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Modelling as a tool of groundwater assessment

title:
Estimation of soil water retention curve parameters by Genetic Algorithm optimization technique

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INTRODUCTION

Transport of fluids through porous media, is of interest to scientists and engineers. Before predicting transport phenomena in a porous medium, its hydraulic properties (i.e., the water retention and hydraulic conductivity relationships) must be determined. The relationship between the volumetric water content and the soil water pressure can be described with a soil water retention curve (soil moisture characteristic curve) that plots the soil water pressure as a function of the soil water content. Recording the pairs of suction and the corresponding water content of the soil sample the soil water retention curve can be constructed (Hunt, Ewing, 2009).

A genetic algorithm (GA), a popular evolutionary computational method, was used for the optimization process to estimate the soil water retention curve (SWRC) based on van Genuchten model (1980) of soils samples and will be discussed further below.

HYDRAULIC PROPERTIES OF SOILS

The soil water content can be expressed by (θ):

$$\theta = \frac{V_l}{V_t} \tag{1}$$

Where V_l, and V_t be the liquid volume and total volume, respectively. In most hydrologic applications, volumetric soil water content is used in no dimensional form:

$$\theta^* = \frac{\theta - \theta_r}{\theta_s - \theta_r} \tag{2}$$

Conventionally, θ_S is referred to as the volumetric soil water content at natural saturation and θ_r as the residual volumetric soil water content.

MOISTURE CONTENT VS. DEPTH

From the ground surface to the top of the capillary fringe, the saturation ratio increases from zero to unity and will remain so to the bottom of the aquifer. The functional relationship of the moisture content and hydraulic conductivity of the unsaturated profile can be demonstrated by the use of soil-water characteristic curve or retention curve. At very low (negative) values of the pressure head (h), both the moisture content and hydraulic conductivity are at minimal values for the system. With increasing values of h, they increase to become constant at the top of the capillary fringe where the saturation index is unity, indicating full saturation (Fig. 1).

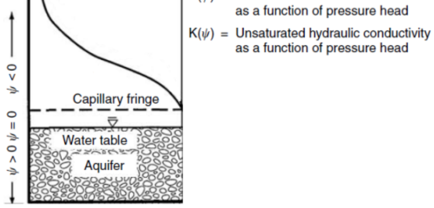

Figure 1. Soil moisture variation depending depth (Delleur, 2004).

SOIL WATER RETENTION MODELS

A SWRC is typically quantified by fitting experimental data to power law, hyperbolic, or polynomial functions (Brooks and Corey, 1946; van Genuchten, 1980). The van Genuchten (1980) model is most commonly used in numerical analyses because it is differentiable for the full range of suctions. Given the saturated, θs, and residual, θr, water contents, the effective saturation Se is defined by:

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \tag{3}$$

The following five-parameter van Genuchten function was used to the describe water retention data (van Genuchten, 1984):

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{\left[1 + (\alpha h)^n\right]^m} \tag{4}$$

Where θ is the soil moisture content (cm^3/cm^3), h is the soil water tension (cm), α, n, m are water retention shape parameters. The water retention shape parameters m and n are frequently related according to:

$$m = 1 - \frac{1}{n} \tag{5}$$

The α parameter controls capillary rising, while n and m parameters control shape and slope of the curve. Additionally, the van Genuchten SWRC is largely empirical and disconnected from basic soil properties, such as pore geometry and adsorption.

MATERIALS AND METHODS

Several techniques are available to determine the SWRC experimentally. A common test is the pressure plate test (Fig. 2), which involves placing a soil specimen on a high air-entry ceramic plate and applying air pressure to the specimen.

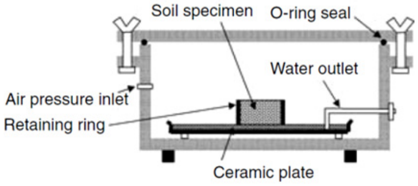

Figure 2. The pressure plate Conventional methods to determine the SWRC (Delleur, 2004).

Soils samples contain 6 soils from the Soil and Water Research Institute of Iran (SWRI) database according to the U.S. Department of Agriculture (USDA) soil textural classification were used to perfume the experimental part (Tab. 1). Retention data were obtained along the main drying curve at tensions of 1, 1.1, 1.33, 2, 3, 5, 10, 15 atm.

Table1. The soils samples used in our Analysis.

Soil type	% Clay	% Silt	% Sand
Loamy sand	6	10	84
Sandy loam	10	25	65
Silt loam	23	54	23
Loam	18	38	44
Sandy clay loam	30	18	52
Clay	57	21	22

GENETIC ALGORITHMS

Genetic algorithms (GAs) were invented by John Holland in the 1960s and were developed by Holland and his students and colleagues at the University of Michigan in the 1960s and the 1970s. Genetic algorithms use computational models of evolutionary processes as key elements in the design and implementation of computer based problem solving systems (Spears et al., 1993). GA has been shown to work well in noisy environments and in complex search spaces.

The GA begins, like any other optimization algorithm, by defining the optimization variables, the cost function. It ends like other optimization algorithms by testing for convergence. Genetic algorithms differ from more traditional search algorithms in that they work with a number of candidate solutions rather than just one or a partial solution (Mitchell, 1999).

A fitness function is designed such that fitness of individuals, or groups of individuals, moves toward an extremum if they carry some desirable traits. If the genes have only two alleles (0s and 1s), the chromosome is called a binary coded chromosome. If the genes are assigned real values, then the chromosome is called a real coded chromosome. Value encoding can be used in problems where values such as real numbers are used. Genetic algorithms start with randomly generating an initial population of possible solutions. The population size is the number of individuals that are allowed in the population maintained by a GA. If the population size is too large, the GA tends to take longer to converge on a solution.

The population is then operated by three basic operators in order to produce better offspring for the next generation. These operators are known as “reproduction”, “crossover” and “mutation” (Randy, Haupt, 2004).

Reproduction is a process in which individual strings are copied according to their fitness (Goldberg, 1989). In a crossover operation, one child chromosome is produced from “mixing” two parent chromosomes. Crossover probability controls that how often crossover will be performed. Crossover is made in hope that new chromosomes will contain good parts of old chromosomes and therefore the new chromosomes will be better. This procedure of crossover, mutation and selection is repeated over many generations until some termination criterion is fulfilled.

The fitness function (f) was based on the minimization of differences between measured and calculated water content values ($\theta_{m,s}$) , and ($\theta_{c,s}$), respectively; that is,

$$Cost = Fitness = f = \frac{1}{N}\sum_{s=1}^{N}\left(\theta_{m,s} - \theta_{c,m}\right)^2 \tag{6}$$

Where *n* is the number of water content measurements (*n* = 8).

The genetic algorithms parameters used in this study are listed in Table 2.

An interesting aspect of GA is that the initial population of individuals need not be very good. In fact, each individual of an initial population usually represents a randomly generated candidate solution. By repeatedly applying selection and reproduction, GA produces satisfactory solutions quickly and efficiently.

Table 2. GA parameters used in the model.

GA parameters	Value
Population size	1000
Number of generations	2000
Number of variables	4
Initial range	0–3
Type of genes/chromosomes	real coded
Crossover probability	0.5
Crossover procedure	heuristic
Type of selection	Roulette wheel
Minimum mutation rate	0.1
Maximum mutation rate	0.25

MATLAB MODELLING AND RESULTS

MATLAB is a commonly used program for computer modeling. The MATLAB Genetic Algorithm Toolbox is a collection of functions that extend the capabilities of the Optimization Toolbox. This Toolbox enables you to solve a variety of optimization problems that lie outside the scope of the standard Optimization technique. To use the Toolbox, you must first write an M-file that computes the function you want to optimize. The M-file should accept a row vector, whose length is the number of independent variables for the objective function, and return a scalar value. Our independent variables are van Genuchten model parameters (α, n, m, θ_s and θ_r). Matrix A represents these independent variables.

$$A = \begin{bmatrix} \alpha_{1,1} \ldots n_{1,2} \ldots \theta_{r,1,3} \ldots \theta_{s,1,4} \\ \alpha_{2,1} \ldots n_{2,2} \ldots \theta_{r,2,3} \ldots \theta_{s,2,4} \\ \ldots\ldots\ldots\ldots\ldots\ldots \\ \ldots\ldots\ldots\ldots\ldots\ldots \\ \ldots\ldots\ldots\ldots\ldots\ldots \\ \alpha_{n,1} \ldots n_{n,2} \ldots \theta_{r,n,3} \ldots \theta_{s,n,4} \end{bmatrix} \tag{7}$$

Where n in Matrix A is the number of Population size (*n* = 2000).

Evolution of the minimum cost of the genetic algorithm, which optimizes van Genuchten model parameters (α, n, m, θ_s and θ_r) appears in Figure 3. The algorithm found the best cost solution 0.007174 in 1000 generations.

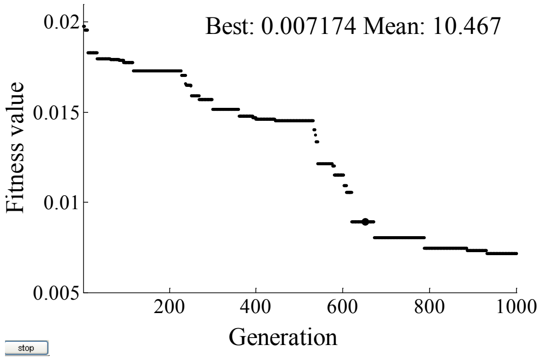

Figure 3. Convergence of the GA for the SWRC parameters optimizations.

On the basis of eqn. (4) we determined the Water retention curve and its parameters for soils samples of Tab. 1. The detailed description of van Genuchten model parameters (α, n, m, θ_s, θ_r) and regression coefficient (R^2) between measured and calculated volumetric water content (θ) values are showed in Table 2.

Table 2. Values of Parameters of water retention curve (α, n, m, θ_s, θ_r) and regression coefficient (R^2) obtained by GA model for soils samples of Table 1.

Soil type	**α**	**n**	**m**	**θ_r**	**θ_s**	**R^2**
Loamy sand	0.046	1.39	0.28	0.012	0.367	0.9966
Sandy loam	0.026	1.41	0.29	0.061	0.285	0.992
Silt loam	0.015	1.81	0.45	0.09	0.245	0.9988
Loam	0.01	1.53	0.342	0.056	0.308	0.9935
Sandy clay loam	0.0061	1.49	0.33	0.076	0.246	0.995
Clay	0.0057	1.81	0.447	0.146	0.546	0.9934

A sample of the experimental water retention curve and the predicted water retention curve for loamy sand sample based on the GA model are showed in Figure 4.

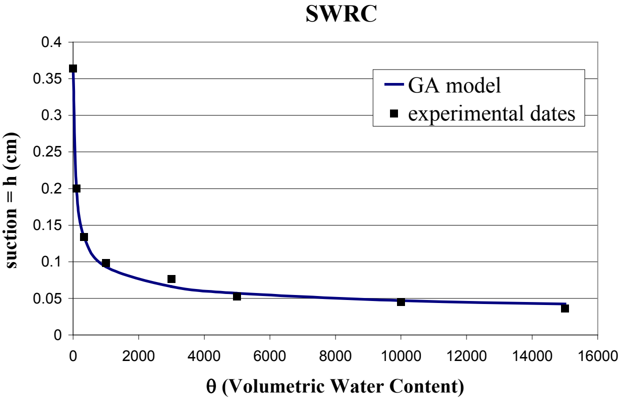

Figure 4. Predicted water retention curves for the Loamy sand soil Sample in Table 1. based on the van Genuchten model.

CONCLUSIONS

A Five-parameter van Genuchten type model was used to describe the water retention curves of our soils sample. In this study, the suitability of using the data driven GA for modeling the water retention curve process in six soils samples was studied. In all cases, GA was able to find the exact solution.

Analysis of the results shows that the increase of clay content in soils samples decreases the α parameter. Additionally, α parameter controls the capillarity phenomenon and n and m parameters controls steep of the SWRC. Results show an increasing value of n and m with increasing percent of fine grains nonlinearly and they have higher values in fine textured soil such as Clay and Sandy clay loam respect to coarser textured soil such as Loamy sand and Sandy loam soils samples. We also observed from the model results that it is not only the three shape parameters (α, n, m) are important, but also the θ_r and θ_s are significant.

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