Measuring the Infiltration rate and estimating the constants of the Kostiaskov equation for selected soils Nineveh Governorate

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Abstract :
This study employed the double-ring infiltrometer method to analyze water infiltration behavior in soils from three different sites within Haj Ali village, Al-Qayarah District, Nineveh Governorate, Iraq. The research investigated the relationship between cumulative infiltration depth and time (2–180 minutes) for three soil textures: sandy loam, loam, and silty clay. The constants of the Kostiakov equation were determined as follows: (a = 7.89, n = 0.659), (a = 5.96, n = 0.623), and (a = 5.843, n = 0.544), respectively. These yielded power functions of the form (I=7.890t^0.659) , (I = 5.96t^ 0.623) and (I = 5.843t^0.544) with determination coefficients ranging from 0.98 to 0.99. Predictive linear equations were also established based on the logarithmic relationship between infiltration depth and time. Measured infiltration rates (in mm/min and mm/hr) closely matched those calculated from the derived equations, with correlation coefficients (R) between 0.96 and 0.98. However, the predicted initial infiltration rates were consistently lower than the measured values.

Keyword : Infiltrometer , Cumulative infiltrated depth , Infiltration rate , Predicted equation .

Introduction:

Infiltration is the vertical downward movement of water from soil surface into the soil profile through its pores, Cumulative infiltration represents the total water depth pass the soil surface. Soil infiltration properties play an effective role in the hydrologic cycle, Irrigation project design , drainage, groundwater recharge , and agricultural soil moisture. (1 (

Infiltration is an important phenomenon in water resources management and reducing the impact of floods, in addition to reducing water loss during irrigation .(13. (
At the onset of the infiltration , high rates are typically observed due to the initial low moisture content of the soil surface . Both equations Kostiakov (1932) and Horton(1941) gave initial infiltration rate values lower than the measured values, although the Horton equation was able to overestimate most values of the instantaneous infiltration rate up to 25 minutes, while the Kostiakov equation was able to overestimate most instantaneous readings of the infiltration rate after 80 minute . Both equations were able to overcome the fluctuation in the infiltration rate values at the field location . the Kostiakov model was the one capable of determining the infiltration values closest to actual one . (4. (
(12)conducted an experiment to compare infiltration rates with irrigation systems in northern Ethiopia using a double ring infiltrometer for five soil textures: clay loam, loam, sandy clay loam, clay, and sandy loam. Six infiltration equation (Kostiakov, Modified Kostiakov, Revised Modified Kostiakov, Philip, Horton, and Novel) were applied in 38 location within study area , and Using

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modern statistical methods (SPSS statistical software using least – square errors) to find the best equation. The result showed that, Revised Modified Kostiakov, Modified Kostiakov, and Novel infiltration equation gave more consistent result with the measured values. Kostiakov 's equation was the best for predicting the infiltration rate for both clay loam and sand clay loam soil textures ($R2 = 0.99 – 0.99$. (

Water infiltration represents an important part of hydrological plan design. The lack of water infiltration data has led those working in this field to apply empirical and semi-empirical equation to estimate infiltration rates . application these empirical and semi-empirical models to estimate the infiltration rate is highly dependent on the method adopted to determine the parameters of models. One of the most common infiltration models known as the Kostiakov model was modified to emendation zero infiltration at the beginning of the infiltration process . And the Kostyakov equation was recently developed by the researcher Gebul (2022), and there are intensive efforts to estimate the parameters of that equation . In this regard, six observed datasets (five from Ethiopia and another from Bangladesh) were collection and three methods or models (1- Graphical model) (2- Simplified approach , Gebul model ,2022) (3- Axcel spreadsheet – based nonliner optimization solver) as well as Observed Infiltration were applied to estimate cumulative infiltration . The results showed that the average Sum of Square Error reduce by more than 50% by applying Excel solver as compared with Simplified approach , The Simplified approach did not give a clear significant difference in development graphical method , the Simplified approach was not as accurate as required (16. (

(5)mentioned that Understanding the properties of soil infiltration is an important effort in the optimal design and efficient management of irrigation projects. For many years, two types of models have been applied to estimate soil infiltration: empirical and models based on the physical properties of the soil . There are many factors (including those related to the properties of the surface soil, as well as the surrounding environmental conditions , etc) that interfere in estimating the parameters of these models and thus affect the application of these models. In this study, field data were collected (in Haramaya University farm \ Ethiopia) to measure infiltration for five locations different in the soil texture (Clay,Silt Clay, Silt Clay ,Sandy Clay and Sandy Clay Loam) . Three available models were used to estimate the parameters of a cumulative infiltration equations (1-Curve fitting / original Kostiakov equation) (2- volume balance method)(3- Simple approach / modified Kostiakov equation) . Several performance indices were applied to demonstrate the accuracy of these models , for example R2 and S.E standard error, whose values ranged from 0.985 to 0.999 and 0.020 to 0.005, respectively, The test and evaluation results proved that the Simple approach equation is the best for describing cumulative infiltration and helping in managing irrigation projects in a practical manner, with S.E (0.005- 0.05) compared with curve fitting equation (0.005 – 0.11 . (

The empirical infiltration equation proposed by (Kostiakov 1932) is expressed as a power function that relates the cumulative infiltration depth, I (cm), to the infiltration time, t (min) , (a) represent the soil infiltration coefficient (cm min -1) and (n) infiltration index constant (dimensionless) , this model is widely applicable and is able to represent infiltration data. . as shown in Equation (1:(

$I = a\ tn$ --------------(1(

Typically, the value of the exponent nn lies between 0 and 1. Consequently, the infiltration rate is a decreasing function, starting from an infinite initial value and approaching zero after extended periods. However, in practice, infiltration rates tend to decline to a positive

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constant value, known as the final infiltration rate, rather than reaching zero.
To address this limitation, the modified Kostiakov equation was developed, which takes the form:

$I = a t^n + fc\, t$ ------------------- (2(

fc as is the basic infiltration rate (cm/min) and the other parameters are as defined in Equation (1(
The first derivative of Equation (2) gives the infiltration rate (i) of the modified Kostiakov equation as Equation (3:(

$i = a n t^{n-1} + f c$ -------------(3(

(8) Non-saline sandy loam soil samples were collected from Isfahan Province\ Iran. A laboratory experiment was conducted using three water treatments and two irrigation regimes: daily irrigation and intermittent irrigation . Five infiltration equations) SCS, Philip , Horton , Kostiakov- Lewis and Kostiakov) were evaluated . The results indicated that the empirical equations particularly the Kostiakov model showed closer agreement with the observed infiltration data compared to the physically based models.
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Material and Methods:
Surface soil samples were collected from three sites within the village of Haj Ali , Al-Qayara District \ Nineveh Governorate. The first sites was situated adjacent to the Tigris River. The second : approximately half a kilometer from the riverbank . and the third about one kilometer from the riverbank , The geographical coordinates (latitude and longitude) of the three sites are presented in the accompanying table .

Table 1. Geographic coordinates of the study sites:

Location	longitude	latitude	Elevation/ meter
First	43° 17’ 56” E	35° 44’ 51”	167
Second	43° 17’ 60” E	35° 44’ 43”	168
Third	43° 18’ 01” E	35° 44’ 9”	169

The double-ring infiltrometer method was employed to evaluate water movement through the soil surface, A constant head of water was maintained during testing . The inner and outer rings were 30 cm and 60 cm in diameter , respectively , with ahight of 40 cm .
.
Particle size distribution determined using the hydrometer method as (6) . Undisturbed soil samples were brought to the laboratory using a metal cylinder with a diameter of 4.6 cm and a height of 5 cm. The following relationship was used (10.(
$\rho b = Ms/Vt$------------1
Shrinkage Limit was estimated by applying (14) equation:
Shrinkage Limite=$\{1/\rho b- 1/\rho t\}$ 100---2
When (ρb dry bulk density) (ρt wet bulk density(
The value of the porosity of the study soils was calculated from knowing the bulk density values and adopting a value of (2.65 Mgm m^{-3}) for the particle density as stated in (10.(

$f=\{1-\rho_b/\rho_s\}100$----3

To estimate the saturated hydraulic conductivity in the laboratory, the constant head method was used for an excited soil sample using a metal cylinder with a diameter of 10 cm and a height of 10 .5 cm, according to what was reported by (10), according to the equation:
$Ks = aL/At \ Ln[H1/H2]$ ---------- 4

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The main weight diameter was estimated by using the dry sieving and wet sieving methods as stated in (9),Equation

$$MWD=\frac{\sum_{i=1}^{n} \bar{x}_i w_i}{\sum_{i=1}^{n} W_i} \quad \text{-----5}$$

Estimate the (Potential Structural Deformation Index) in soil structure (2) according to the equation

Moisture characterization curves were obtained in the laboratory and described by (10) for all soil samples at (0 , 33,100, 300 ,500 , 800 ,1000,1500) kPa by means of a pressure cooker with a ceramic disc.

The degree of hydrogen ion concentration pH and electrical conductivity were estimated in a soil extract at a ratio of (1:1) using the pH-meter and EC-meter, respectively, according to the method mentioned in (3). The total calcium carbonate was estimated by the titration method , as stated in (15). The organic matter was estimated by estimation of organic carbon by oxidation using concentrated sulfuric acid and potassium dichromate titrated with ammonium ferrous sulfate, as stated in (7). The proportion of gypsum was estimated according to the (15) method

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

The studied properties	Unites	First- Location	Second- Location	Third - Location
Clay	g Kg^{-1}	169	269	419
Silt	g Kg^{-1}	100	400	450
Sand	g Kg^{-1}	731	331	131
Soil naming		Sandy loam	Loam	Silty Clay
Organic mater	g Kg^{-1}	10.6	13.1	8.9
EC	dS m^{-1}	0.32	0.41	0.55
pH		7.6	7.7	7.2
$CaCO_3$	g Kg^{-1}	235	310	335
Gypsum	g Kg^{-1}	Nile	Nile	Nile

Estimating the height of the water column by capillary tube : using glass tubes 125 cm long and 2.7 cm in diameter filled with soil to an apparent density similar to its value in the field. With 1 cm of water column below the soil column.

Result and Discussion :

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Tables (2) and (3) present the properties of the study soils, the texture were classified as (sandy loam , loam and silty clay) respectively , al soils were non-saline calcareous with relatively low organic matter content . These soil aggregates susceptible from deterioration , especially when wet. As clay content increased notable reduction in saturated hydraulic conductivity was observed .

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

The studied properties	Unites	First-Location	Second-Location	Third - Location
Bulk density	Mg m $^{-3}$	1.20	1.10	1.11
Total bulk density	Mg m $^{-3}$	1.25	1.27	1.31
Shrinkage Limit	%	3.33	11	13.1
porosity	%	54.71	58.49	58.11
D.M.W.D	mm	deterioration	5.74	6.94
W.M.W.D	mm	deterioration	deterioration	deterioration
PSDI	%	----------	100	100
Saturated hydraulic conductivity	cm hr $^{-1}$	7.20	2.88	1.97
Water holding capacity	cm m $^{-1}$	3.60	11.40	15

Figures (1) and (2) show that with an increase in the percentage of clay, the ability of the soil to retain moisture increases, where the available water is (3.96 , 11.46 and 16.56) % respectively.

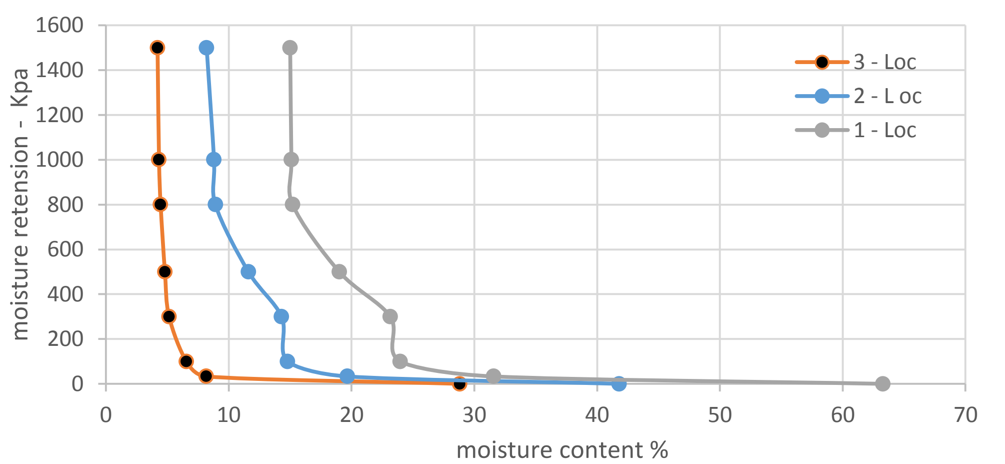

Figure (1) Soil volumetric moisture retension curve%

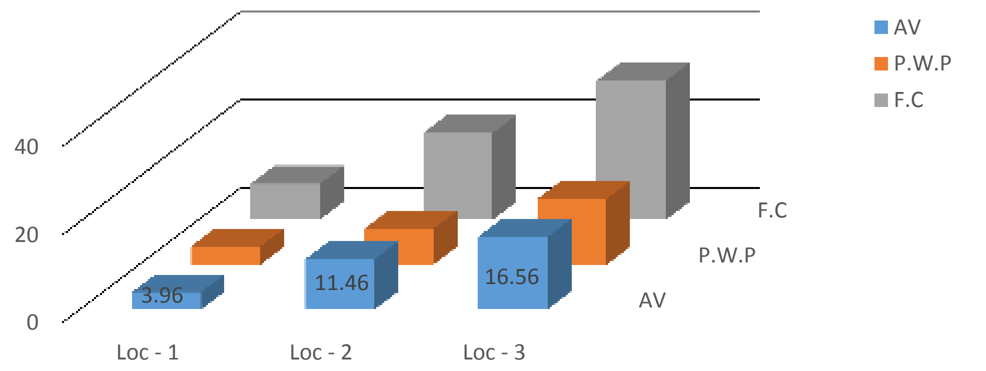

Figure (2) Soil volumatric moisture content %

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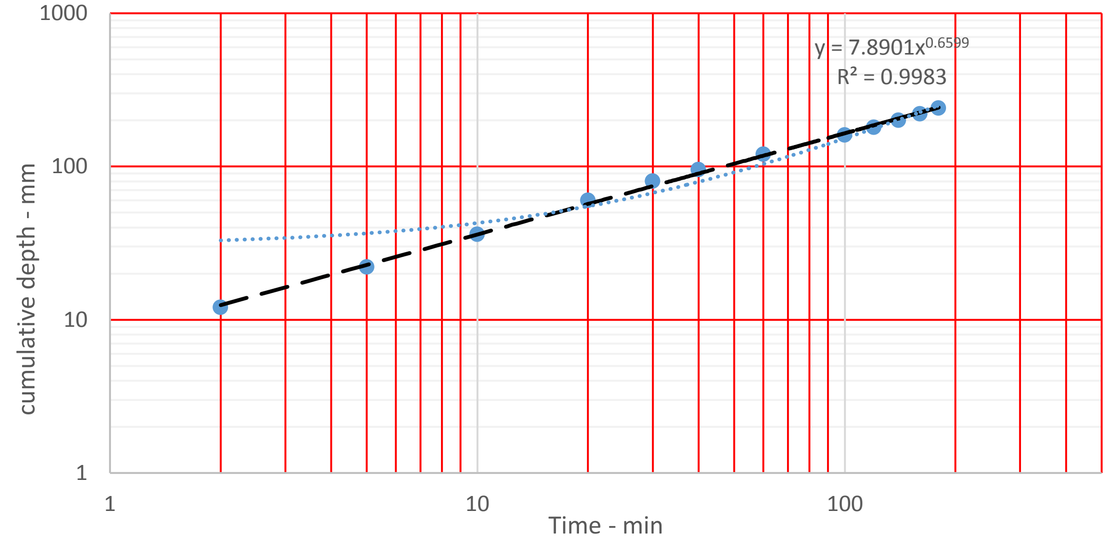
Table (4) : The cumulative infiltration depth for a three locatio

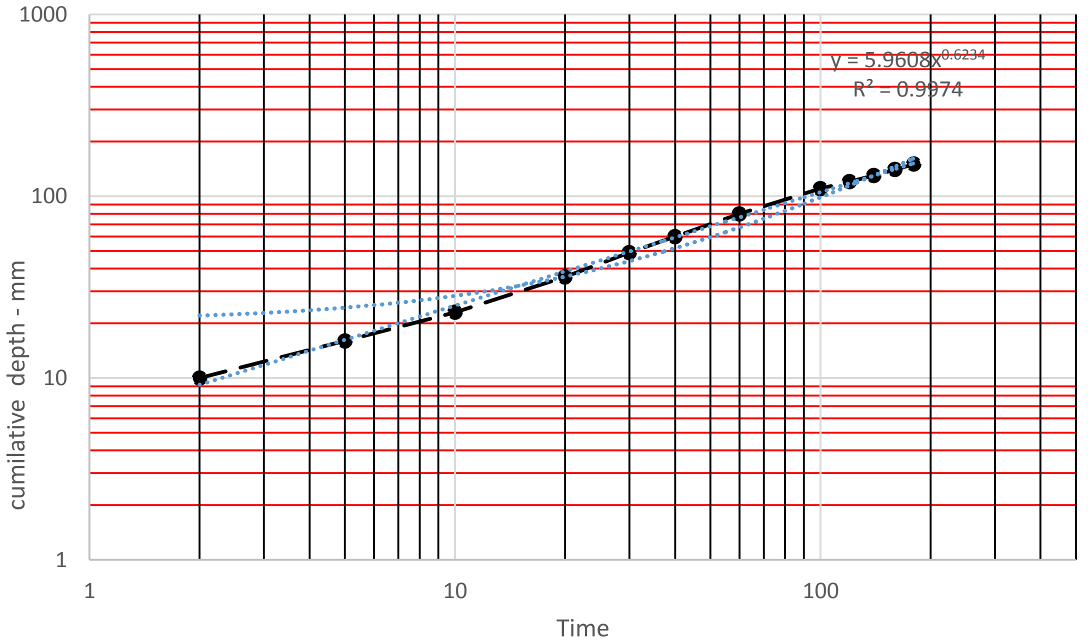
Time - min	Time - hour	The cumulative infiltrated depth - mm		
		First - location	Second - Location	Third - Location
0	0	0	0	0
2	0.033	12	10	8
5	0.083	22	16	12
10	0.166	36	23	20
20	0.333	60	36	35
30	0.5	80	49	44
40	0.666	95	60	50
60	1	120	80	60
100	1.666	160	110	70
120	2	180	120	75
140	2.333	200	130	80
160	2.666	220	140	85
180	3	240	150	90

Figure (3) represents the relationship between the cumulative infiltrated depth of the sandy loam soil of the first location with time (2-180) minutes. Where the constants of the Kostiakov equation (a = 7. 89 n= 0.65) . The power equation be I= 7.890t ^ 0.659 with determination coefficient 0.99 .



Figure(3) Cumulative Infiltrated depth with time (First-Loc)

Figure (4) represents the relationship between the cumulative infiltrated depth of the loam soil of the second location with time (2-180) minutes. Where the constants value of the Kostiakov equation less than sandy loam soil (a = 5. 96 n= 0.623) . The power equation be I= 5.960t ^ 0.623 with determination coefficient 0.99.



Figure(4) Cumulative infiltrated depth with time (second - Loc)

Figure (5) represents the relationship between the cumulative infiltrated depth of the silty clay soil of the third location with time (2-180) minutes. Where the constants value of the Kostiakov equation less than loam soil (a = 5. 842 n= 0.544) .The power equation be I= 5.842t ^ 0.544 with determination coefficient 0.98.

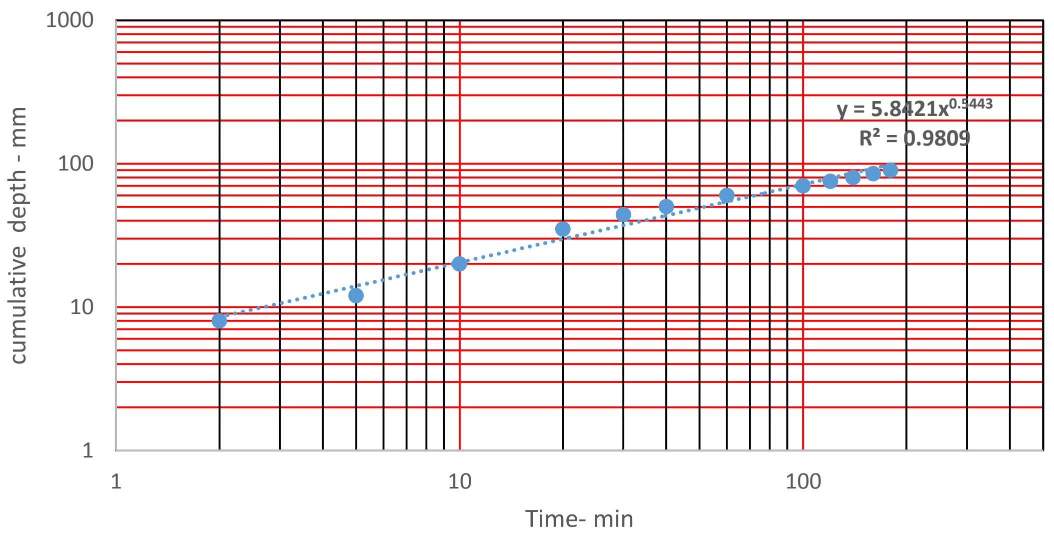


Figure (5)Cumulative infitrated depth with time (third - Loc)

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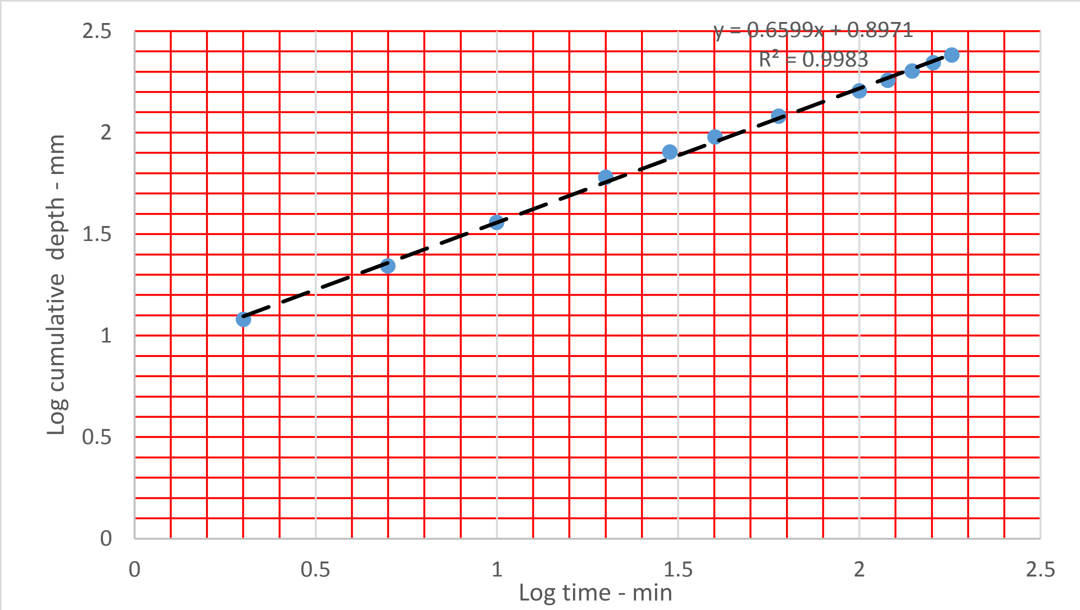
Curve (6) gives a predictive linear equation for estimating the logarithms of the cumulative infiltration depth for (sandy loam soil) from knowledge of the time logarithms per minute. Where the equation

I = 0.659 t + 0.897



Figure(6)Log cumulative infiltrated depth with Log time(First -Loc)

Curve (7) gives a predictive linear equation for estimating the logarithms of the cumulative infiltration depth for (loam soil) from knowledge of the time logarithms per minute. Where the equation

I = 0.623 t + 0.775

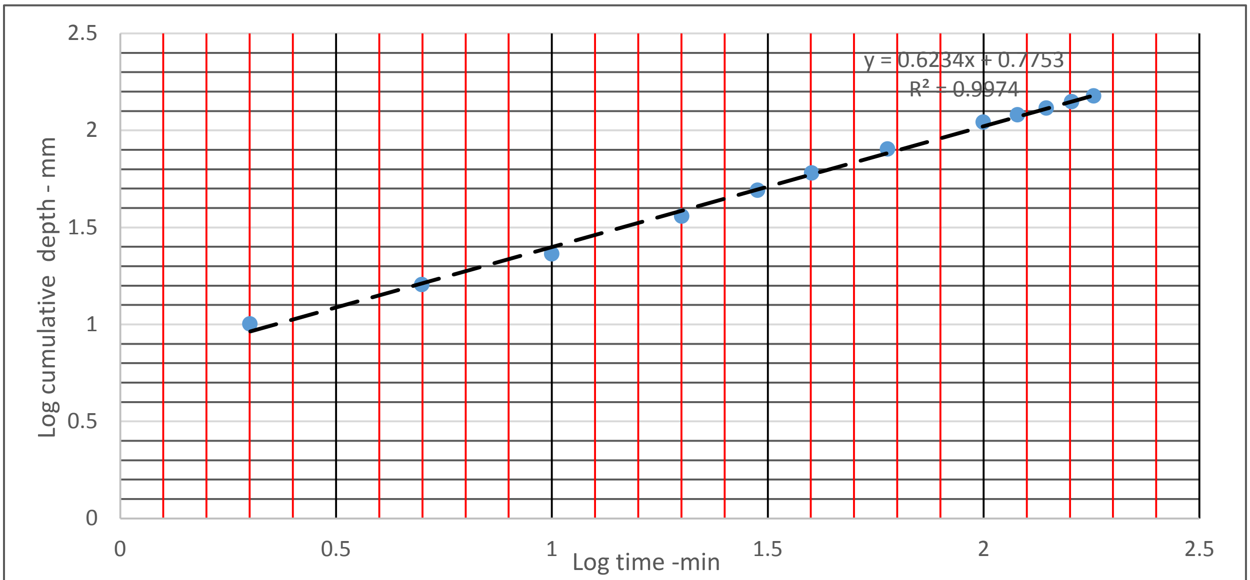


Figure (7) Log cumilative infiltrated depth with Log time (second -Loc)

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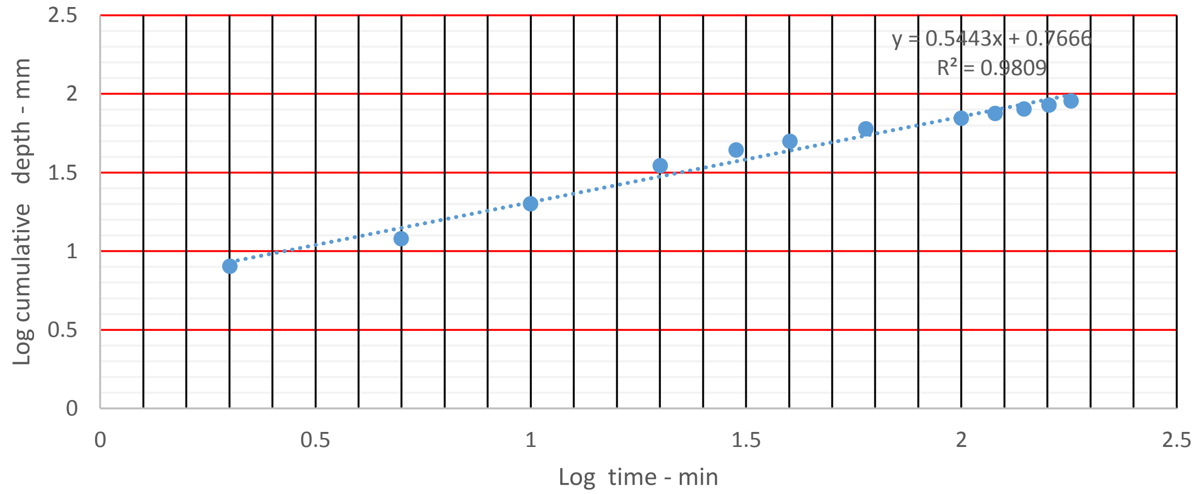
Curve (8) gives a predictive linear equation for estimating the logarithms of the cumulative infiltration depth for (silty clay soil) from knowledge of the time logarithms per minute. Where the equation

I = 0.544 t + 0.766



Figure(8) Log cumulative infiltrated depth with Log time (third - Loc)

Figure (9) In first location : the infiltration rate curve measured in (mm/min) and(mm/hour) , as well as the infiltration rate curve calculated by integrate the cumulative infiltrated equation I= 7.890t ^ 0.659 . The correlation coefficient between the measured and calculated infiltration rate is R= 0.98.

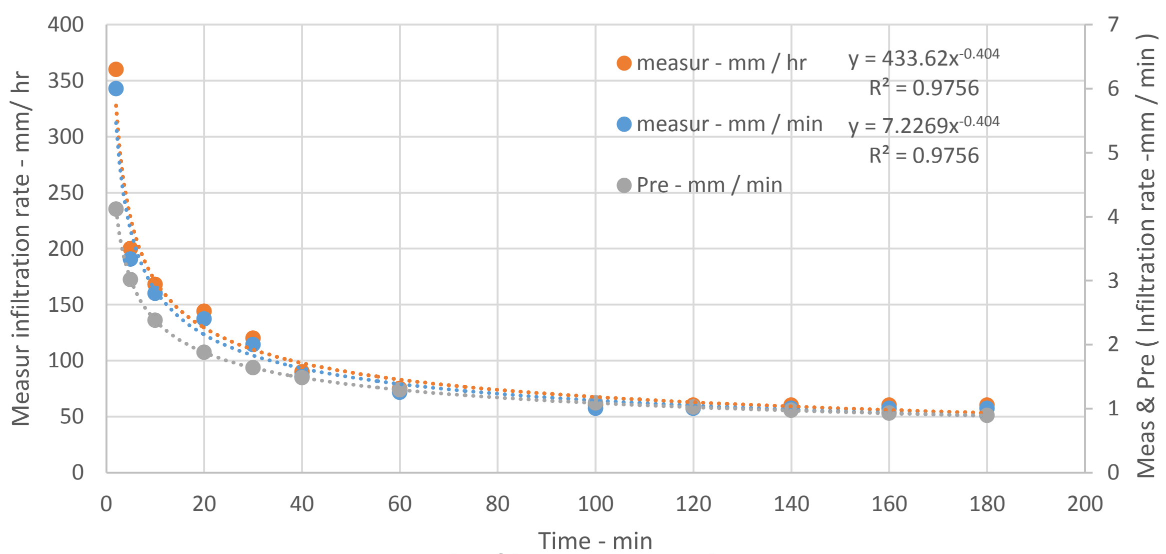


Figure (9) Soil infiltration rate with time (First - Loc)

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Figure (10) In second location the infiltration rate curve measured in (mm/min) and(mm/hour) , as well as the infiltration rate curve calculated by integrate the cumulative infiltrated equation I= 5.960t ^ 0.623 . The correlation coefficient between the measured and calculated infiltration rate is R= 0.96.

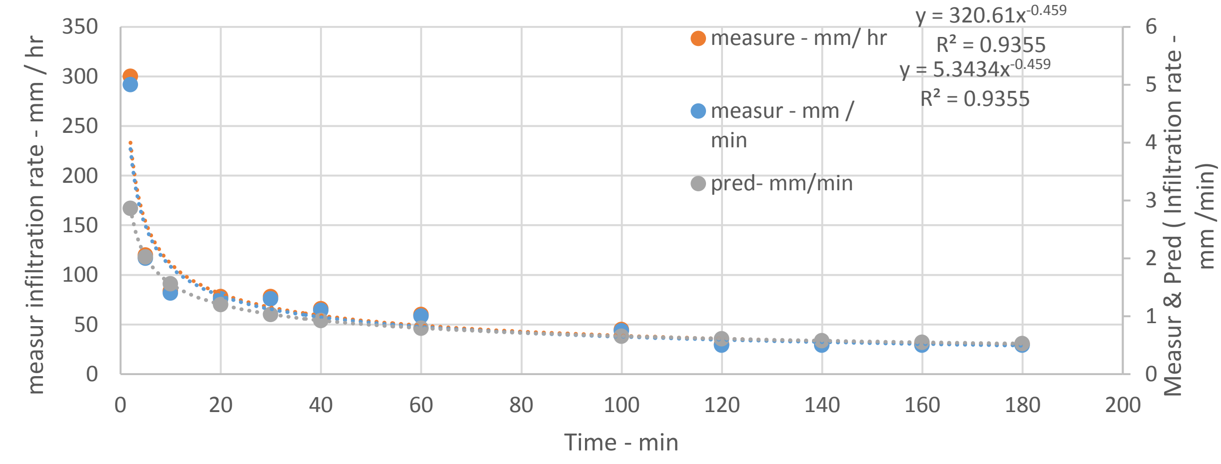


Figure (10) Soil infiltration rate with time(second -Loc)

Figure (11) In third location the infiltration rate curve measured in (mm/min) and(mm/hour) , as well as the infiltration rate curve calculated by integrate the cumulative infiltrated equation I= 5.842t ^0.544 . The correlation coefficient between the measured and calculated infiltration rate is R= 0.98.

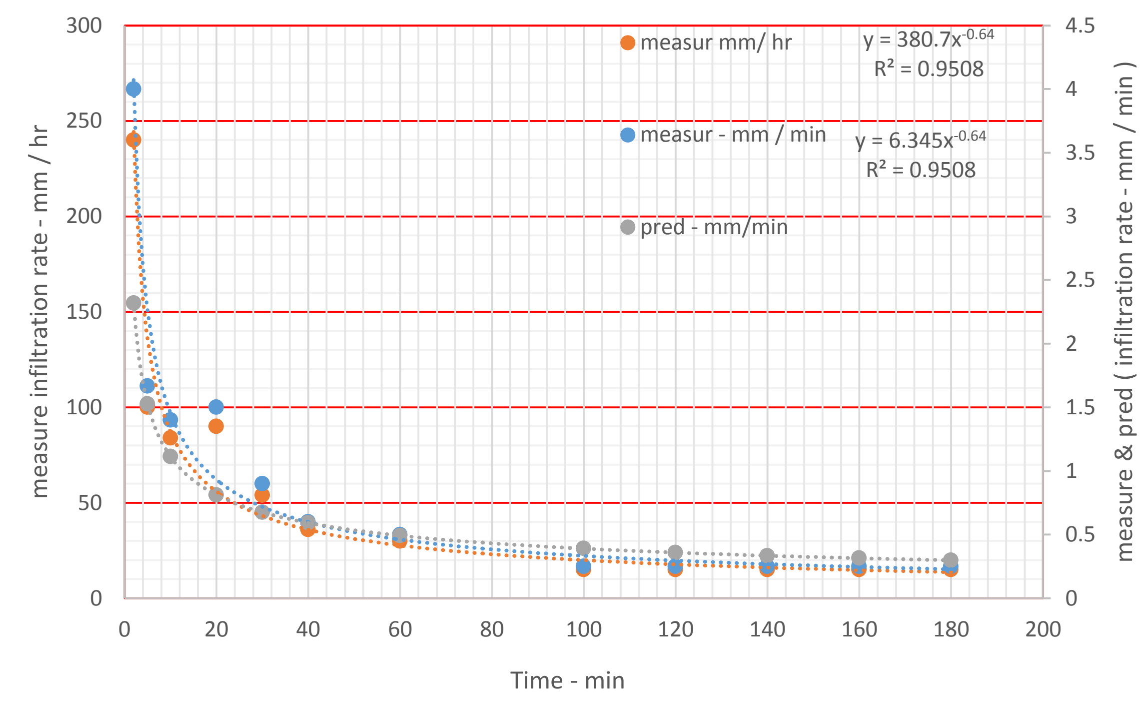
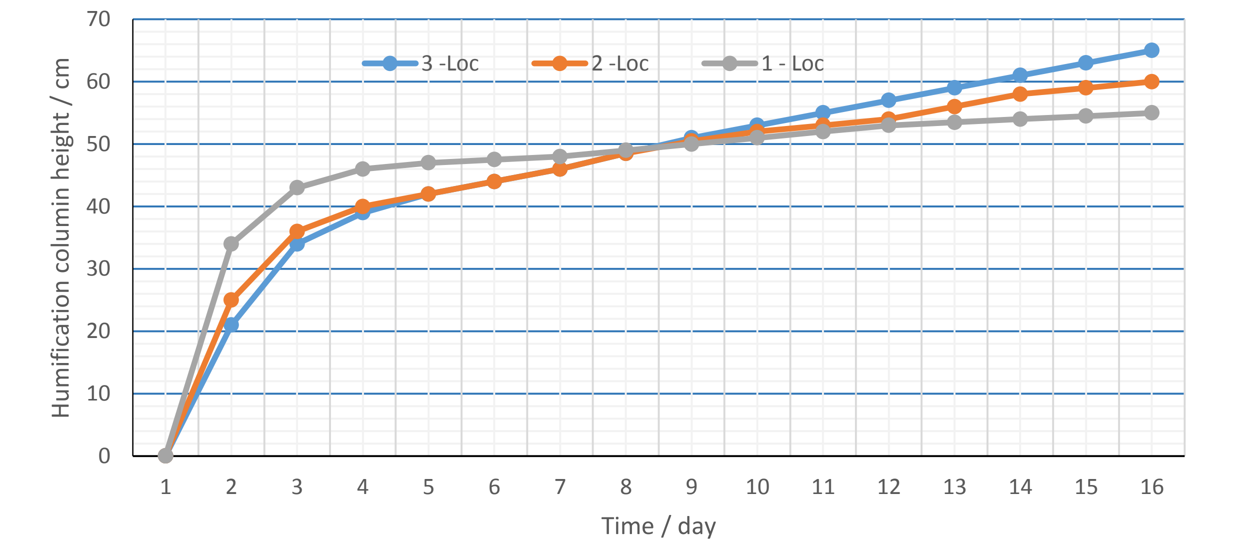


Figure (11) Soil infiltration rate with time (third - Loc)

From the curve (9) (10) and (11) it is clear that the value of the initial infiltration rate of predicted reading

The figure (12) shows the effect of soil texture for the three location on the capillary water rise . The effect is more evident in sandy loam soil, while the effect of silty clay soil became clearer after eight



Figer (12) Height of the humidification column over time

days of the experiment.

The figure(13) shows that the rate of rising capillary action is more pronounced in sandy soil, where it reaches (34 cm/day). This rate decreases, especially after the fourth day, when the rate of water capillary rise in silty clay soil increases compared to the another soils.

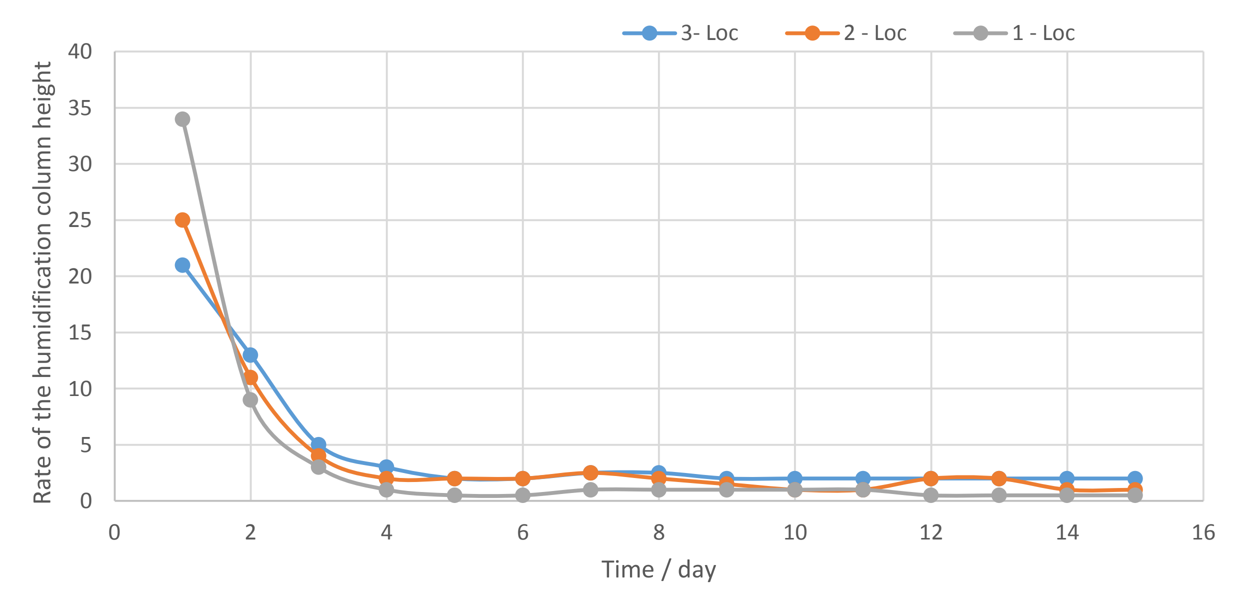


Figure (13) Rate of the humidification column height over time

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Conclusions :

The conclusion of this study showed that the predicted values of cumulative infiltrated depth of the studied soil with texture (sandy loam , loam and silty clay) by Kostiakov equation were best fit with the measured value at all locations . Also, the calculated values of infiltration rate were best fit with the measured value , the initial infiltration rate value of predicted reading is less than it s measured reading at all sites.

Conflict of interest
The authors have no conflict of interest with the publication of this research.

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