Variation of some physical and hydrological soil characteristics of selected sites in Telkayf District

Mooatasim Daood Agha[1], Yousif Hasan Al-Naser[2], Noor Almola[3], Ahmed Ali Khudhur[4]
College of Agriculture & Forestry, University of Mosul, Mosul, Iraq [1,2,3,4]
Corresponding author: mooatasim@uomosul.edu.iq
[1]alnaseryousif10@uomosul.edu.iq [2]noorjamalalmola@uomosul.edu.iq
[3]ahmed_akhudhur@uomosul.edu.iq

Abstract:
This research was carried out in the Telkayf District of Nineveh Governorate, utilizing three distinct soil textures characterized as calcareous and slightly alkaline . A logarithmic scale was used to analyze the relationship between infiltration time (1–180 min) and cumulative infiltration depth (mm). The modeling results demonstrated that soil water infiltration behavior was best represented , consistent with the results of the Gebul eq . , with a high coefficient of determination (R^2= 0.99). An inverse relationship was observed between the slope parameter of the linear equation (n) and the fine soil particles, confirming the crucial influence of soil texture on infiltration dynamics. Moreover, the measured cumulative infiltration depths closely matched the values predicted by the Gebul eq., as indicated by an r =0.99. Field measurements indicated initial infiltration rates ranging between 300 and 360 mmh^{-1}, which then decreased over time. The steady-state infiltration rates were 72 mm h^{-1} at Kibah, 60 mmh^{-1} at Qawsiate, and 21 mmh^{-1} at Telaskuf. The initial infiltration rates predicted by the Gebul and Horton equations were consistently lower than the corresponding field-measured values. In contrast, the Gebul eq. showed a tendency to overestimate the basic infiltration rate, reaching approximately twice the measured value in Kibah soils. Therefore, this study aims to establish the foundations for selecting a suitable infiltration equation for different soil sites , this reduces the burden of fieldwork in assessing the filtration rate.

Keywords: Infiltration modeling; Horton equation; Gebul equation; Calcareous soils

ISSN 2072-3857

Introduction

Infiltration refers the vertical movement of water from the soil surface into the soil profile [13] . Cumulative infiltration represents the total depth of water that has enter the soil surface over time. Several factors influence cumulative infiltration, including saturated hydraulic conductivity and soil absorptivity, which are linked to the capillary properties of the soil [1] . According to [14] , infiltration models can be classified into three main categories: Empirical models-derived from field infiltration data, these models are simple and widely applied. A common example is the Kostiakov eq.[7] . Semi-empirical models-Incorporating simplified hydraulic factors, these models include the widely used Horton eq. [4] . Physical models are widely used to simulate soil water dynamics because they are based on physical principles related to water flow in porous media. These mathematical models describe soil water movement by combining Darcy's law with the continuity equation, resulting in the Richards equation, which represents water flow under non-constant saturation conditions. This equation incorporates soil hydraulic properties, such as hydraulic conductivity and water retention curve. These indicators are essential for predicting infiltration, drainage, and water redistribution in the soil and are typically represented using mathematical models such as the van Genochten-**Mualem** formula. Thus, physical approaches are the standard framework for soil water flow modeling, and their applications are used in irrigation management and hydrological modeling { [12] [9] } . [2] investigated infiltration in field soils from the Agricultural Research Center of Irati University in the state of Amazonas, Brazil, using a double-ring (10 and 30 cm diameter, 15 cm height). Field data of infiltration rate versus time, plotted on graph paper, allowed for parameter estimation usingthe Horton eq.[4]: $f_p = f_c + (f_o - f_c)e^{-kt}$. The Horton equation was developed for the study of soils with coarse texture: $f_p = 261 + (290.64)e^{-1.41\ t}$, Cumulative infiltration was described using the Kostiakov eq.: $I = a\ t^n$. For soil with a coarse texture and an instantaneous infiltration rate of (840 mm h^{-1}) the Kostiakov eq. provided estimates that closely matched actual field infiltration measurements: $i = 401\ t^{-\ 0.8451}$. According to [3], measuring infiltration is essential not only for understanding crop growth but also for water resources management and irrigation planning, as it is directly related to effective rainfall and

ISSN 2072-3857

groundwater recharge. A field experiment was conducted to estimate cumulative infiltration using a double-ring infiltrometer at a depth of 30 cm in a sugar beet field at Haramaya University, Ethiopia. Measurements were taken at five sites with varying soil textures (clay, silty clay, silty clay, sandy clay, and sandy clay loam).

Field data were analyzed using a graphical method to determine the parameter of the Kostiakov equation (an empirical power function). Since initial infiltration rates are extremely high (approaching infinity) and basic infiltration rates are near zero, [3] proposed a modified version of the equation to better represent field conditions. The basic infiltration rate (fc) was measured using two furrows at each site, each 16–32 m long with a slope of 0.5%. Therefore, he suggests modifying the equation to make it more realistic: $I=a\ t^{n} + f\_(c)\ t$. The infiltration rate equation can be derived as follows: $i= ant^{n-1}+f\_c$. The application of the modified Gebul equation yielded results that closely matched field cumulative infiltration data, with coefficients of determination (R^2) ranging from 0.98 to 0.99 and standard error values between 0.005 and 0.20. [5] defined soil sorptivity as the property that characterizes the movement of water toward the soil surface during the early stages of infiltration, typically within the first five minutes. At this stage, the factor (At) approaches zero in the initial infiltration measurements: $I=S\ t^{0.5} +At$, $I=S\ t^{0.5}$. In general, the applicability of the equations used to estimate cumulative infiltration varies across sites, depending largely on soil characteristics [15] . The root mean square error (RMSE) values were 1.45, 1.88, and 2.01 cm hr^{-1} for the Horton, Kostiakov, and Philip models, respectively. These results suggest that the Horton model provides higher predictive accuracy than the Kostiakov model for estimating infiltration [11] .

Material and Methods

Table (1) shows the geographic coordinates (latitude and longitude) of the study sites. Soil samples were collected from three sites within the boundaries of Telkayf District, Nineveh Governorate .

ISSN 2072-3857

Table 1. Geographic coordinates of the study sites:

Location	longitude	latitude	Elevation (m)
Kibah	43° 00' 15" E	36° 24'15" N	233
Qawsiat	43° 04' 39" E	36° 27'39" N	283
Telaskuf	43° 06' 06" E	36° 34' 37" N	340

The double-ring infiltrometer method (30 – 60 cm diameter and 40 cm height)was used to study the dynamics of water infiltration into the soil at a constant depth, following the methodology of [8] . The size distribution of soil particles was determined using the hydrometer method, while undisturbed soil samples were collected to estimate the bulk density (ρb) according to the methodology of [8] using the following equation:

ρb = Ms/Vt ……………………1

Where: ρb = dry bulk density,

ρt = wet bulk density

Soil porosity was derived from bulk density values assuming a particle density of 2.65 Mg m^{-3}, as suggested by [8] :

$$f = \left\{1 - \frac{\rho_b}{\rho_s}\right\} 100 \quad \ldots\ldots\ldots\ldots\ldots \quad 2$$

Saturated hydraulic conductivity (Ks) was measured using the falling-head method with undisturbed soil cores (10 cm in diameter and 10.5 cm in height), following [8] methodology. The hydraulic conductivity was calculated as follows:

Ks = aL/At Ln [H_1/ H_2] ……. 3

The mean weight diameter was determined using both dry and wet sieving techniques, as described by [6] .

$$MWD = \frac{\sum_{i=1}^{n} \bar{x_i}\ w_i}{\sum_{i=1}^{n} W_i} \quad \ldots\ldots\ldots\ldots \quad 4$$

The Potential Structural Deformation Index was estimated according to [10] .

$$PSDI = \left(1 - \frac{WMWD}{DMWD}\right) \quad \ldots\ldots\ldots \quad 5$$

Based on the methods described in [8] , the following was done: Soil moisture retention curves were obtained at water potentials of 0, 33, 100, 300, 500, 800, 1000, and 1500 kPa using a pressure plate apparatus fitted with ceramic plates. The soil pH and electrical

ISSN 2072-3857

conductivity were measured in a 1:1 extract using a pH meter and an electrical conductivity meter. The total soil gypsum content and soil calcium carbonate ($CaCO_3$) content were determined by titration, while the soil organic matter content was estimated by organic carbon oxidation and titration with ammonium ferrous sulfate.

Result and Discussion

Table (2) shows that the soil textures were sandy loam, loam, and silty clay. They are also calcareous, non-saline, and have low organic matter content.

Table (2): Selected general properties of the studied soils

properties		Kibah	Qawsiat	Telaskuf
Clay	$g\ kg^{-1}$	169	269	419
Silt		100	400	450
Sand		731	331	131
Class		Sandy loam	Loam	Silty Clay
EC	$dS\ m^{-1}$	0.32	0.41	0.55
pH		7.6	7.7	7.2
OM	$g\ kg^{-1}$	10.6	13.1	8.9
$CaCO_3$		235	310	335
Gypsum		Nile	Nile	Nile

Table (3) shows that the soil aggregates had low stability and are therefore highly susceptible to structural deterioration. Increasing the clay fraction in the studied soils was associated with a decrease in saturated hydraulic conductivity.

Table (3): Some physical properties of the studied soils

properties	Unites	Kibah	Qawsiat	Telaskuf
Bulk density	$Mg\ m^{-3}$	1.2	1.1	1.11
Total bulk density		1.25	1.27	1.3
Porosity	%	54.71	58.49	58.11
Dry Mean Weight Diameter	mm	deterioration	5.74	6.94
Wet Mean Weight Diameter		deterioration	deterioration	deterioration

ISSN 2072-3857

Potential Structural Deformation Index	%	----------	100	100
Saturated hydraulic conductivity	cm hr^{-1}	7.2	2.88	1.97

The measured cumulative infiltration curves showed a high coefficient of determination (R^2= 0.99). The predicted cumulative infiltration, obtained using the Gebul equation, demonstrated that the parameter values (a and n) are soil-specific and vary with experimental data. Parameter *a* ranged from 6.48 to 6.94, with the lowest value recorded in Telaskuf soil and the highest in Qawsiat soil. Parameter *n*, representing the slope of the linear equation, decreased with increasing fine particles. The highest value (n= 0.69) was observed in Kibah (sandy loam), while the lowest (n= 0.35) was found in Telaskuf soil with silty clay texture.

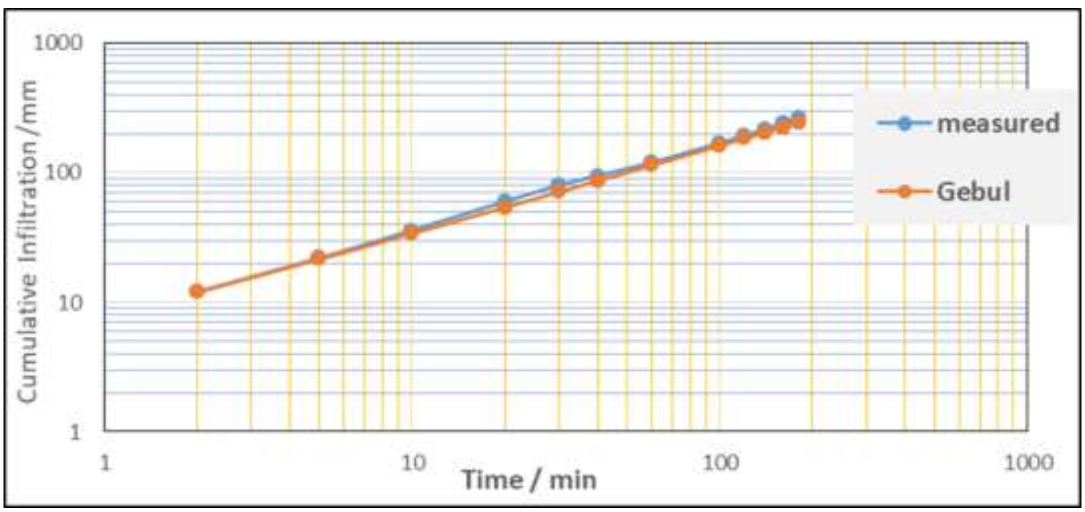

Figure (1-a) cumulative infiltration of Kibah soil

Figure (1) illustrates the logarithmic relationship between time (1–180 minutes, x-axis) and cumulative infiltration depth (mm, y-axis) for the soils. These forms show Gebul equation for (Kibah, Qawsiat and Telaskuf) soils respectively.

$$I = 6.69\ t^{0.69} + 1.2$$
$$I = 6.94\ t^{0.66} + 1.0$$
$$I = 6.48\ t^{0.35} + 0.35$$

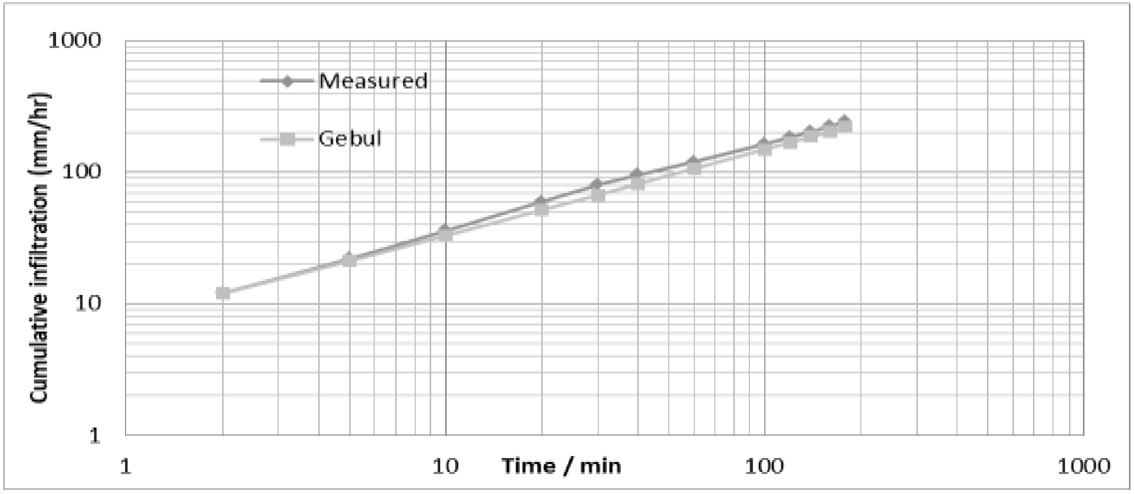

Figure (1- b) Cumulative infiltration curve for Qawsiat soil

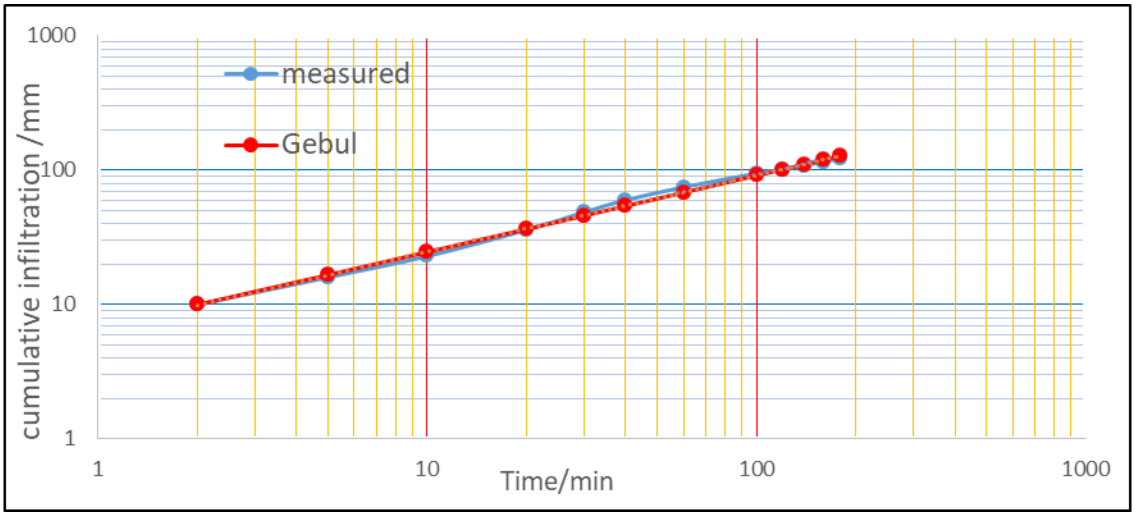

Figure (1- c) cumulative infiltration for Telaskuf soil

Figure (2) shows the correlation between measured cumulative infiltration (y-axis) and predicted cumulative infiltration (x-axis) using the Gebul equation , with a linear equation and high correlation coefficient (r = 0.99) across the studied sites.

ISSN 2072-3857

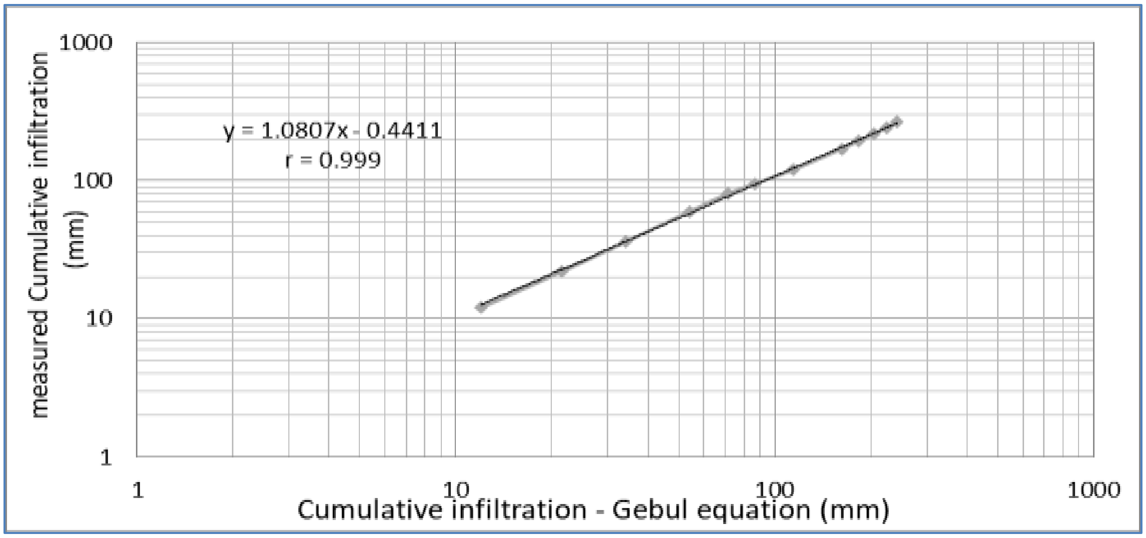

Figure (2- a) measured and predicted cumulative infiltration value for Kibah soil

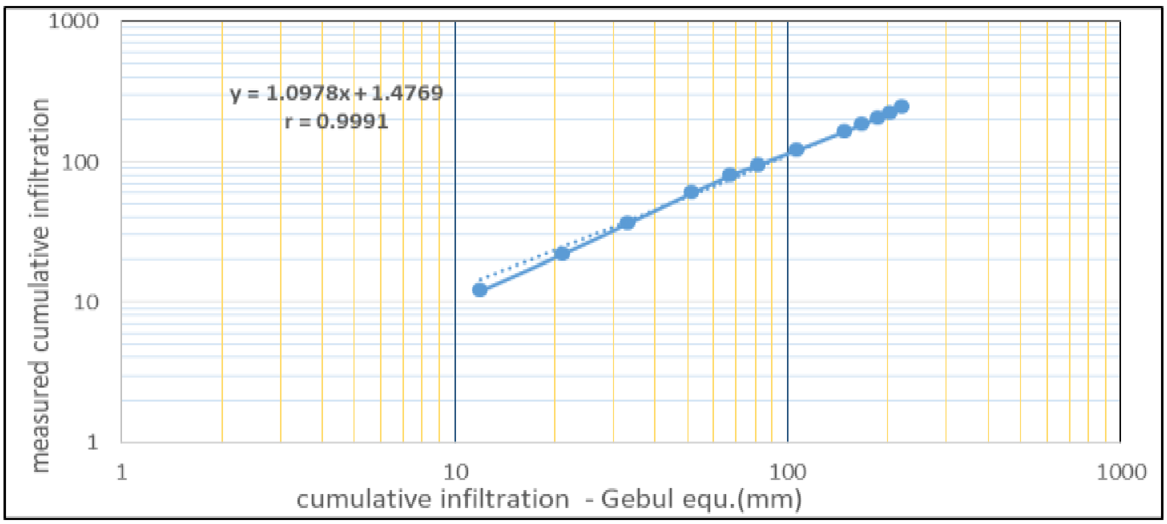

Figure (2- b). Measured and predicted cumulative infiltration for Qawsiat soil

ISSN 2072-3857

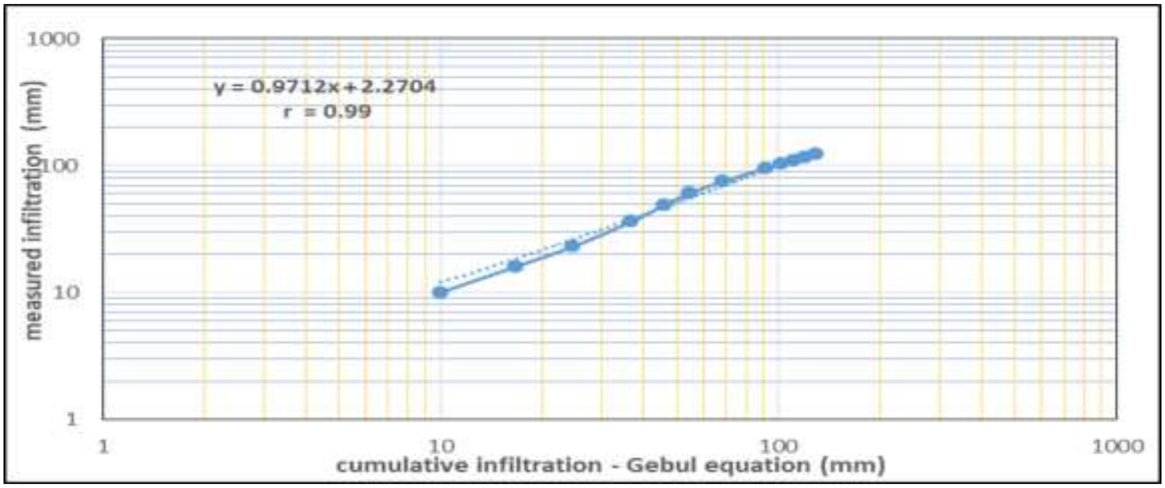

Figure (2- c). Measured and predicated cumulative infiltration for Telaskuf soil

Figure (3) depicts infiltration rate (cm h^{-1}) versus time (0–180 minutes). The initial infiltration rate, measured in the field, ranged between 300–360 mm h^{-1}, depending on soil properties and initial moisture content. Infiltration rates declined significantly after approximately one hour, stabilizing at 72, 60, and 21mm h^{-1} for Kibah, Qawsiat, and Telaskuf soils, respectively. Predicted infiltration rates derived from the Gebul equation revealed that the basic infiltration rate was overestimated, reaching nearly double the field-measured values, with the discrepancy being most pronounced in Al-Kibah (sandy loam soil). The reason may be the effect of the value of the factor (n-1), where is ranged of (-0.31, - 0.42), on the result of the equation

ISSN 2072-3857

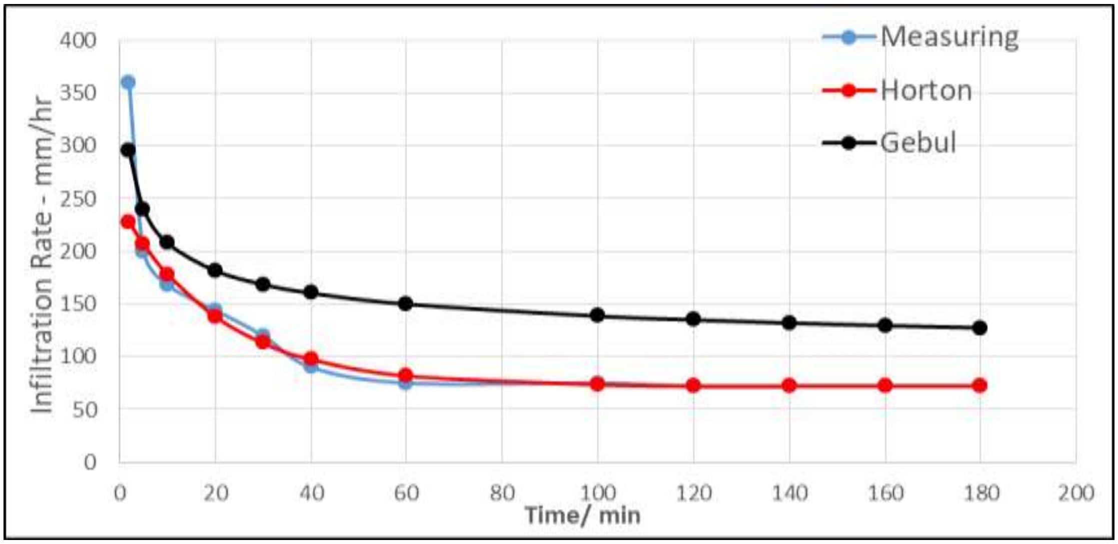

Figure (3 -a). Measured and predicted infiltration rate for Kibah soil

$i = 4.01\ \ t^{-\ 0.31}\ +\ 1.2$
$i = 4.60\ \ t^{-\ 0.336}\ +1.0$
$i = 3.718\ \ t^{-\ 0.65} + 0.35$

Applying Horton's equation also indicated that predicted initial infiltration rates were lower than field measurements. With increasing time, infiltration rates decreased, and the predicted basic infiltration rate in Kibah soil showed a high correlation coefficient (r = 0.92), which declined (r = 0.77) with higher fine particle content (Telaskuf soil). Horton's parameter values (K) were estimated as 0.048, 0.037, and 0.015 for Kibah, Qawsiat, and Telaskuf soils, respectively. This result is in agreement with the findings of [11] , who reported that the Horton model provides superior predictive accuracy compared to other models for estimating soil infiltration.

ISSN 2072-3857

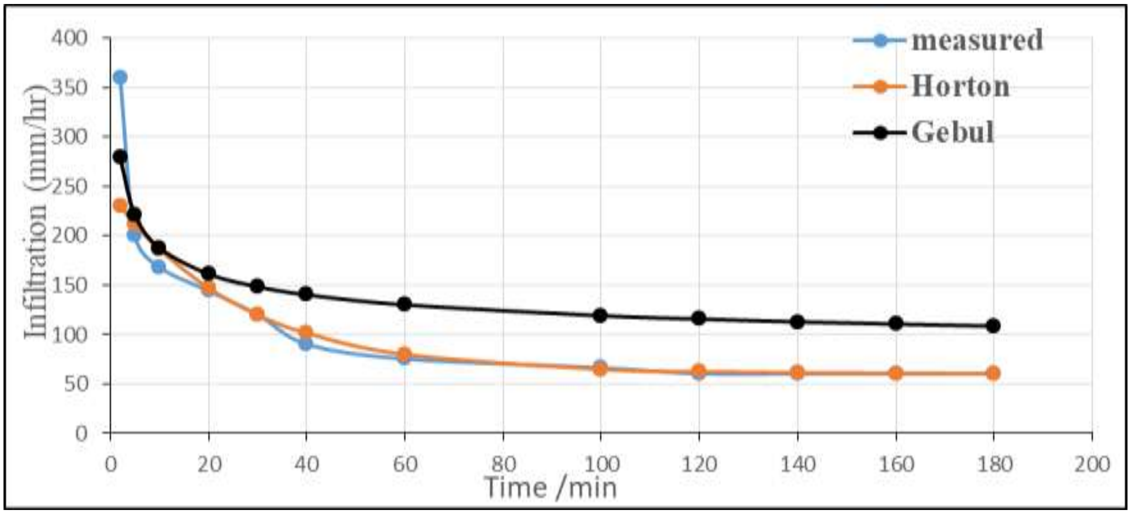

Figure (3- b). Measured and predicated infiltration rate for Qawsiat soil

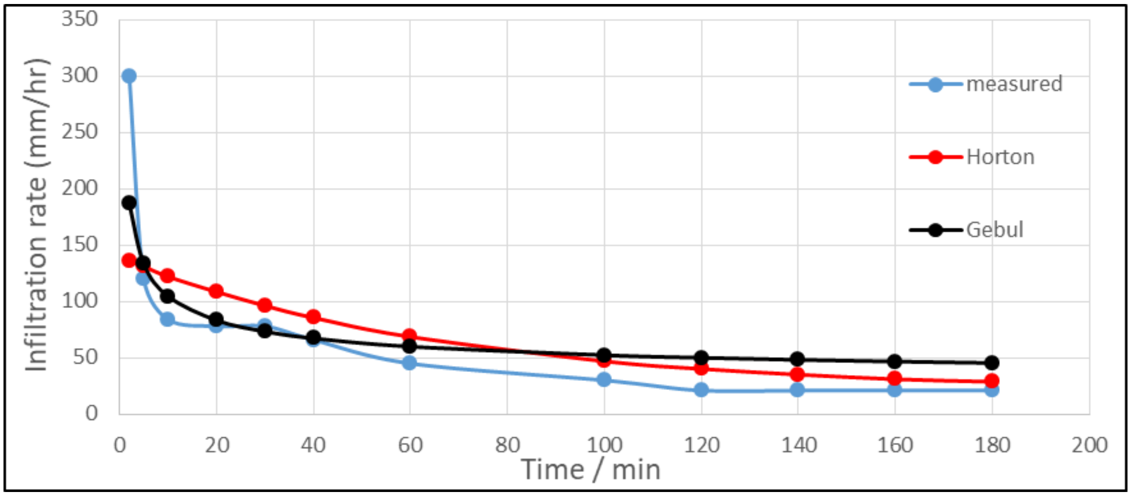

Figure (3- c). Measured and predicted infiltration rate for Telaskuf soil

Figure (4) presents the relationship between the mass moisture content at field capacity, permanent wilting point, and available water for all studied soils. Telaskuf soil with silty clay texture exhibited the highest available water (AW= 9.83%), followed by Qawsiat soil (7.32%) with loam texture and Kibah site (6.58%) with a sandy loam texture.

The increased availability of water observed in Telaskuf soil is primarily due to its higher content of fine particles, which enhances water retention capacity relative to the other studied soils.

ISSN 2072-3857

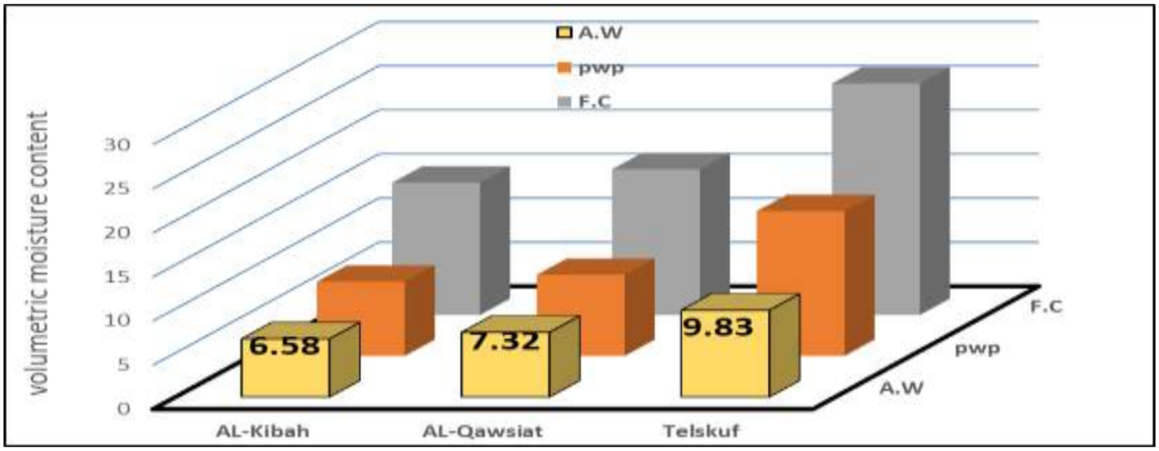

Figure (4) Available Water for studied soils

ISSN 2072-3857

Conclusions and Recommendations

The study demonstrated the feasibility of applying the Gebul eq. to soils of varying textures in different locations within Nineveh Governorate to estimate cumulative infiltration.

The results of the Gebul eq. showed a high correlation coefficient with field readings of cumulative infiltration. In contrast, the results of applying the Horton eq. also showed a high correlation coefficient with field readings of the basic infiltration rate compared to the Gebul eq. Therefore, we recommend that researchers to apply more infiltration equations and to propose the most suitable equations, thereby the burden of fieldwork will be reduced .

Acknowledgements

The authors would like to thank our colleagues for their encouragement and moral support in completing this research.

References

[1] Angelaki, A., Sihag, P., Sakellariou-Makarantonaki .M., and Tzimopoulos, C. (2021). The effect of sorptivity on cumulative infiltration. Water Supply. 21(2)606–614. https://doi.org/10.2166/ws.2020.297

[2] Florentino R . W ; G. R . T . Coelho ; M . H . Zilch ; T . B . Veiga ; K . G . Martins and A . C . B . Kummer. ..2023 . Assessing Horton and Kostiakov models focused on estimating soil water infiltration . Brasileira de Ciência, Tecnologia e Inovação . DOI: https://doi.org/10.18554/rbcti.v8i2.7022.

[3] Gebul, M. A. (2022). Simplified approach for determination of parameters for Kostiakov's infiltration equation.Water Practice &Technology.17(11)2435. https://doi.org/10.2166/wpt.2022.142.

[4] Horton, R. E. (1940). An approach toward a physical interpretation of infiltration capacity. Soil Sci. Soc. Am. J.5(C), 399417.

[5] Kalibová, J., Petrů, J., Luca, M., & Štibinger, J. (2023). Ponding time, hydraulic conductivity, and sorptivity-experimenta and numerical determination. Agricultura Tropica et Subtropica, 56(1), 32-38. https://doi.org/10.2478/ats-2023-0004

[6] Kemper, W. D. ,and . Rosenau ,R. C. (1986) . Aggregate stability and size distribution . In : A. klute et al. (eds.) , Methods of Soil Analysis . Part 1. 2nd ed. Agron 9 , ASA , Madison , WI , PP. 425-442.

[7] Kostiakov, A.N. (1932) On the Dynamics of the Coefficient of

Water Percolation in Soils and the Necessity for Studying It from a Dynamic Point of View for Purposes of Amelioration. In: Transactions of the Sixth Commission of the International Society of Soil Science , Part A , Russia, 17-21.

[8] Klute, A. (1986). Methods of soil analysis. Am. Soc. of Agronomy, Part 1, Physical and Mineralogical Methods, 2nd edition. American Society of Agronomy and Soil Science Society of America, Madison, USA.

[9] Li, Y., Sun, Q., Fu, Y. and Wei J. (2025). Solving the Richards infiltration equation by coupling physics-informed neural networks with Hydrus-1D. Sci Rep15,18649. https://doi.org/10.1038/s41598-025-02978-w

[10] Mbagwu, J.S. and P. Bazzoffi (1989). Effects of freezing and thawing on the stability of soil aggregates treated with organic wastes. Cold Regions Sci. & Technol, 16: 191-199. https://doi.org/10.1016/0165-232X(89)90020-7

[11] Muneer, A.R., Sayl, K. N. and Kamal, A. H.(2022). A Comparative study to assess the suitable models for prepicting the infiltration rate in an arid region. Iraqi journal of civil engineering.14(1),29-38. https://doi.org/10.37650/ijce.2020.172873

[12] Peters, A., Hohenbrink, T. L., Iden, S. C., van Genuchten, M. Th., & Durner, W.(2023).Prediction of the absolute hydraulic conductivity function from soilwater retentiondata.Hydrology and Earth System Sciences, 27,1565–1582. https://doi.org/10.5194/hess-27-1565-2023

[13] Radcliffe, D.E., & Simunek, J. (2010). Soil Physics with HYDRUS:Modelingand Applications (1st ed.). CRC Press. https://doi.org/10.1201/9781315275666

[14] Uloma, A.R., Samuel, A.C. and Kingsley, I. K. (2014). Estimation of Kostiakov's infiltration model Parameters of some sandy loam soils of Ikwuano-Umuahia, Nigeria. Open Transaction. Geosciences.1 (1),34-38. https://doi.org/10.15764/GEOS.2014.01005

[15] Zakwan, M. (2023). Analysis of a simplified approach for the determination of modified Kostiakov model parameters. Water Science & Technology. 88 (12): 3110–3118. https://doi.org/10.2166/wst.2023.405