002).

(4) Root Mean Square Deviation

Tietje and Tapkenhinrichs (1993) also introduced root mean square deviation (RMSD) as a measure of the absolute deviation from the observed data. RMSD between measured and predicted water contents for K number of water retention curves was calculated as:

$$\mathrm{RMSD} = \frac{1}{K}\sum_{i=1}^{K}\left[\frac{1}{b-a}\int_a^b \left[\hat{\theta}-\theta\right]^2 d(\log_{10}h)\right]^{1/2} \qquad (18)$$

The RMSD equals zero if there is no difference between the predicted and the measured values. The parameters a and b were set to the same values as for MD calculation.

The results of performance evaluation of the developed PTFs for Horizons A and B1 are presented in Tables 31.1 and 31.2.