Infiltration and Some Physical Properties of Soil

Haqqi I. Yasin  
haqqiismail56@gmail.com

Entesar M. Ghazal  
entesarzal@gmail.com

Dams and Water Resources Engineering Department, Collage of Engineering, University of Mosul

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ABSTRACT

The research aims to study the effect of some physical properties of the soil as soil components of sand, silt, and clay, as well as bulk density, and the initial soil moisture, on both cumulative infiltration depth, infiltration rate, and basic infiltration rate. Depending on data of 31 laboratory infiltration tests represented by 516 values for cumulative infiltration depth and cumulative infiltration time, including a wide range of change in soil physical properties. Using the statistical program (SPSS), and by applying the nonlinear regression method, the best empirical equation has been derived to estimate the cumulative infiltration depth, with a determination coefficient of 0.975, as a function of some physical properties of soil and in the form of Kostiakov’s equation to include estimation of basic infiltration rate.

Key words: Infiltration, Initial soil moisture, Bulk density, Soil texture.

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1. INTRODUCTION

Infiltration is the process of water entering the soil through its surface. The main forces that cause the infiltration process are the capillary forces that originate from the adhesion forces between water molecules and soil particles and the Earth’s gravitational force [2-1].

The infiltration process is affected by many factors, including soil bulk density, initial soil moisture, soil type, soil structure and soil organic matter, and other physical and chemical properties of the soil [3]. Kostiakov equation is one of the oldest and most common positivist equations to describe infiltration of water in soil [4]:

\[ D = CT^M \]  

(1)

Where \( D \) is the cumulative infiltration depth (mm), \( T \) is the cumulative infiltration time (min), \( C \) and \( M \) constants. To obtain an equation to describe the infiltration rate, equation (1) is differentiated with respect to time as follows [1]:

\[ I = 60*C*M*T^{M-1} \]  

(2)

Where \( I \) is the infiltration rate (mm/hour), and to obtain the basic infiltration rate \( Ib \) (mm/hour) is done from equation 2 at infiltration time \( T \) equals the infiltration time \( Tb \) (min), which is found as follows [1]:

\[ Tb = \frac{600*(M-1)}{C} \]  

(3)

Several mathematical models describe the infiltration and the factors affecting it. Two equations were devised to estimate the cumulative
infiltration depth for different initial moisture levels and from higher to lower moisture level or vice versa [5]. Multiple linear relationships were found between soil infiltration rate and some physical properties that represent moisture content, silt content, clay content, bulk density and soil organic matter using data for 100 field infiltration tests [6].

In addition, multiple linear relationships were found between the basic infiltration rate and some physical properties that represent the moisture content, proportions of soil components of sand, silt, clay, bulk density, soil particle density, and soil organic carbon using data for 25 field infiltration tests in loam and loamy sand and sandy loam soils [7].

In a laboratory study, fine and coarse soil were mixed in seven different ratios (fine / coarse), and an infiltration test was performed for each mixture to know the infiltration rate over time. An equation was proposed in a polynomial formula, and results show that from knowing the mixing ratio, the infiltration rate can be estimated as a function of this ratio and time with the constancy of other factors at the fine mixing ratio [8].

Despite the numerous research to study the infiltration that covers some of the physical factors affecting the water infiltration ends by devising an empirical equation, it expresses either both the cumulative infiltration depth and the infiltration rate or it expresses the basic or final infiltration rate. Where there is no empirical equation covering several physical factors affecting the cumulative infiltration depth, infiltration rate and basic infiltration rate.

Therefore, the study deals with devising an equation that includes cumulative infiltration depth, infiltration rate and basic infiltration rate, in the form of Kostakov’s equation, and to cover the effect of physical factors within the equation coefficient so that the basic infiltration rate can be easily expressed as well.

2. MATERIALS AND METHODS:

2.1. Data:

Data were approved for 31 laboratory tests of infiltration conducted by [8, 9, 10, 11, 12, 13, 14, 15], represented by cumulative infiltration depth and cumulative infiltration time. Table (1) displays the soil texture, the percentages of soil

<table>
<thead>
<tr>
<th>Reference</th>
<th>Data</th>
<th>Texture</th>
<th>% Sand</th>
<th>% Silt</th>
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components such as sand, silt, and clay, in addition to initial soil moisture and bulk density adopted in soil compaction for all tests.

2.2. Infiltration estimation:

With 516 values for cumulative infiltration time T (minutes), volumetric initial soil moisture Mc and bulk density of Bd (g/cm$^3$) and percentage of soil components of sand $S_a$, Silt $S_i$, and clay $Cl$. Using the Special Program for Statistical System (spss), and by applying nonlinear regression method, the best empirical equation was devised to estimate the cumulative filtration depth as a function of the above factors and in the following form:

$$D = 2.403 \times T^{0.539} \times Bd^{-1.934} \times Mc^{-0.25} \times [51.734 \times S_a^{12.366} \times 3.271 \times Si^{22.978} \times 1.169 \times Cl + 2.24]$$

\[ (4) \]

By differentiating equation 4 with respect to time, the infiltration rate $I$ is obtained, and when it is expressed in mm / hour, it is as follows:

$$I = 77.713 \times T^{-0.461} \times Bd^{-1.934} \times Mc^{-0.25} \times [51.734 \times S_a^{12.366} \times 3.271 \times Si^{22.978} \times 1.169 \times Cl + 2.24]$$

\[ (5) \]

Since the formula of Equation 4 is similar to the formula of Equation 1, therefore, the basic infiltration time is equal to 276.6 minutes. Thus, the basic infiltration rate $I_b$, expressed in mm / hour, as follows:

$$I_b = 5.818 \times Bd^{-1.934} \times Mc^{-0.25} \times [51.734 \times S_a^{12.366} \times 3.271 \times Si^{22.378} \times -1.169 \times Cl + 2.24]$$

\[ (6) \]

3. RESULTS AND DISCUSSION

Figure (1) shows a comparison between the cumulative infiltration depth measured from the above-mentioned tests and the estimated cumulative infiltration depth from the inferred equation. Equations 4, 5 and 6 were adopted in drawing relationships to illustrate the effect of initial soil moisture, soil bulk density, and soil texture on both the cumulative infiltration depth, the infiltration rate, and the basic infiltration rate.

\[ \text{Figure (1): The comparison between the measured infiltration depths and estimated from equation (4).} \]

3.1. Effect of initial soil moisture on infiltration:

Figure (2) shows the relationship between the cumulative infiltration depth and time in loamy soil having a bulk density of 1.45 g / cm$^3$ and for different levels of initial soil moisture. It is evident from the figure that the cumulative infiltration depth increases with time, and increases with the decrease in the initial moisture, and that increase is greater as the initial moisture decreases. Figure (3) presents the relationship of the infiltration rate with time in loamy soil having a bulk density of 1.45 g / cm$^3$ and for different levels of the initial soil moisture. The figure shows that the infiltration rate decreases with time and with the increase in the initial soil moisture. Figure (4) presents the relationship of basic infiltration rate and the change in bulk density of loamy soil for different levels of soil moisture. It is evident from the figure that the basic infiltration rate decreases with the increase in the bulk density, and that at any specific value of the bulk density, the basic infiltration rate increases with the decrease in the initial soil moisture, and that increase is greater at lower initial moisture.

Figure (5) presents the relationship between relative infiltration and relative initial soil moisture, relative infiltration can be a relative cumulative infiltration depth, relative infiltration rate, or relative basic infiltration rate.
The values for the cumulative infiltration depth \( (D_0, D_1, D_2, D_3, \ldots) \) at the same infiltration time, or the values for the infiltration rate \( (I_0, I_1, I_2, I_3, \ldots) \) at the same infiltration time. Or the values of the basic infiltration rate \( (I_{b0}, I_{b1}, I_{b2}, I_{b3}, \ldots) \) at soil initial moisture \( (M_{c0}, M_{c1}, M_{c2}, M_{c3}) \). The relative values of the accumulative infiltration depth are \( \left( \frac{D_0}{I_0}, \frac{D_1}{I_1}, \frac{D_2}{I_2}, \frac{D_3}{I_3}, \ldots \right) \). The relative values of the infiltration rate \( \left( \frac{I_0}{I_{b0}}, \frac{I_1}{I_{b1}}, \frac{I_2}{I_{b2}}, \frac{I_3}{I_{b3}}, \ldots \right) \). The relative values of the basic infiltration rate \( \left( \frac{M_{c0}}{M_{c0}'}, \frac{M_{c1}}{M_{c1}'}, \frac{M_{c2}}{M_{c2}'}, \frac{M_{c3}}{M_{c3}'}, \ldots \right) \). Based on equations 4 and 5 at the same infiltration time and equation 6 the following equation obtained:

\[
\frac{D_1}{D_0} = \frac{I_1}{I_0} = \frac{I_{b1}}{I_{b0}} = \left( \frac{M_{c1}}{M_{c0}} \right)^{0.25} \quad \text{............(7)}
\]

This equation is presented in Figure (5), in which it is clear that the relative infiltration, whether it is the relative cumulative infiltration depth, relative infiltration rate, or relative basic infiltration rate, decreases with the increase in the relative initial moisture according to equation (7).
3.2. Effect of bulk density on infiltration

Figure (6) presents the relationship of the cumulative infiltration depth with time in loamy soil having initial moisture of 10.5% and for different values of bulk density. The figure shows that the cumulative infiltration depth increases with time and with a decrease in bulk density. Figure (7) shows the relationship between infiltration rate and time in loamy soil having initial soil moisture content of 10.5% and for different values of bulk density. The figure shows that the infiltration rate decreases with time and with increasing bulk density. Figure (8) also shows the relationship between the basic infiltration rate with the initial soil moisture of a loamy soil for different levels of soil bulk density. It is evident from the figure that the basic infiltration rate decreases with the increase in the initial soil moisture, and that at any specific value of the initial soil moisture, the basic infiltration rate increases with the decrease increases with time and with a decrease in the bulk density. Figure (9) shows the relationship between relative infiltration with relative bulk density, relative infiltration, which was defined above, and the relative values of soil bulk density based on equations 4 and 5 and at the same infiltration time and equation 6 results:

$$\frac{D_i}{D_0} = \frac{I_i}{I_0} = \frac{I_b}{I_{b0}} = \frac{B_d}{B_{d0}} = 1.934$$  \(\ldots\) (8)
effect of relative bulk density is much greater than the effect of relative initial moisture content on relative infiltration.

3.3. Effect of soil texture on infiltration
Figure (10) shows the relationship between the cumulative infiltration depth and infiltration time for different soil textures having initial soil moisture content of 10.5% and a bulk density of 1.45 g/cm³. The figure shows that the accumulative infiltration depth increases with time and with increasing coarse soil particles. Figure (11) presents the relationship between the infiltration rate and infiltration time with a bulk density of 1.45 g/cm³ and an initial moisture content of 10.5% for soils of different textures. The figure shows that the infiltration rate decreases with time and with decreasing coarse soil particles.

Figures (12-14) shows the variation of the basic infiltration rate for different soil textures, and different values of bulk density for a specified level of initial soil moisture (3.5%, 10.5% or 17.5%) respectively. From these figures, it can be seen that the basic infiltration rate increases with increasing coarse soil particles and decreasing the initial soil moisture. The basic infiltration rate also increases with a decrease in the bulk density, and this increase increases as the initial soil moisture decreases. It is also found that the effect of the bulk density change, from 1.25 g/cm³ to 1.65 g/cm³, indicating the change in soil structure, on the basic infiltration rate is greater than the change of soil texture from clay to other textures up to the sandy mix.

Determining the value of the basic infiltration rate for a specific soil texture at a specific initial moisture and bulk density was done by calculating the rate for the values of the basic infiltration rate for a group of soils of varying proportions of their components of sand, silt and clay, but representing the same texture.

Figure (15) shows the relationship between the relative infiltration with relative sand value, the relative infiltration defined
Figure (10): The relationship of the cumulative infiltration depth with time for different soil textures having initial soil moisture content of 10.5% and a bulk density of 1.45 gm/cm³.

Figure (12): The variation of the basic infiltration rate for different soil textures its initial moisture 3.5% at different values of bulk density.

Figure (11): The relationship of the infiltration rate with time for different soil textures having initial soil moisture content of 10.5% and a bulk density of 1.45 gm/cm³.

Figure (13): The variation of the basic infiltration rate for different soil textures its initial moisture 10.5% at different values of a bulk density.
Above, the relative values of sand are
\( \left( \frac{S_{a_0}}{Sa_0}, \frac{S_{a_1}}{Sa_1}, \frac{S_{a_2}}{Sa_2}, \frac{S_{a_3}}{Sa_3}, \ldots \right) \). Based on equations 4 and 5 at the same infiltration time and equation 6 results:

\[
\frac{D_i}{D_0} = \frac{l_i}{l_0} = \frac{l_{bi}}{l_{b0}} = 51.734 \times S_{ai}^{12.366} - 3.271
\]

\( S_{i}^{12.978} - 1.169 \times (1-S_{ai}) + 2.24) / 51.734 \times S_{ai}^{12.366} - 3.271 \times S_{i}^{22.978} - 1.169 \times (1-S_{ai}) + 2.24\]

\[\ldots (9)\]

Equation (9) is presented in Figure (15), in which it is clear that the relative infiltration, whether it is the relative cumulative infiltration depth, relative infiltration rate, or relative basic infiltration rate, increases with the increase in the relative sand values according to Equation 9, and this increase is greater at the smaller silt percentage.

4. CONCLUSION:

* Devising an empirical equation to estimate the cumulative infiltration depth, infiltration rate, and basic infiltration rate as a function of the initial moisture and soil bulk density and the proportions of sand, silt and clay in the soil.

*Relative infiltration, whether it is relative cumulative infiltration depth, relative infiltration rate, or relative basic infiltration rate, decreases with increasing relative initial moisture content or increasing relative bulk density, and increases with increasing relative sand values.

5. References:


الارتشاح وبعض صفات التربة الفيزيائية

حقي إسماعيل ياسين

انتصار محمد غزال

haqqiismail56@gmail.com

entesarzal@gmail.com

جامعة الموصل - كلية الهندسة - قسم هندسة السدود والموارد المائية

الخلاصة

يهدف البحث إلى دراسة تأثير بعض صفات التربة الفيزيائية ككيميائة التربة من رمل وعدين وطين والكثافة الظاهرية للترية والرطوبة الابتدائية للترية، وذلك على كل من عمق الارتشاح التراكمي ومعدل الارتشاح ومعدل الارتشاح الاتجاهي، اعتماداً على بيانات لـ 38 فحص مختبر للارتشاح تمثلة بـ 516 قيمة لعمق الارتشاح التراكمي ومن الارتشاح التراكمي وشملت مدى واسع من التغير في صفات التربة الفيزيائية. ولإفتراضية الارتشاح الابتدائي، تم استخدام أفضل معادلة تجريبية لتخميم عميق الارتشاح النذرية، بيعمل معامل تحديد 0.975 كنلا لبعض صفات التربة الفيزيائية وبصخصة معادلة كوسراكوف لتشمل تخميم معدل الارتشاح الأساسي.

الكلمات الدالة:
الارتشاح، طبيعة التربة الابتدائية، الكثافة الظاهرية، نسبية التربة.