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PREDICTION OF UNSATURATED HYDRAULIC CONDUCTIVITY FOR THREE MAJOR EGYPTIAN SOILS

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ABSTRACT

The unsaturated soil hydraulic conductivity K(θ) is quite important and required for many hydrological processes and soil-water flux modeling, and agricultural applications, including land-use evaluation, estimate of drainage, chemical leaching, and others. Measurements of K(θ) are difficult, laborious, time consuming, and highly variable. These problems necessitating large number of sampling and measurements to achieve reasonable values of K(θ) or to characterize an area of land. This will be costly and economically not feasible. Rather than measuring the K(θ) directly, different predictive models were used to estimate K(θ). In the recent years, intensive uses of pedotransfer functions as an approach to translate simple characteristics of soil surveys into more complicated parameters, *i.e.* K(θ). We approach local best-fit of data models that accurately predict K(θ). Such models are rarely found and quite needed for the Egyptian soils to be used in several applications and models.

There are numerous models of estimating K(θ). We evaluated K(θ) for three major Egyptian soils: alluvial-lacustrine, calcareous, and sandy using different predictive models. The proposed models:Best-fit of data (BFD), Campbell , 1974 (CAM), Gilham *et al*., 1976 (GIL), Mualem-van Genuchten, 1980 (MVG), Rawls and Brakensiek, 1989 (R&B), and Saxton *et al.,* 1986 (SAX).

Data showed that the BFD model best described K(θ) for the given soils. Other predictive models showed variations in their errors and precisions with different types of soils. The relative magnitude of the highest possible mean error (ME) were 2.6, 28.6, 7.8, 89.6, 93.5, and 100% for alluvial-lacustrine soil; 3.0, 52.7, 11.8, 78.8, 82.7, and 100% for calcareous soil; 6.0, 79.3, 84.7, 92.4, 100, and 66.0% for sandy soil; and 5.1, 68.7, 55.6, 93.4, 100, and 86.4% for all over types of the studied soils with the BFD, GIL, MVG, CAM, R&B, and SAX models, respectively.

INTRODUCTION

The quantification of soil hydraulic properties is vitally important to model hydrological process (Schaap and Leig, 2000), soil-water flux and transport process (Vereecken *et al*., 1990; Yates *et al*., 1992; Stolte *et al.,* 1994; Poulsen *et al*., 1999; Fares *et al*., 2000; and Wösten *et al*., 2001), and for many agricultural management (Chen and Payne, 2001) including land use evaluation (Wösten *et al.,* 1999) and estimates of drainage (Klaij and Vachaud, 1992) or chemical leaching (Normand *et al.,* 1997). However, measurements of soil hydraulic properties are difficult, time consuming, and expensive, in particular unsaturated hydraulic conductivity (Puckett *et al*., 1985; Brocher *et al.,* 1987; Wösten and van Genuchten, 1988; Schaap and Leig, 2000). Rather than measuring the hydraulic properties directly, estimation methods that utilize physical or empirical relations of such properties and other soil variables is an alternative approach. The advantage of such approach is that the input variable, e.g. soil texture, are easily measured and widely available, through soil surveys, than the hydraulic properties (Puckett *et al*., 1985; Saxton *et al*., 1986; Wösten and van Genuchten, 1988; Rawls and Brakensiek, 1989; Vereecken *et al*., 1990; Schaap and Leig, 2000; Chen and Payne, 2001). This procedure is referred to as *pedotransfer function* which is a powerful tool in predicting physical and chemical properties of soils, and have the clear advantage that they are relatively inexpensive and easy to drive and to use (Tietje and Tapkenhinrichs, 1993; and Tomasella and Hondnett, 1997; and Wösten *et al*., 2001). Far fewer alternatives exits for unsaturated hydraulic conductivity. For many purposes, general estimates based on soil water characteristics are sufficient (Pachepsky *et al.*, 2000). Hydraulic conductivity is one of the most variable and uncertain soil properties (Poulsen *et al*., 1999; and Wösten *et al*., 2001). Therefore, the prediction of saturated or unsaturated hydraulic conductivity of a soil is not an easy task due to their high spatial variability.

A great deal of effort is being made at present to develop field scale models of flow and transport throughout the soil-plant-atmosphere continuum to be used as research and management tools. Incorporating an inaccurate flow, predicted from invalid $K(\theta)$, into a contaminant-transport model can seriously affect the accuracy of the transport simulation. A first prerequisite for obtaining reliable results with soil-water flow models is the reliability of the input data. As mentioned, the problem of determining $K(\theta)$ is confounded by the expense number of observations required to adequately characterized the spatial distribution due the commonly occurring field-scale variability. Although many studies of individual models exist, comparisons of models are rare. In Egypt, few and scarce directly measured $K(\theta)$ data are available, and limited to small areas.

More recently, statistical formule, have been developed to relate basic soil survey data, e.g., soil texture, bulk density, and organic matter to hydraulic properties such as water retention characteristics and $K(\theta)$. Despite the importance of $K(\theta)$ to so many applications, and the increasing use of pedotransfer functions in many applications and models, comparative studies of different methods of $K(\theta)$ estimation are surprisingly rare.

The objective of this study is to develop local models that are useful for the prediction of unsaturated soil hydraulic conductivity and to evaluate the validation of other sited predictive models for three major Egyptian soils: alluvial-lacustrine, calcareous, and sandy.

MATERIALS AND METHODS

Measured Data

Three locations were selected for this study: Abis (31°22′N, 29°56′E) of alluvial-lacustrine soil, El-Hammam (30°51′N, 29°28′E) of calcareous soil, and Southern El-Tahrir (30°39′N, 30°42′E) of sandy soil. Their soils classified as Thermic Typic Torrifluvent, Thermic Typic Calcigypsiorthids, and Thermic Typic Torripsamments, respectively. Fifteen sites were randomly assigned at each location to collect surface (0-25 cm) and subsurface (25-50 cm) disturbed and undisturbed soil samples. Disturbed soil samples were air dried and passed through a 2-mm sieve. Particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986), bulk density by the dry core method (Blake and Hartge, 1986), and saturated hydraulic conductivity (K_s) by the constant head method (Klute and Dirksen, 1986). Soil water content-matric potential relationship was determined using undisturbed soil cores in a pressure chamber apparatus up to 500 kPa and thereafter, in a pressure membrane apparatus up to 1500 kPa (Klute, 1986). The porosity was calculated from the bulk density and particle density (assumed to be 2.65 Mg m^{-3}). Unsaturated hydraulic conductivity was performed on randomly selected undisturbed soil samples from the three studied regions using the one-step outflow method (Borcher *et al.*, 1987). This procedure provides reliable data for K(θ) (Stolte *et al.*, 1994).

Estimated Data

The Models

Six models with simple formulations were selected for this study to predict the K(θ) of samples from selected sites at each region. The description and algorithms of these models are summarized in Table (1).

A best-fit of data (BFD) model was developed relating the K(θ) and volumetric soil water content (θ) for each site, each soil type (region), and overall soil types (regions). The program Tablecurve (SPSS, Chicago, IL) was used to generate the numerical functions.

The Campbell, 1974 (CAM) model estimated the K(θ) using single measurement of K_s , and the relative saturation setting the residual soil water content equal to zero. The fitting includes an empirically determined constant.

The Gilham *et al.,* 1976 (GIL) model directly relates K(θ) and(θ) through using two soil-dependent fitting parameters.

The Maulem-van Genuchten (MVG) model is based on van Genuchten (1980) empirical equation for the relative saturation (S_e):

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \frac{1}{\left[1 + (\alpha h)^n\right]^{(1-1/n)}} \quad (1)$$

where θ is the volumetric water content ($m^3 m^{-3}$), θ_r and θ_s are residual and saturated volumetric soil water contents, respectively ($m^3 m^{-3}$), α (m^{-1}) is related to the inverse of air entry pressure, and n is a measure of the pore-size distribution. Non linear regression (STATGRAPHICS, Ver. 7.0, Manugistics, Inc., Rockville, MD) was used to fit the van Genuchten equation (1) and providing α and n values. Combining van Genuchten empirical equation with the theoretical pore size distribution model of Mualem (1976) leads to Mualem-van Genuchten model:

$$K(S_e) = K_s (S_e)^{\ell} \{1 - [1 - (S_e)^{n/(n-1)}]^{1-1/n}\}^2 \quad (2)$$

substituting S_e=(θ - θ_r)/(ø- θ_r), and l=0.5 (default value), yields the following closed-form expression:

$$K(\theta) = K_s[(\theta - \theta_r)/(\text{ø} - \theta_r)]^{0.5}\{1-[1-[(\theta- \theta_r)/(\text{ø} - \theta_r)]^{n/(n-1)}]^{1-(1/n)}\}^2 \qquad (3)$$

Equation (3) is known as Mualem-van Genuchten equation's and frequently used to estimate $K(\theta)$ considering θ_r as the volumetric soil-water content at 1500 kPa suction.

The Rawls and Brakensiek, 1989 (R&B) model estimated the parameters of the Brooks and Corey (1964) equation for hydraulic conductivity:

$$K(\theta) = K_s(S_e)^n = K_s[(\theta - \theta_r)/(\text{ø} - \theta_r)]^n \qquad (4)$$

Their model represents regression equation for estimating λ parameter as a function of clay, sand, and total porosity, and then n= 3+2/ λ. We considered θ_r as the volumetric soil-water content at –1500 kPa.

The Saxton *et al.,* 1986 (SAX) model was developed using multiple nonlinear regressions using soil water content, percent sand, and percent clay as independent variables from 10 texture classes using 230 selected data point to estimate the hydraulic conductivity.

Table 1. The description of the models used in the estimation of the unsaturated hydraulic conductivity of soil.

Model	Algorithms† and parameters
Best-Fit (BFD)	$K(\theta) = a + b(\theta) + c(\theta)^{1.5} + d(\theta)^2 + e[1/\ell n(\theta)]$ $K(\theta)=-0.001642+0.034462(\theta)+0.0684729(\theta)^{1.5}$ $+0.067987(\theta)^2+0.008303[1/\ell n(\theta)]$
Campbell, 1974 (CAM)	$K(\theta) = K_s[\theta/\text{ø}]^n$
Gilham, 1976 (GIL)	$K(\theta) = a(\theta)^n$
Mualem-van Genuchten, 1980 (MVG)	$K(S_e) = K_s[(S_e)]^{\ell}\{1-[1-(S_e)^{n/(n-1)}]^{1-(1/n)}\}^2$ $K(\theta) = K_s[(\theta - \theta_r)/(\text{ø} - \theta_r)]^{0.5}\{1-[1-[(\theta - \theta_r)/(\text{ø} - \theta_r)]^{n/(n-1)}]^{1-(1/n)}\}^2$
Rawls & Brakensiek, 1989 (R&B)	$K(\theta) = K_s[(\theta - \theta_r)/(\text{ø} - \theta_r)]^n$ $n = 3+(2/\lambda)$ $\lambda = \exp[-0.7842831+0.0177544\times sand-1.062498\times \text{ø}$ $-0.00005304\times sand^2-0.00273493\times clay^2+1.11134946\times \text{ø}^2$ $-0.03088295\times sand\times \text{ø}+0.00026587\times sand^2\times \text{ø}^2$ $-0.00610522\times clay^2\times \text{ø}^2-0.00000235\times sand^2\times clay$ $+0.00798746\times clay^2\times \text{ø}-0.00674491\times \text{ø}^2\times clay]$ $K_s = 2.778\times10^{-6}\exp[19.52348\times\text{ø}-8.96847-0.028212\times clay$ $+0.00018107\times sand^2-0.00298\times sand^2\times\text{ø}^2$ $-0.019492\times clay^2\times\text{ø}^2+0.0000172\times sand^2\times clay$ $+0.02733\times clay^2\times\text{ø}+0.00143\times sand^2\times\text{ø}$ $-0.0000035\times clay^2\times sand$
Saxton *et al*., 1986 (SAX)	$K(\theta)= 2.778\times10^{-6}\{\exp[12.012-0.0755 sand+[-3.8950$ $+0.03671\ sand -0.1103\ clay+8.7546\times10^{-4}\ clay^2]\ (1/\theta)]\}$

† $K(\theta)$=unsaturated hydraulic conductivity (m s^{-1}), K_s=saturated hydraulic conductivity (m s^{-1}), S_e=relative saturation, ℓ = lumped parameter indicates tortuosity and connectivity of pores,
θ=volumetric soil-water content ($m^3\ m^{-3}$), θ_r=residual volumetric soil-water content ($m^3\ m^{-3}$), ø=total porosity, sand= % sand (50-2000 µm), clay= % clay (< 2 µm), and (a, b, c, d, e, λ , and n) are fitting parameters.

Models Evaluation

The accuracy of the unsaturated hydraulic conductivity models were evaluated through the calculations of mean error (ME, calculated as the mean of the measured values minus the estimated values) and its standard deviation (sd) associated with their estimations, and the objective function (OB) as reported by Vereecken *et al.* (1990); and Schaap and Leij (2000), and given as:

$$OB = \sum_{i=1}^{n} [\log_{10}(K_m)_i - \log_{10}(K_p)_i]^2 \quad (5)$$

where $(K_m)_i$ and $(K_p)_i$ are the measured and predicted unsaturated hydraulic conductivities, respectively, and n is the number of points. They suggested that at the level of an observation of the model performance, the model with smallest value of the objective function performs best. Also, the predictive capacity of a model can also be visually inspected by comparing the graphs of estimated and measured curves (Vereecken *et al*., 1992).

RESULTS AND DISCUSSION

The mean error may be interpreted as the mean "estimation error" or "bias" of the method used , whereas the standard deviation of errors is a "precision" of the methods (Vereecken *et al*., 1992; and Wösten *et al*., 2001). The ME and sd, and OB values for each of the used models are listed in Tables (2) for Abis, El-Hammam, Southern El-Tahrir, and overall regions, respectively. Generally, based on ME values, overestimation of K(θ) were noticed with either BFD or MVG model, and underestimation with the other predictive models for each soil and all over soil types. Comparing the effectiveness of each model in K(θ) prediction for a soil type based on OB values showed that CAM, MVG, and R&B were superior in the order: calcareous>sandy>alluvial-lacustrine soil. Similarly, the superiority was found in the order: calcareous>alluvial-lacustrine>sandy, alluvial-lacustrine>calcareous>sandy, and sandy>alluvial-lacustrine>calcareous with BFD, GIL, and SAX models, respectively.

For the alluvial-lacustrine soils of Abis region, the average of 2.6, 28.6, 7.8, 89.6, 93.5, and 100٪ of the highest ME, 13.5, 66.7, 91.3, 100, 99.2, and 98.4٪ of the highest sd, and 0.2, 0.6, 10.4, 25.7, 29.7, and 100٪ of the highest OB were found with BFD, GIL, MVG, CAM, R&B, and SAX models, respectively. The best performance of a model that resulted in low errors and sd values was in the same order: BFD>GIL>MVG>CAM>R&B >SAX.

For the calcareous soils of El-Hammam region, the average of 3.0, 52.7, 11.8, 78.8, 82.7, and 100٪ of the highest ME, 10.2, 85.0, 88.6, 88.6, 97.5, and 100٪ of the highest sd, and 0.0, 0.2, 0.4, 0.6, 0.6, and 100٪ of the highest OB were found with BFD, GIL, MVG, CAM, R&B, and SAX models, respectively. The best performance of a model that resulted in low errors and sd values was in the order: BFD>MVG>GIL>CAM>R&B>SAX.

For sandy soils of Southern El-Tahrir region, the average of 6.0, 79.3, 84.7, 92.4, 100, and 66.0٪ of the highest ME, 6.7, 92.6, 98.2, 100, 99.1, and 91.5٪ of the highest sd, and 1.4, 6.5, 14.6, 19.8, 23.2, and 100٪ of the highest OB were found with BFD, GIL, MVG, CAM, R&B, and SAX models, respectively. The best performance of a model that resulted in low errors and sd values was in the order: BFD>GIL>SAX>MVG>CAM>R&B.

Overall the studied regions, the average of 5.1, 68.7, 55.6, 93.4, 100, and 86.4٪ of the highest ME, 8.1, 89.3, 95.9, 100, 99.3, and 94.7٪ of the highest sd, and 0.1, 0.5, 1.7, 3.3, 3.8, and 100٪ of the highest OB were found with BFD, GIL, MVG, CAM, R&B, and SAX models, respectively. The best performance of a model that resulted in low errors and sd values was in the order: BFD>MVG>GIL>SAX>CAM>R&B.

It was noticed that the prediction of K(θ) is more accurate and precise in the order of alluvial-lacustrine, calcareous, and sandy soils. The reliability of the studied predictive models is shown in Fig. 1, as some models provides close match to measured values and others do not at different sites. SAX model resulted in several order of magnitude less than the measured and predicted of K(θ) values by other used models.

The quite needed estimation of unsaturated K (m s^{-1}) for the modeling and agricultural applications in the Egyptian soils at certain volumetric soil water content (θ) developed according to GIL model $K(\theta) = a\,\theta^{n}$ is given as:

$K(\theta) = 15.4\times10^{-2}\ \theta^{5.97}$ $R^2=0.834^{**}$… for alluvial-lacustrine soil
$K(\theta) = 3.65\times10^{-2}\ \theta^{2.74}$ $R^2=0.810^{**}$… for calcareous soil
$K(\theta) = 5.51\times10^{-2}\ \theta^{2.03}$ $R^2=0.866^{**}$… for sandy soil
$K(\theta) = 3.66\times10^{-3}\ \theta^{1.16}$ $R^2=0.625^{**}$… for overall soil types

Alternatively, the estimation of unsaturated K (m s^{-1}) at certain volumetric soil water content (θ) developed according to CAM model: $K(\theta) = K_s\,(\theta/ø)^{n}$, where K_s and ø are directly measured or estimated, is given as:

$K(\theta) = K_s\ (\theta/ø)^{5.99}$ $R^2=0.780^{**}$… for alluvial-lacustrine soil
$K(\theta) = K_s\ (\theta/ø)^{2.82}$ $R^2=0.753^{**}$… for calcareous soil
$K(\theta) = K_s\ (\theta/ø)^{2.06}$ $R^2=0.783^{**}$… for sandy soil
$K(\theta) = K_s\ (\theta/ø)^{1.17}$ $R^2=0.538^{**}$… for overall soil types

Also, for the major Egyptian soils, the estimation of unsaturated K (m s^{-1}) at certain volumetric soil water content (θ) developed according to BFD model is given as:

$K(\theta) = 0.01/[-382.26 - (178.06\ \ln\theta)/\ \theta^2]$
$R^2=0.839^{**}$… for alluvial-lacustrine soil
$K(\theta) = 0.01/[-116.55 - (25.92\ \ln\theta)/\ \theta^2]$
$R^2=0.884^{**}$… for calcareous soil
$K(\theta) = -1.70\times10^{-5} + 1.22\times10^{-2}\ \theta^3$
$R^2=0.862^{**}$… for sandy soil
$K(\theta) = -1.64\times10^{-3}+3.45\times10^{-2}(\theta)+6.85\times10^{-2}(\theta)^{1.5}+6.80\times10^{-2}(\theta)^2 + 8.30\times10^{-3}\ [1/\ell n\ (\theta)]$
$R^2=0.711^{**}$… for overall soil types

Table 2

Fig. 1

Pooling points from all soil (regions) increased scatter in K(θ) and reduced model R^2 reflecting spatial variability (Chen and Payne, 2001). The large disparity among results for K(θ) naturally raised the questions about the accuracy and appropriateness of the different models used in this study. It was reported that the predictive approach introduces a bias into the estimates of the K(θ) and a predictive approach with scaling did not significantly improve the estimates of the unsaturated hydraulic conductivity (Yates *et al.*, 1992). Pachepsky *et al.* (2000) reported that reducing the number of parameters and refitting the model to the data decreased the accuracy of estimation. Additionally, Chen and Payne (2001) reported the difficulty of extrapolating K(θ) outside the range of measured θ. Some functions can only fit the data in a limited range of soil water contents whereas the formulation of some other functions may lead to a mathematical problems when fitting conductivity data or during the simulation of subsurface flow and transport.

The BFD model appear to be accurate. Also, GIL, MVG, or CAM model could be an attractive alternative if their input parameters are reliable, especially where only limited data and financial resources are available.

Wösten *et al*. (2001) reported that the spatial variability of the basic soil properties is directly translated to variations in hydraulic characteristics and, subsequently, to variations in simulated functional soil behavior. In addition, the prediction error of a model results in variations in the predicted soil hydraulic characteristics.

Mecke *et al*. (2000) reported that high amount of organic matter in the surface horizons strongly retarded the water flow due to the change in pore size distribution by filling and blocking the flow channels. For example, the water content at –100 kPa, which depends on pore-size distribution and C content which produce a strong retarding effect on water flow were most important predictors for K at –35 kPa tension. Also, they reported that K at –0.35 kPa varied by a factor of 500 between sites.

Leij *et al*. (1996) reported that different types of conductivity data were well described by a Gardener (1958), Brooks and Corey (1964), and van Genuchten (1980), respectively. Poulsen *et al.* (1998) recommended calibration for the constant of the K(θ) model based on undisturbed soil data set.

Finally, it is strongly recommended that models should not be more accurate than data used in model development. The model is considered to be sufficient accurate if the average error does not significantly differ from zero (Wösten *et al*., 2001).

CONCLUSION

Predictive functions translate data *we have* into data *we need*. The criteria in used function are accuracy and reliability levels and desired, preferable and necessary input variables, and appropriate techniques to evaluate the function. The accuracy is that correspondence between measured and predicted data for the data set in which a predictive function has been developed. The reliability is that correspondence between measured and predicted data for the data set other than the one used to develop a predictive function.

Search for additional soil properties, as inputs in pedotransfer function are important directions for improving accuracy and reliability. However, the accurate measurement of hydraulic characteristics is the most important factor for future progress (Pachepsky *et al.*, 2000; and Wösten *et al*., 2001).

The study reflects the general applicability of the models to different regions to account for different nature and properties in addition to the spatial variability. The predictive regression models are useful for estimating the unsaturated soil hydraulic properties of large areas of land, but need improvement for application to specific sites (Lin *et al*., 1999). The usefulness of any statistical functions is limited to the data population used in their development. The empirical nature of pedotransfer function warrants their best use as starting points for quick and economic estimations of necessary model input parameters, particularly when a large number of hydraulic property data are required (Lin *et al*., 1999).

The formulation and validity of indirect methods relies on the availability and quality of directly measured data (Stolte *et al*., 1994; and Tomasella and Hodnett, 1997). As few data of K(θ) are currently available, further direct measurements are quite essential for developing and verifying new or existing predictive models (Borcher *et al*., 1987; and Wösten and van Genuchten, 1988). Any judgement about the accuracy of the predictive hydraulic functions should be based on the desired accuracy for management applications.

For all studied soils, the locally developed BFD model resulted in the lowest ME and its sd, and OB, as compared to the other studied models. It reveals a minimum error and a maximum precision in estimating K(θ). The comparisons of different models showed variations in their errors and precisions in predicting the K(θ) of the investigated soils. If a local model is not available, GIL, MVG, or CAM model is a reasonable alternative in K(θ) prediction. Due to the difficult in measurements and high spatial variability of K(θ), further intensive studies for all soil types in Egypt are needed to establish reliable predictions of K(θ) for all management and modeling purposes.

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توقع التوصيل الهيدروليكى غير المشبع لثلاث أنواع رئيسية من الأراضى المصرية

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تعد خاصية التوصيل الهيدروليكى غير المشبع كدالة للمحتوى الرطوبى للتربة على جانب كبير من الأهمية ونحتاج إليها فى العديد من النماذج الرياضية لوصف العمليات الهيدرولوجية وتدفق الماء بالتربة وفى الكثير من التطبيقات الزراعية مثل تقويم استخدام الأرض، تقدير الصرف، غسيل الكيماويات، وغيرها. وتعتبر قياسات التوصيل الهيدروليكى غير المشبع صعبة الأداء وتحتاج لجهد وتستهلك الكثير من الوقت بالإضافة إلى أنها عالية الاختلافات. وهذه المشاكل تحتم الاحتياج لعدد كبير من العينات والقياسات للحصول على قيم مناسبة من التوصيل الهيدروليكى غير المشبع للوقوف على خصائص مساحة من الأرض. وهذا بالطبع سوف يكون مكلفاً وغير ذات جدوى اقتصادياً. والبديل هنا عن هذه القياسات المباشرة هو استخدام العديد من النماذج الرياضية لتوقع التوصيل الهيدروليكى غير المشبع . ولقد حظيت الدالات البيدوتحويلية فى الآونة الأخيرة على الكثير من الاهتمام كأسلوب لتحويل صفات التربة البسيطة المتحصل عليها من حصر الأراضي إلى خصائص أكثر تعقيداً مثل التوصيل الهيدروليكى غير المشبع. ولقد تم إيجاد نماذج رياضية محلية كأفضل تمثيل للنتائج وذلك للتوقع الدقيق للتوصيل الهيدروليكى غير المشبع وهى ما نحتاج إليها بشده فى العديد من التطبيقات والنماذج الرياضية للأراضى المصرية.

ولقد تم تقويم نتائج العديد من النماذج الرياضية المستخدمة فى توقع التوصيل الهيدروليكى غير المشبع وذلك لثلاث أنواع من الأراضي المصرية وهى الرسوبية-البحيرية، الكلسية، والرملية. والنماذج الرياضية المقترحة للدراسة هى: المحلى كأفضل تمثيل للنتائج، كامبل (١٩٧٤)، جيلهام وآخرون (١٩٧٦)، موالم- فان جنختن (١٩٨٠)، راولز وبراكنسيك (١٩٨٩)، ساكستون وآخرون (١٩٨٦).

ولقد ظهر جلياً من هذه الدراسة أن النموذج الرياضى المحلى والناتج من أفضل تمثيل للنتائج هو الأفضل وصف التوصيل الهيدروليكى غير المشبع للأراضى المدروسة. فى حين كانت النماذج الأخرى متباينة فى نسبة الخطأ وفى دقتها مع أنواع التربة المختلفة. ولقد كانَ الخطأ النسبى لأى نموذج رياضى من أقصى قيمة متوسط خطأ نتج من عمليات التوقع هى ٢,٦ ، ٢٨,٦ ، ٧,٨ ، ٨٩,٦ ، ٩٣,٥ ، ١٠٠ % فى الأرض الرسوبية- البحيرية، وكانت ٣,٠ ، ٥٢,٧ ، ١١,٨ ، ٧٨,٨ ، ٨٢,٧ ، ١٠٠ % فى الأرض الكلسية، وكانت ٦,٠ ، ٧٩,٣ ، ٨٤,٧ ، ٩٢,٤ ، ١٠٠ ، ٦٦,٠ % فى الأرض الرملية ، وكانت ٥,١ ، ٦٨,٧ ، ٥٥,٦ ، ٩٣,٤ ، ١٠٠ ، ٨٦,٤ % لنتائج الأراضي الثلاث معاً وذلك لنماذج التوقع: المحلى كأفضل تمثيل للنتائج ، جيلهام وآخرون ، موالم- فان جنختن ، كامبل ، راولز وبراكنسيك ، ساكستون وآخرون ، وذلك على التوالى.