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Pedotransfer Functions for Estimating Soil Hydraulic Properties: A Review

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ABSTRACT

Characterization of soil hydraulic properties is important to environment management; however, it is well recognized that it is laborious, time-consuming and expensive to directly measure soil hydraulic properties. This paper reviews the development of pedotransfer functions (PTFs) used as an alternative tool to estimate soil hydraulic properties during the last two decades. Modern soil survey techniques like satellite imagery/remote sensing has been used in developing PTFs. Compared to mechanistic approaches, empirical relationships between physical properties and hydraulic properties have received wide preference for predicting soil hydraulic properties. Many PTFs based on different parametric functions can be found in the literature. A number of researchers have pursued a universal function that can describe water retention characteristics of all types of soils, but no single function can be termed generic though van Genuchten (VG) function has been the most widely adopted. Most of the reported parametric PTFs focus on estimation of VG parameters to obtain water retention curve (WRC). A number of physical, morphological and chemical properties have been used as predictor variables in PTFs. Conventionally, regression algorithms/techniques (statistical/neural regression) have been used for calibrating PTFs. However, there are reports of utilizing data mining techniques, *e.g.*, pattern recognition and genetic algorithm. It is inferred that it is critical to refine the data used for calibration to improve the accuracy and reliability of the PTFs. Many statistical indices, including root mean square error (RMSE), index of agreement (d), maximum absolute error (ME), mean absolute error (MAE), coefficient of determination (r^2) and correlation coefficient (r), have been used by different researchers to evaluate and validate PTFs. It is argued that being location specific, research interest in PTFs will continue till generic PTFs are developed and validated. In future studies, improved methods will be required to extract information from the existing database.

Key Words: database, generic PTF, hydraulic conductivity, predictor properties, PTF development tools, regression, statistical indices, water retention curve

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INTRODUCTION

Research interest in soil moisture dynamics is continuously increasing with increasing attention on environment management. Automated handling of soil information through computer systems has opened up new vistas in agricultural research. Recent advances in soil sampling and soil physical property analysis and interpretation have never before enabled possibilities of embedding soil data into the applications related to agriculture, hydrology, civil engineering, geo-science, petroleum engineering, environmental sciences, *etc.* Thus, there is a great demand for soil database. Soil information has been routinely collected through soil surveys in many countries, but such soil data rarely include soil hydraulic properties like water retention curve (WRC) and saturated hydraulic conductivity (K_s). Inexpensive and rapid ways to estimate these properties are needed (Schaap *et al.*, 2001; Givi *et al.*, 2004; Alvarez-Acosta *et al.*, 2012). Minasny and Hartemink (2011) opined that the dearth of soil property measurements is large in many tropical countries. Furthermore, soil information is unavailable on a regional scale in many countries around the world. Researchers, planners and decision makers in these countries are often faced with inadequate data to work with (Patil *et al.*, 2010, 2011).

For these reasons, several methods have been proposed to estimate soil hydraulic properties (Parsuraman *et al.*, 2007; Vereecken *et al.*, 2010) from easily measured soil properties, *e.g.*, texture and bulk density (BD), and/or limited data collected during soil surveys. An equation/model developed for indirect estimation of soil property is termed pedotransfer function (PTF) (Bouma 1989). Because of the time-consuming nature of direct field measurement of hydraulic condu-

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ctivity and in view of the field-scale spatial variability problem, predictive models (including those that predict the hydraulic properties from soil texture and related data) provide the only viable means of characterizing hydraulic properties of large areas of land, whereas direct measurement may prove to be cost effective only for site-specific problems (Wösten *et al.*, 2001; Patil and Chaturvedi, 2012).

As expected, there has been a consistent research interest in PTFs and many reports in the literature on PTF development in different parts of the globe (Oliveira *et al.*, 2002; Givi *et al.*, 2004; Wei *et al.*, 2004; Parasuraman *et al.*, 2007; Minasny and McBratney, 2008; Minasny and Hartemink, 2011; Botula *et al.*, 2012), which no doubt reveals the fact that PTFs are empirical in nature, thus forcing researchers to develop site-specific PTFs for different applications. The advent of acquisition of satellite-based data and developments in the field of data mining have provided an opportunity to ill-equipped nations to develop soil information systems that are relatively cheap and labour saving.

An analogous example could be drawn from the field of telecommunications. Many countries in the world could not develop network of telephone landlines and did not pass through the stages of development like the other developed countries, but they leapfrogged to cell phone technology, saving enormous investments that they would have otherwise incurred. Similarly, with the progression of technology, development of soil inference system has achieved a technological breakthrough and future developments will mostly rely on data acquisition through remote sensing tools with actual field data measurement relegated to the secondary status serving mostly as a verification tool.

Notable review articles dwelling on PTF development and their applications include Wösten *et al.* (2001) and Minasny and Hartemink (2011). Wösten *et al.* (2001) discussed the accuracy and reliability of PTFs and emphasized that the future developments in PTFs would come from better data mining tools like neural networks and group methods of data handling. Minasny and Hartemink (2011) opined that soils of the tropics have received inadequate research attention, where the need for accurate and up-to-date soil property information and hence development of PTFs is urgent. The topics for future development in tropics were identified. This review is an attempt to summarize the developments in PTFs mostly over the last two decades with a target audience of researchers in developing countries and focuses on the current status of PTF development for estimating soil hydraulic properties because of their importance. Irrespective of the property of interest, the underlying principle in developing PTFs is a need to avoid direct measurement of soil properties that are expensive and resource consuming.

METHODS OF PTF DEVELOPMENT

Based on the theoretical approach, methods for predicting soil properties can be grouped into two types, mechanistic and empirical approaches. Mechanistic approaches translate easily measured soil properties like texture (particle-size distribution, PSD), BD and particle density into an equivalent pore-size distribution model. This model is then related to water content at different soil water matric heads (potentials). Among these models the most prominent one is a physico-empirical model (Arya *et al.*, 1999), which interestingly has roots in petrochemical engineering. It makes use of the similarity in shape between water retention curve and cumulative PSD. First, PSD is translated into the PSD model. Then, the cumulative pore-size volumes, corresponding to progressively increasing pore radii, are divided by the sample bulk volume to give the volumetric water content and the pore radii are converted to equivalent soil water pressure using the equation of capillarity. This model was modified by several researchers to predict WRC. However, it was reported to work well only for sandy soils and perform poorly for clayey and loamy soils.

Numerous attempts have been made to predict hydraulic conductivity from WRC based on PSD. Mualem model (Mualem, 1976) is one of the most widely accepted models. It predicts unsaturated hydraulic conductivity from measured water retention data. Mualem (1976) also showed that there are a number of approaches to predict unsaturated hydraulic conductivity. However, the sheer volume of work reported in the literature indicates that researchers prefer empirical approaches to predict hydraulic properties.

Empirical approaches attempt to develop relationships between the predictor and response variable. Two empirical approaches are commonly used: 1) point PTFs, which relate estimates of field capacity (FC), permanent wilting point (PWP), available water capacity (AWC) and K_s to soil properties, and 2) parametric PTFs, which relate model parameters to soil properties. General form of the empirical equation is:

$$\theta(h) = C_1 \times \text{sand} + C_2 \times \text{silt} + C_3 \times \text{clay} + C_4 \times \text{bulk density} + \cdots + C_i \times X_i \qquad (1)$$