IDW Interpolation of Soil Moisture Retention Curve Utilizing GIS

Huda W. Abdulwadood¹,a, Gheidaa S. H. Al-Hassany¹, and Reem I. Mustafa¹,b
¹College of Science, University of Baghdad, Baghdad, Baghdad, Iraq.
²eng_huda_wajood@yahoo.com, b_reem.ibrahim7@yahoo.com
Corresponding author

Abstract. This search aim to analyse the Soil Moisture Retention Curve (SMRC) by spatial interpolation mapping using Inverse Distance Weighted scheme (IDW). The SMRC is a Graphical Representation the mathematical relationship between the metric suction of soil (it represents the difference between the pore of air pressure (uₚ), and the pore of water pressure (uₚ₅) and either soil water contents (volumetric and gravimetric) or S (degree of saturation). The soil samples were obtained from three locations of Baghdad University by drilling pits of depth 0.5 to 1 m under the ground level. An extensive Laboratory Testing Program was performed on the studied samples. Rosetta program was utilized to estimate Unsaturated Hydraulic properties from the data of surrogate soil such as the data of soil texture and bulk density. After obtaining the properties for the three soil samples applying IDW spatial interpolation techniques by utilizing the Arc Map-GIS program on a satellite image of the Landsat-8 satellite with a high recognition accuracy for studding properties for the areas surrounding calculated points.

Keywords: Inverse distance weighting; GIS; partially saturated soil; moisture retention curve; water characteristic curve

1. Introduction
1.1 Soil Moisture Retention Curve
The soil water characteristic curve (SWCC) which also called soil moisture retention curve (SMRC) describes the amount of water retained in a soil (expressed as a volume or mass of water content, θ, or θᵢₚ) under equilibrium of a known (MP). A SWCC is an important hydraulic property which related with volume and connect ends of pore spaces. Matric potential is mostly formed at a logarithm progression. Typical SWCC of various textures were illustrated in Figure 1 to demonstrate the porosity effects and different curves of the resulted relationships of a variables pore magnitude distribution.

1.2 SWCC measurement relationships
Different techniques utilized to determine requisite θₜₐₚ values for estimating the SWCC. Potentially experimental troubles are including the limit functionally range of tension-meter (tension meter). It is mostly utilized of instiit (at location) measurements, inaccurate θ measurements of several states, the poverty of obtain undisturbed samples of the laboratory accounts and tardy rates of equilibrium under low MP (matric suction). In situ techniques are active to characterize SWC’s and measurement above a widely range values of ψₚₜₐₚ-θ. The installation of time domain reflectometry (TDR) is representing an active method to obtain simultaneous measurements of θₜ (volumetric water content) and ψₚₜ (matric suction). The probes of TDR are in close proximity to transducer tension meters with a monitoring attribute (during variable soil wetness). High changes of θₜ and ψₚₜ would expect when highly evaporative conditions occur nearly of the soil surface, or in the presence of active plant roots.
Figure 1. SWCC of various textures.

2. Mathematical-models to estimate SWCC
In both management and research of problems involving flow and transport processes of the sub-surface, the population of Mathematical-Models has increased. Unsaturated-hydraulic functions represent the key to the input data for vadose zone processes of numerical-models. It is possible to obtain UHFs in two ways: first, directly (by measurement). Second, indirectly calculated based on the use of quasi-empirical models, by prediction of more easily measured results. Using Rosetta (V1.0) to estimate unsaturated-hydraulic-properties of surrogate-soil data such as bulk-density and soil-texture data is a Windows-95/98 application. When they transform the basic soil data into hydraulic properties, models of this kind are known as Pedo-Transfer-Functions (PTFs). To estimate the following properties, Rosetta may be used:

- Water-Retention-Parameters [1].
- Hydraulic-saturated-conductivity [1].
- Unsaturated-Hydraulic-Conductivity-Parameters (UHCP)
- Comprehensive description of the hydraulic functions Rosetta provides five PTFs that allow limited or more extended sets of input data to predict the hydraulic properties.

2.1 Input and output data
Rosetta program is based on ACCESS- 97 (database tables which let efficient handling and look-up of Data of small and large volumes). Data may be either manually input or read from the files. The estimated Hydraulic Properties may be exported in the files and applied in other programs.

2.2 The download and install of Rosetta
The compressed file ROSETTA.EXE may be downloaded from the software download site of user. The download of the file ROSETTA.EXE (about 3 MB) is: First, store it in a temporary directory. Second, run it of the Windows Start menu (i.e. start, run). Third, go to the Start menu again. Fourth, run SETUP.EXE from the same directory used for ROSETTA.EXE. These steps will install Rosetta on the user PC. Rosetta will operate around 6 MB of disk space. (needs 32-bit Windows).

3. GIS technique and IDW interpolation
3.1 GIS technique
Geographic Information System (GIS) or geographic (or geographical) information science firstly was utilized at the date 1950’s in the North of America, mostly with maps automated production. GIS
presents a system of management, analysis and display of Geographic Information. Typically, the representation of Geographic Information is by a series of geographic datasets that lets the model geography utilizing be simple and generic data structures. To work with geographic data, GIS is including a set of comprehensive tools [2].

GIS is powerful computer-based tools such as the capture, storage, management, retrieval, analysis, and spatial data presentation. GIS ability (spatial data processing and the availability of analyses tools) can be utilized for management of a wide range of data. GIS lets the integration, derivative and creation of disparate data sets not complex. GIS facilities the development and analysis of spatially explicit variables. The integration has the potential to present a powerful analytical toolbox. It is enabling the regional and social scientists to gain fundamentals insight into the nature of spatial structures of regional development [3-5].

GIS techniques have been widely utilized in different fields, such as agriculture, ecology, forestry, environmental management, mining and geosciences, and remote sensing. Users use GIS more commonly to make maps. Also, GIS techniques may be utilized as a powerful analysis tool. It may be utilized to setting up and join spatially and descriptively data for problem of solving spatially modelling and for presenting the results in: tables, maps or graphics. Probably, the ability of it for integrating databases, through their spatially relationships, that could be sometimes impossible to do outside the GIS environment is present the mostly powerful feature of GIS of a planner’s perspective [6].

Arc-GIS Desktop Products include Arc-Reader, Arc-View, Arc-Editor and Arc-Info, which are utilized for creating, importing, editing, querying, mapping, analyzing, and publishing Geographic Information. Every one of them is provide a high-level functionality. Each Arc-GIS Desktop is product a share common architecture, so any user may share his work with other users. Arc-Map, Arc-Catalogue, Arc-Toolbox, Model-Builder and Arc-Globe are Arc-GIS Desktop applications. They may be utilized in a union to: perform maps, geographically analysis, data management and storage, data editing and compilation, geo-processing, and visualization [7].

3.1.1 Interpolation techniques (IT)
Interpolation is the process of utilizing known data values for estimating unknown data values. Various IT are often utilized on atmospheric sciences. Linear interpolation (LI) (one of the simplest methods) is require a knowledgegment of two points and the constant rate of changes between the two. These methods are mostly used on station datasets of irregular spacing among stations. Interpolation can predict values of cells in a raster of a limited account of sample data points. It may be utilized for predicting unknown value of any geographic point data like elevation, rainfall, and noise levels. “Spatial interpolation is the procedure of estimating the values of properties at non sampled sites within an area covered by existing observations.” The estimations of about all Spatial Interpolation techniques may be presented as weighted averages of the sampled data. They all have share of the general estimation formula, as following:

\[ \hat{z}(x_0) = \sum_{i=1}^{n} \lambda_i z(x_i) \]  

where \( \hat{z} \) represents the estimating value of an attribute at the location of interest point \( x_0 \), \( z \) represents the observing value at the sampled point \( x_i \), \( \lambda_i \) represents the weight assigned for the sampled point and \( n \) is the number of sampled points utilized of the estimation. So, the attribute is usually known as the primary variable (especially in geostatistics field) [8].

3.1.2 Interpolation method types
1) Deterministic Interpolators (DI): makes predictions of the mathematically formulas that forming the weighted averages for the nearby known values.
   i) Local: -Inverse Distance Weighting (IDW), Nearest Neighbor, Fixed Radius and SP lines.
   ii) Global: -Classifications, Trend Surfaces and Regressions.
2. Geo-statistics interpolators (GI): uses weighted averages, in addition to probability models to make predictions of Kriging (optimal weighting interpolation), Co-Kriging.

3.2 IDW Interpolation
IDW Interpolation is implement a basic law of geography: Things that are close to each other are more alike than those that are not close. To estimate a value of any unknown location, IDW utilizes the known surrounding values of the estimation location. These measured values (closest to the estimation location) are having high influence on the estimated value than the others that are not closest (for this rezone, it Known inverse distance weighted). The included values of the calculation may be obtained by a specification and customization of the search neighborhood, which representing the regions of the map around the interested point, in which the data points are dependent of the extrapolation [9]. IDW represents an "exact" Interpolator; it means the estimations will be exactly equal to the measured value when the estimation occurs at location where data has been collected. Basically, this method is depending on the predicting of the height of the unknown points by computing the distances among the measured point to the other known points. It is mathematically represented as follows:

\[
 z(x, y) = \frac{\sum_{i=1}^{n} \frac{z_i}{d_i^p}}{\sum_{i=1}^{n} \frac{1}{d_i^p}} 
\]

\[
 z(x, y) = \sum_{i=1}^{n} \lambda_i \times z_i \text{Where} \sum_{i=1}^{n} \lambda_i = 1 
\]

\[
 d_i = \sqrt{(x_i - x)^2 + (y_i - y)^2} 
\]

Where \( z(x, y) \) represents the estimated value at the unmeasured location \((x, y)\); \( i \) represents the number of sample points in the defining neighborhood; \( z \) and the known location \( i \); \( \lambda_i \) is the distance dependent weight associated with each known point; and \( p \) represents the power parameter that is define the rate reduction in the weight as the distance increasing [10].

4. Study area and soil sampling
This research includes experimental work. The experimental work can be explained by testing program, as shown in Figure 2, and containing a detailed description of the perform laboratory tests. In this research, three soil samples had collected of various locations. The locations were chosen in Baghdad University (inside Al-Jadriyah district).

4.1 Soil sampling
Three soil samples (disturbed and undisturbed) were obtained from three locations inside the campus of University of Baghdad at Al-Jadriyah district. The designation of soil samples used in tests are described below:
- The first sample was obtained of the site of College of Science.
- The second sample is obtained of the site of College of Engineering.
- The third sample is obtained of the College of Agriculture.

4.2 Study area and coordinates
The region is University of Baghdad. By utilizing differential global position system (DGPS) of type Topcon Hyper-II, its survey was obtained. The Coordinate System of the studied Data Set was adopted as a Geographic and Projection Coordinate System by: WGS84/UTM- ZONE38. The differential GPS (DGPS) is the basic concept of correcting and augmenting the GPS position solution. DGPS is based on the principle that all receivers in the same vicinity simultaneously experience common errors. There are
three elements where the DGPS system is composed of, which includes firstly, at a known location, an antenna of GPS receiver (base station), secondly, at an unknown location, another GPS receiver (user receiver) and finally, between these two receivers, a communication medium is present. The used DGPS in this study is the Topcon Hipper-II receiver belonged to the Remote Sensing Unit/College of Science/University of Baghdad. The Hipper-II receiver is a multi-frequency Global Navigation Satellite System (GNSS) receiver. The coordinates of the soil sampling locations are given in Table 1.

![Figure 2. The research graphic.](image)

| Location             | Easting (m) | Northing (m) | Elevation (m) |
|----------------------|-------------|--------------|---------------|
| College of Science   | 442354.444  | 3681992.205  | 23.209        |
| College of Engineering| 442101.869  | 3681446.882  | 26.667        |
| College of Agriculture| 441755.035  | 3681647.5    | 25.167        |

5. Results and discussion

5.1. Determination of moisture content

The Moisture Content of soil sample is defined as the mass of water in the sample expressed as the percentage of the dry mass (usually heating at 105°C).

\[
\text{Moisture Content, } \omega = \frac{M_w}{M_d} \times 100 \text{ (\%)}
\]

Where

- \( M_w \) = Mass of water.
- \( M_d \) = Dry mass of soil sample.

The results of water content for the three locations are given in Table 2. From the results, it can be seen that the lowest water content (20%) at the site of College of Agriculture and the highest water content (23%) is at the site of College of Science. This deviation in water content is clear in Figure 3 shows the variation in water content inside the campus of University of Baghdad produced by IDW utilizing from GIS technique. The elevation of ground with respect to the sea level may be the main cause of this result.
Table 2. The results of moisture content and grain-size distribution of tested soils.

| Sample                        | Water content, % | Sand, % | Silt, % | Clay, % |
|-------------------------------|-----------------|---------|---------|---------|
| Sample one (College of Science) | 23              | 5       | 76      | 19      |
| Sample two (College of Engineering) | 21              | 5       | 76      | 19      |
| Sample three (College of Agriculture) | 20              | 5       | 74      | 21      |

Figure 3. The IDW interpolation of the results of moisture content tests.

5.2 Particle-size distribution

Grain size distribution was obtained by Sieve Analysis which was conducted in accordance with ASTM D422-02 (dry sieving) which is a suitable technique for cohesionless soils (coarse grained soils) with little or no fines. Also, utilizing kerosene as non-polar solvent (wet sieving). The wet sieving technique included washing the Soil Samples upon sieve No. 200 is oven dried at 45°C and then analyzed utilizing dry and wet sieving.

The results of particle size distribution for three locations are given in Table 2 and Figure 4. According to the results of tests, the soil of three locations is mainly silt (about 76%) with approximately constant percentage of sand (5%), and small deviation in the percentage of clay. Also, using IDW interpolation with the aid of GIS technique, three thematic maps can be produced for the variation of sand, silt, and clay as shown in Figures 5 to 7.
Figure 4. Particle-size distribution curve of the tested soil samples.

Figure 5. Distribution of sand in the soil of the site of University of Baghdad using IDW.
Figure 6. Distribution of silt in the soil of the site of University of Baghdad using IDW.

Figure 7. Distribution of clay in the soil of the site of University of Baghdad using IDW.
5.3 Atterberg’s limits (LL and PL)

The liquid and the plastic limits were performed depending on the procedure of ASTM designed as D4318-00. The result of tests is given in Table 3. The thematic maps showing the variation of liquid limit, plastic limit, and plasticity index produced using IDW and GIS techniques are given in Figures 8 to 10.

Table 3. Atterberg’s limits and specific gravity of tested soil samples.

| Sample              | Liquid limit, % | Plastic limit, % | Plasticity Index, % | Specific gravity |
|---------------------|-----------------|------------------|---------------------|------------------|
| College of Science  | 29              | 19               | 10                  | 2.68             |
| College of Engineering | 30          | 14               | 16                  | 2.60             |
| College of Agriculture | 40          | 29               | 11                  | 2.70             |

Figure 8. Variation of liquid limit in the soil of the site of University of Baghdad using IDW.

Figure 9. Variation of plastic limit in the soil of the site of University of Baghdad using IDW.
Figure 10. Variation of plasticity index in the soil of the site of University of Baghdad using IDW.

5.4 Specific gravity

Be attention to determine representative samples of a SGT. It is easy to start the test with an oven-dried sample. So, some soils (particularly those with a high organic content), are not easy to rewet. These must test at their natural water content and obtain the oven-dried weight (at the end of the test). The results of test are given in Table 3 and map of variation of specific gravity of soil in the campus of University of Baghdad is shown in Figure 11.

Figure 11. Variation of specific gravity in the soil of the site of University of Baghdad using IDW.

5.5 Field density

FDT was performed depending on ASTM D1556-00 to find the density of the soil in the field by the sand cone method. The results of tests are reflected in thematic map showing the variation of filed density in the campus of University of Baghdad, see Figure 12.
Figure 12. Variation of field density in the soil of the site of University of Baghdad using IDW.

6. Soil water characteristic curve from Rosetta program

The results of variation of matric suction with the moisture content for three types of soil tested in this study are given in Table 4 and Figure 13. The results obtained using Rosetta program depending on Van Genuchten (1980) model. The input data used in this study are given in Table 5 and the output data obtained using IDW utilizing from Rosetta program are given in Equation 6. The parameters of Eq. 6 are given in Table 6.

\[ \theta(h) = \theta_r + \frac{\theta_s - \theta_r}{[1 + \alpha |h|^n]^m} \]  

(6)

Table 4. The variation of moisture content with matric suction for the soil samples.

| Matric suction (kPa) | College of Science | College of Agriculture | College of Engineering |
|----------------------|--------------------|------------------------|------------------------|
| 0.1                  | 0.48559935         | 0.526099164            | 0.463299461            |
| 10                   | 0.484308819        | 0.524563643            | 0.462168539            |
| 50                   | 0.468470636        | 0.50636742             | 0.447928532            |
| 100                  | 0.43895444         | 0.473355818            | 0.420796059            |
| 200                  | 0.380377408        | 0.409499125            | 0.365625161            |
| 330                  | 0.324353595        | 0.34952463             | 0.311805801            |
| 500                  | 0.277434327        | 0.299656454            | 0.266283536            |
| 1000                 | 0.21121959         | 0.229282121            | 0.201802803            |
| 2000                 | 0.164387076        | 0.179156603            | 0.156319174            |
| 3000                 | 0.14470433         | 0.157912782            | 0.13730136             |
| 5000                 | 0.126070558        | 0.137652364            | 0.119385347            |
| 10000                | 0.108808534        | 0.118697448            | 0.102899942            |
| 15000                | 0.101766773        | 0.110890974            | 0.096219335            |
Figure 13. Soil water characteristic curve from Rosetta program using Van Genuchten (1980) model.

Table 5. Input data of Rosetta program.

| Results of grain-size | College of Science | College of Agriculture | College of Engineering |
|------------------------|--------------------|------------------------|------------------------|
| Sand                   | 5                  | 5                      | 7                      |
| Silt                   | 76                 | 74                     | 75                     |
| clay                   | 19                 | 21                     | 18                     |

Table 6. Output data of Rosetta program.

| Parameter | Eq. 6            | Site                                |
|-----------|------------------|-------------------------------------|
| θs        | 0.4856           | College of Science                  |
|           | 0.5261           | College of Agriculture              |
|           | 0.4633           | College of Engineering              |
| θr        | 0.0784           | College of Science                  |
|           | 0.0842           | College of Agriculture              |
|           | 0.0745           | College of Engineering              |
| α         | 0.0054           | College of Science                  |
|           | 0.0056           | College of Agriculture              |
|           | 0.0052           | College of Engineering              |
| n         | 1.6503           | College of Science                  |
|           | 1.6334           | College of Agriculture              |
|           | 1.6621           | College of Engineering              |
| m         | 0.394049567      | College of Science                  |
|           | 0.387780091      | College of Agriculture              |
|           | 0.398351483      | College of Engineering              |

7. Conclusion
In Baghdad University, three soil samples were obtained (disturbed and undisturbed sample). These samples were: Collected and sieve analysis, Atterberg limits, water content test and specific gravity test. Sieve analysis has determined the grain size distribution curve of soil. The Atterberg’s limits have determined the Liquid Limit and Plastic Limit of soil. The ranges of Liquid Limit are between 29% and 40%, then Plastic Limit range is between 14% and 29%. The Plasticity Index was determined out to be in the range of (10 – 16). The specific gravity was determined too. About the specific gravity Test, the values of Specific Gravity of the soil samples are between 2.6 and 2.7. These geotechnical parameters were used as guideline of this region. This work reveal that integrative utilization of field investigations, laboratories test, and spatial techniques is optimized for experimental results modelling and simulation specially when each sample demands many lab tests and generate lots of results (i.e. when the field samples were not too many but had a well distribution across the region of interest.
References

[1] Van Genuchten, M.T., 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil science society of America journal, 44(5), pp.892-898.

[2] Abdulwadood, H.W., Hadi, G.S., Ibrahim, O.A. and Mustafa, R.I., 2020. Comparison the accuracy of computing point coordinats between different instruments and applications of GPS. The Iraqi Journal of Agricultural Science, 51(4), pp.1149-1159.

[3] AC00599609, A. ed., 1992. Understanding GIS: The Arc/Info Method. Environmental Systems Research Institute.

[4] Karkush, M.O., Zaboon, A.T. and Hussien, H.M., 2013. Studying the effects of contamination on the geotechnical properties of clayey soil. Coupled phenomena in environmental geotechnics, pp.599-607.

[5] Karkush, M.O., Ahmed, M.D., Sheikha, A.A.H. and Al-Rumaithi, A., 2020. Thematic maps for the variation of bearing capacity of soil using SPTs and MATLAB. Geosciences, 10(9), p.329.

[6] Corey T. 1999. Using ArcToolbox, ISBN: 1-879102- 98- 6, ESRI, USA.

[7] ESRI websit, ESRI history, 2005. http://www.esri.com/company/about/history.html, Access 10-21.

[8] Webster, R. and Oliver, M.A., 2007. Geostatistics for environmental scientists. John Wiley and Sons.

[9] Surfer (tm) help for windows version 6.xx Golden software incorporated, help for Surfer package, (1995).

[10] Israa, J.M., 2010. High resolution digital elevation model (DEM) for University of Baghdad campus. Doctoral dissertation, Ph. D. Thesis, College of Science, University of Baghdad.