

Excel Approach for Infiltration Capacity for Different Lands

ABSTRACT

This paper presents an Excel approach for infiltration capacity for different types of lands. That is to employ the popular Microsoft Excel software to represent the measured infiltration data graphically. Regression analysis is performed for the accumulated infiltration versus the time. Equations are obtained to predict the accumulated infiltration at required times.

Thirty one raw infiltration measurements from various sources are gathered, studied and analyzed applying this approach. Measurements include different types of soil textures and land covers. The infiltration rates are measured by the commonly used infiltrometer. Both single infiltrometer and double infiltrometer are employed. It is concluded that the presented polynomial infiltration model of Excel approach for the accumulated infiltration is associated with high accuracy, where the values of coefficient of determination (R^2) range between 0.9850 and 0.9998. The obtained equations can help in irrigation processes.

All the gathered raw experimental infiltration measurements are also analyzed employing both Horton and Kostiakov infiltration models. It is found that the polynomial infiltration model of Excel approach has higher accuracy, followed by Kostiakov infiltration model, and finally Horton infiltration model. Also, the values of different constants of Horton and Kostiakov infiltration models for all cases are obtained.

Keywords: accumulated infiltration, single infiltrometer, double infiltrometer, Horton infiltration model, Kostiakov infiltration model, runoff, irrigation.

1. INTRODUCTION

Infiltration occurs when water on the land surface enters into the soil. Infiltration rate is the rate at which soil is able to absorb rainfall or irrigation water. It decreases as the soil becomes saturated. When the precipitation rate exceeds the infiltration rate, runoff will occur. It is related to the saturated hydraulic conductivity of the near-surface soil.

The process of infiltration continues when there are spaces for additional water at the soil surface. The available volume for additional water in the soil depends on the porosity of the soil. The infiltration capacity is the maximum rate that water can enter a soil in a given condition.

There are several methods to predict the rate of infiltration. For uniform initial soil water content and a deep well-drained soil, there are some approximate methods to solve for the infiltration such as the Green and Ampt method [1] and [2]. It is a function of the soil suction head, porosity, hydraulic conductivity and time. There are also empirical methods such as Horton and Kostiakov methods.

Horton method [2] and [3] suggested that infiltration capacity declines rapidly and tends towards an approximately constant value. It is an empirical formula showing that infiltration starts at some value and is decreasing exponentially with time. After some time when the soil saturation level reaches a certain value, the rate of infiltration tends to a constant rate.

Kostiakov method [4] includes an empirical equation assuming that the intake rate declines over time according to a power function. The major limitation of the equation is its reliance on the zero final intake rates. In most cases the infiltration rate instead approaches a finite steady value, which in some cases may occur after short periods of time.

The Kostiakov-Lewis method [5], also known as the “Modified Kostiakov” equation, corrects for this by adding a steady intake term to the original equation.

The rate of infiltration is often measured in millimeters per hour or inches per hour. It can be measured using an instrument that called infiltrometer. The common double infiltrometer, [6] and [7], is shown in figure 1 with

falling head and constant head arrangements. There is also a single infiltrometer, [8] and [9], which is illustrated in figure 2.

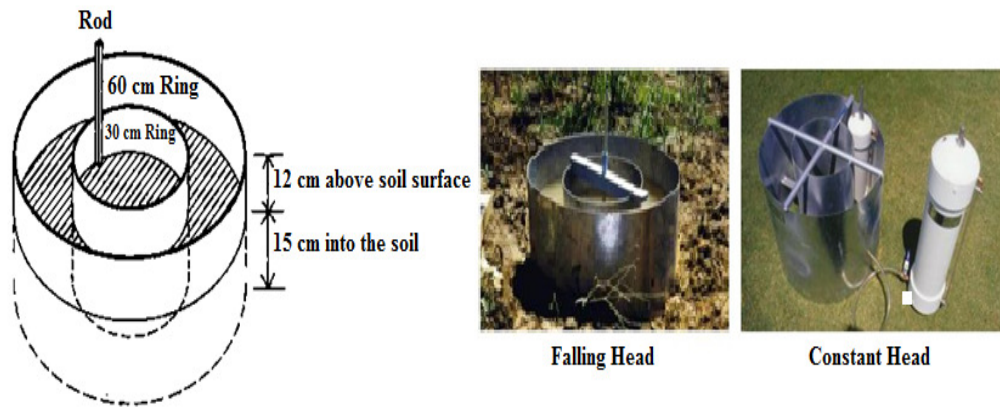


Fig. 1. Double infiltrometer, [6] and [7]

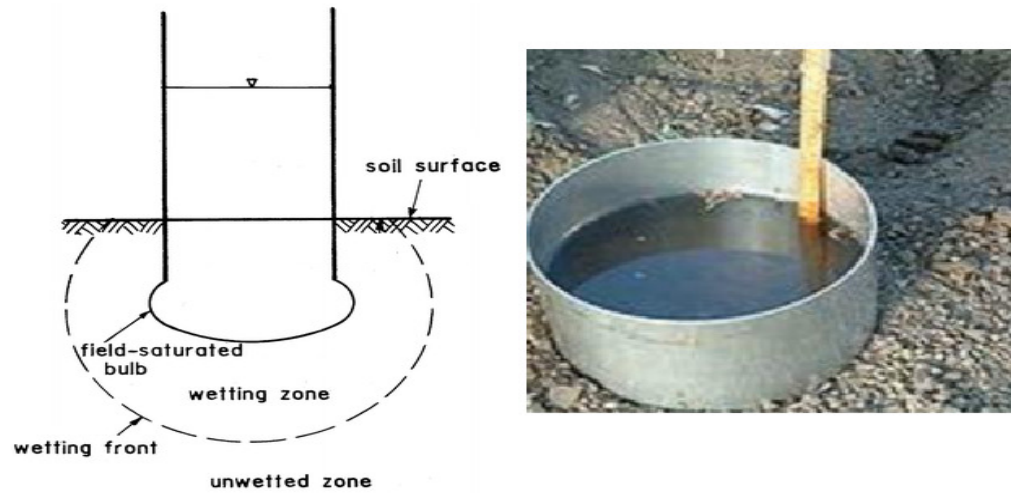


Fig. 2. Single infiltrometer, [8] and [9]

The infiltration rate is affected by soil characteristics including the soil texture and structure, water content of the soil, and types of land cover. Many researches are done to investigate the effect of these parameters on the infiltration rate. For example, effect of specific grazing land conservation practices on watershed processes is necessary for future planning and resource allocation, [10]. Also, vegetation and/or better land management can prevent soil from drying out quickly, which is important in agriculture and irrigation practices, [11].

An Excel approach for infiltration capacity for different types of soils and land covers is introduced. That is to employ the popular Microsoft Excel software to represent the measured infiltration data graphically. The accumulated infiltration is plotted versus the time. Polynomial regression analysis is performed for the accumulated infiltration against the time. Equations are obtained easily to predict the accumulated infiltration. The introduced polynomial infiltration model of Excel approach for the accumulated infiltration has higher accuracy than the widely used Horton and Kostikov infiltration models.

2. MATERIALS AND METHODS

An Excel approach for infiltration capacity for different types of soils is introduced. That is to employ the popular Microsoft Excel **software** to represent the measured infiltration data graphically. The accumulated infiltration is plotted versus the time. Regression analysis is performed for the accumulated infiltration against the time. Equations are obtained to predict the accumulated infiltration at required times. The obtained equations can help in irrigation processes. It is possible to determine how long it will take to infiltrate a certain amount of water, which is important to determine the irrigation time and quantity. **Thirty one** raw infiltration measurements from various sources are gathered, studied and analyzed applying this approach. Raw infiltration measurements include various locations with different types of soil textures and land covers. The studied infiltration rates are measured by the commonly used infiltrometer. Both single infiltrometer and double ring infiltrometer are used for these measurements. All the gathered raw experimental infiltration measurements are also analyzed employing both Horton and Kostiakov infiltration models. The values of different constants of Horton and Kostiakov infiltration models for all cases are obtained.

3. RESULTS AND DISCUSSION

All the gathered **thirty one** raw infiltration measurements from various sources represent field tests. In dry soil, water infiltrates rapidly, which is called the initial infiltration rate. As more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches a steady rate, which is called the basic infiltration rate, [6]. It is recommended that at least two infiltration tests should be carried out at a site to make sure that the correct results are obtained. Also, the infiltration curve should be determined for normal soil moisture conditions before irrigation takes place (usually when the top soil is dry), [6].

Experimental infiltration measurements are carried out at an irrigated farm, [6], with loam soil using a double ring infiltrometer with inside diameter of 30 cm and outside diameter of 60 cm, as shown in table 1. Excel approach is applied on the raw infiltration data, where figure 3 illustrates the accumulated infiltration versus the time, a polynomial regression, and the obtained equation with a very high **coefficient of determination** R^2 . For the obtained equation; AI is the acc. (accumulated) infiltration in mm, and T is the time in min. (minutes).

Table 1. Raw measurements, [6], for infiltration in loamy irrigated farm with a double ring infiltrometer

Time, min	Accumulated Infiltration, mm
2	8
5	15
10	25
20	42
30	53
40	60
60	69

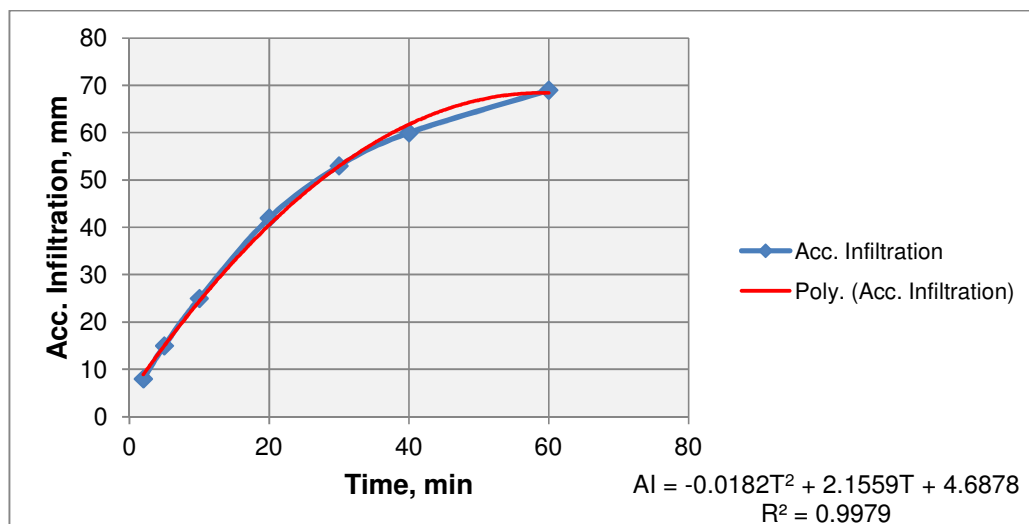


Fig.3. Accumulated infiltration and the obtained equation in loamy irrigated farm

Excel approach is applied on another experimental infiltration measurements that are carried out at an irrigated land, [12], with sandy clay loam soil using a double ring infiltrometer with diameters of 30 cm and 60 cm. Raw infiltration data are shown in table 2, while figure 4 illustrates the accumulated infiltration versus the time, the polynomial regression, and the obtained equation with a very high R^2 .

Table 2. Raw measurements, [12], for infiltration in sandy clay loam irrigated land with a double ring infiltrometer

Time, min	Accumulated Infiltration, mm
1.0	14
1.5	24
2.0	33
2.5	40
3.0	46
3.5	52
4.0	58
4.5	63
5.0	68

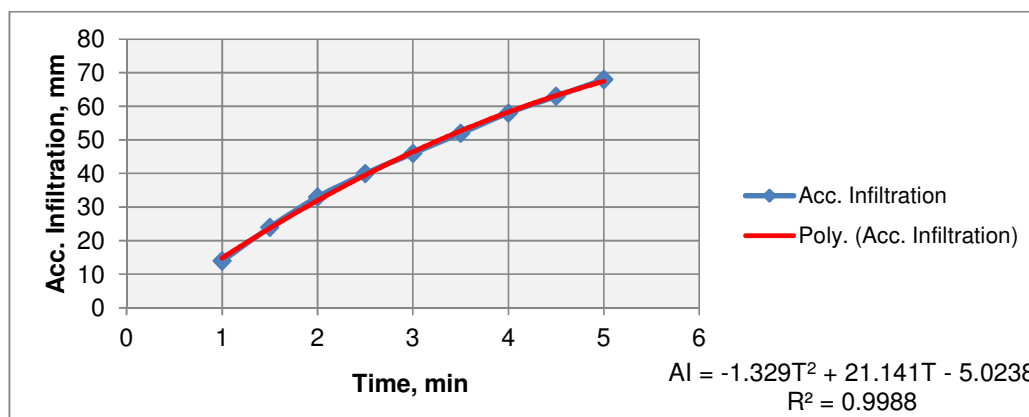


Fig.4. Accumulated infiltration and the obtained equation in sandy clay loam irrigated land

Using a double ring infiltrometer with diameters of 30 cm and 60 cm, experimental infiltration measurements are performed at ten locations in two different agricultural lands, [13]. Soil texture analyses and land covers are shown in table 3. The raw infiltration data for the accumulated infiltration are presented in tables 4 and 5. Applying Excel approach, figures 5 and 6 illustrate the accumulated infiltration versus the time, the polynomial regression, and the obtained equations with very high R^2 .

Table 3. Soil texture analysis, [13], and land covers for two different agricultural lands

Location	Land Cover	% Sand	% Silt	% Clay	Soil Texture
A 1	Bare land	64	23	13	Sandy Loam
A 2	Bare land	69	18	13	Sandy Loam
A 3	Bare land	55	25	20	Sandy Clay Loam
A 4	Vegetation land	74	15	11	Sandy Loam
A 5	Vegetation land	71	20	9	Sandy Loam
B 1	Bare land	71	20	9	Sandy Loam
B 2	Bare land	77	16	7	Loamy Sand
B 3	Bare land	79	14	7	Loamy Sand
B 4	Vegetation land	51	32	17	Loam
B 5	Vegetation land	56	30	14	Sandy Loam

Table 4. Raw measurements, [13], for infiltration in the first agricultural land

Location	A 1	A 2	A 3	A 4	A 5
Time, min	Acc. Infiltration - A1, mm	Acc. Infiltration - A2, mm	Acc. Infiltration - A3, mm	Acc. Infiltration - A4, mm	Acc. Infiltration - A5, mm
5	19	24	24	28	26
10	26	33	45	37	50
15	30	37	63	44	65
20	33	39	69	47	76
25	36	41	75	50	87

Table 5. Raw measurements, [13], for infiltration in the second agricultural land

Location	B 1	B 2	B 3	B 4	B 5
Time, min	Acc. Infiltration - B1, mm	Acc. Infiltration - B2, mm	Acc. Infiltration - B3, mm	Acc. Infiltration - B4, mm	Acc. Infiltration - B5, mm
5	61	86	50	51	95
10	109	139	79	90	172
15	150	183	101	117	240
20	186	221	126	140	280
25	208	250	147	154	317
30	229	277	166	167	349
35	250	304	185	180	381

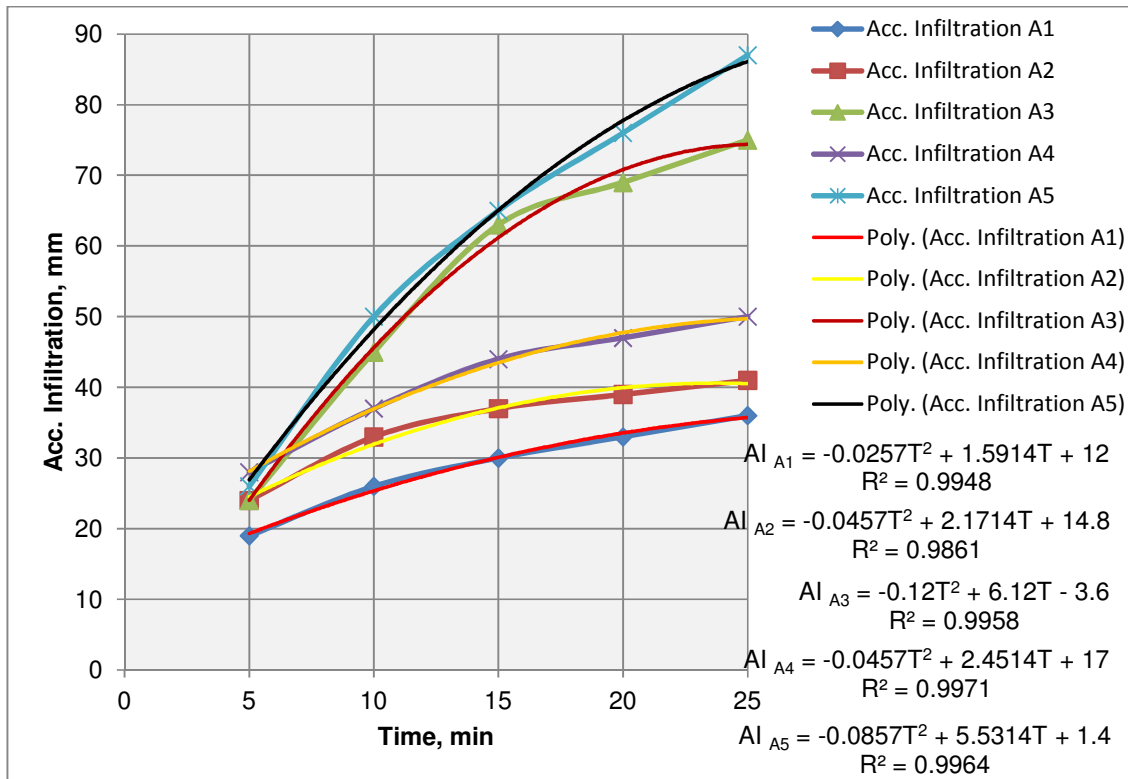


Fig.5. Accumulated infiltration and the obtained equations for the first agricultural land

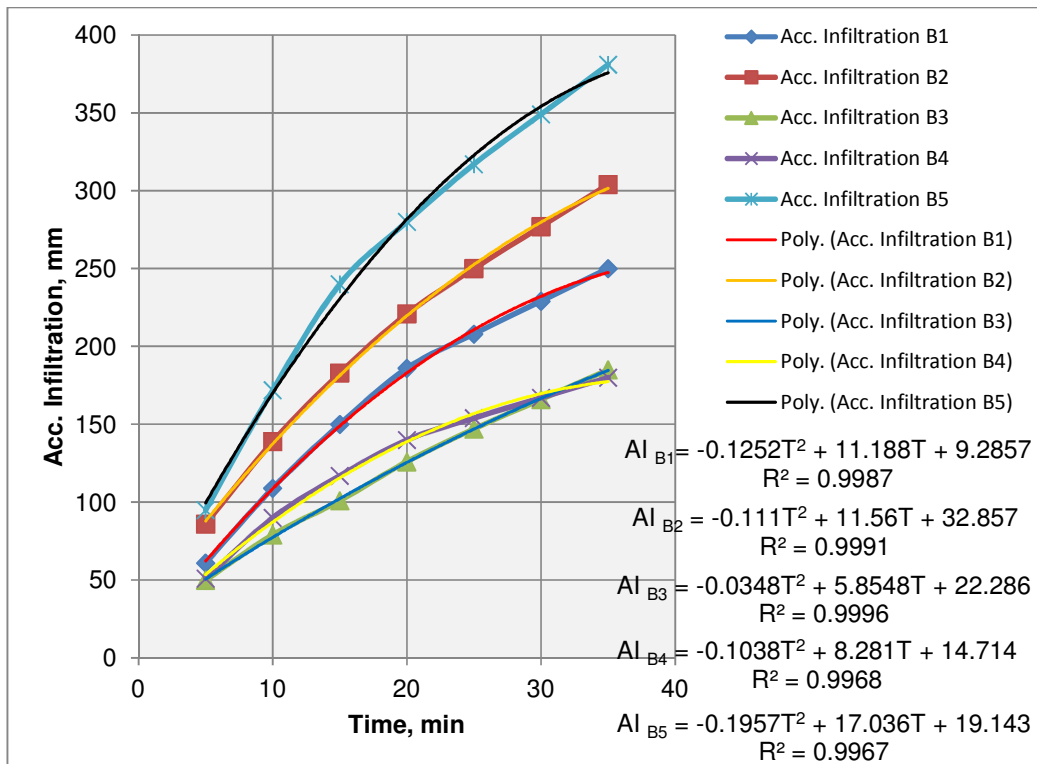


Fig.6. Accumulated infiltration and the obtained equations for second agricultural land

Employing a double ring infiltrometer with diameters of 45 cm and 60 cm, experimental infiltration measurements are executed three different times for a forest land, [14], as shown in table 6. Excel approach is applied on the raw infiltration data, where figure 7 illustrates the accumulated infiltration versus the time, the polynomial regression, and the obtained equations with very high R^2 .

Table 6. Raw measurements, [14], for infiltration in a forest land with a double ring infiltrometer

Time, min	Experiment 1	Experiment 2	Experiment 3
	Acc. Infiltration 1, mm	Acc. Infiltration 2, mm	Acc. Infiltration 3, mm
10	40	20	16
20	75	31	25
30	100	40	31
40	120	49	35
50	135	57	38
60	150	62	41

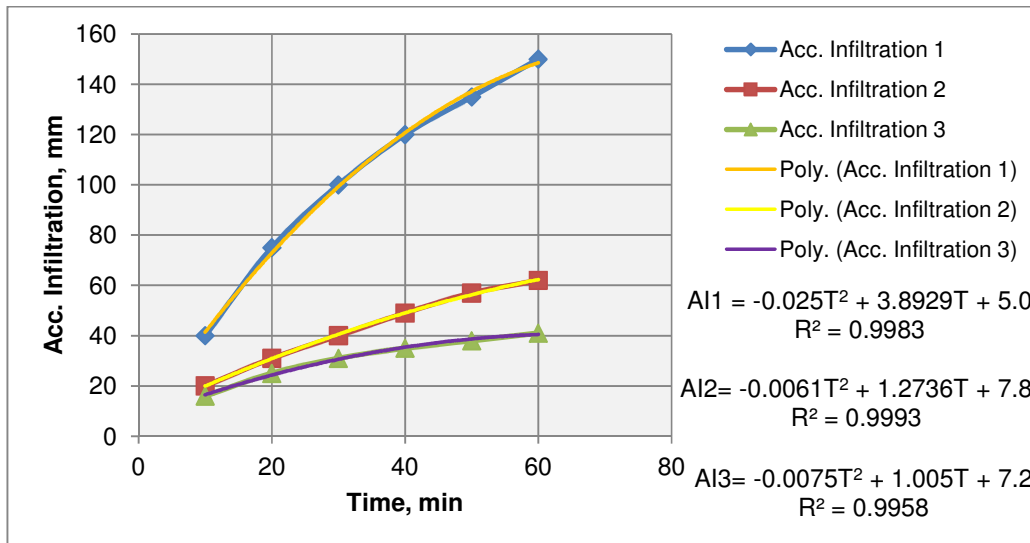


Fig.7. Accumulated infiltration and the obtained equation for a forest land

A single infiltrometer is employed to get experimental measurements for infiltration rates in a forest land, [14]. A single infiltrometer with 15 cm diameter obtained the infiltration measurements shown in table 7, and another single infiltrometer with 30 cm diameter gave the infiltration measurements shown in table 8.

Table 7. Raw measurements, [14], for infiltration in a forest land with 15 cm diameter single ring infiltrometer

Time, min	Experiment 4	Experiment 5	Experiment 6
	Acc. Infiltration 4, mm	Acc. Infiltration 5, mm	Acc. Infiltration 6, mm
10	15	13	12
20	20	15	17
30	25	17	22
40	28	19	25
50	30	21	27
60	32	23	29
70	34	24	---

Table 8. Raw measurements, [14], for infiltration in a forest land with 30 cm diameter single ring infiltrometer

Time, min	Experiment 7	Experiment 8	Experiment 9
	Acc. Infiltration 7, mm	Acc. Infiltration 8, mm	Acc. Infiltration 9, mm
10	10	18	17
20	15	26	24
30	20	33	31
40	25	40	36
50	30	47	41
60	32	53	44
70	---	---	47

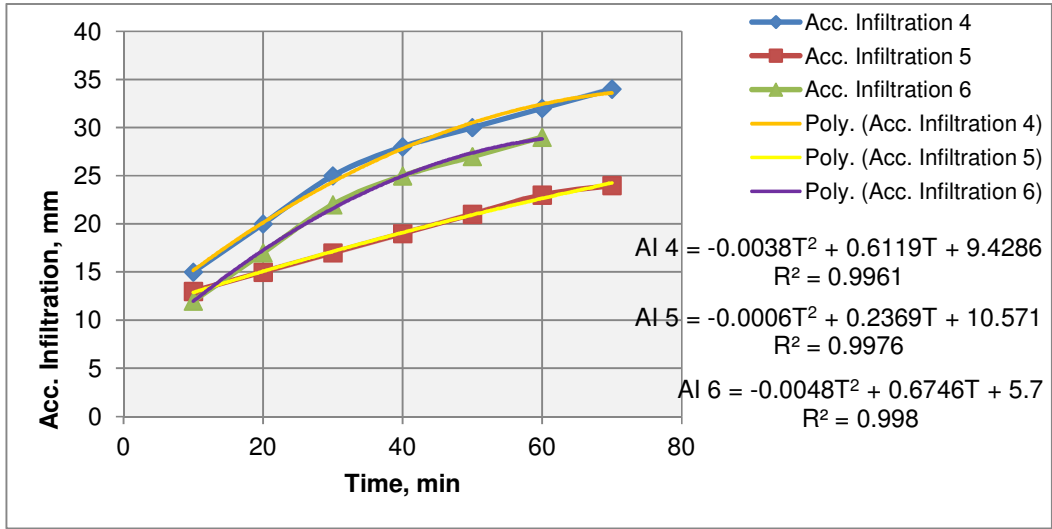


Fig.8. Accumulated infiltration and the obtained equation using 15 cm diameter single infiltrometer

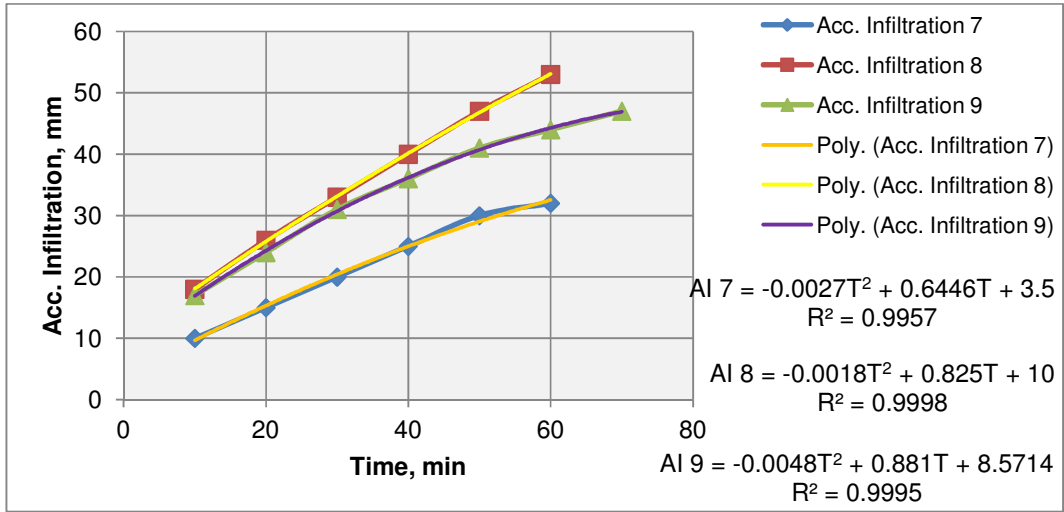


Fig.9. Accumulated infiltration and the obtained equation using 30 cm diameter single infiltrometer

Employing a double ring infiltrometer with diameters of 30 cm and 60 cm, experimental infiltration measurements are carried out for two types of soil textures, [15], which are shown in table 9. Applying Excel approach on the raw infiltration data shown in table 10, figure 10 illustrates the accumulated infiltrations versus the time, the polynomial regressions, and the obtained equations with very high R^2 .

Table 9. Soil texture analysis, [15], in two different sites

Depth, cm	Site 1	Site 2
0 – 30	Sandy clay	Sandy clay
30 – 60	Sandy clay	Clay

Table 10. Raw measurements, [15], for infiltration in two sites with different soil textures

Site	Site 1	Site 2
Time, min	Acc. Infiltration - 1, mm	Acc. Infiltration - 2, mm
5	44	05
10	122	17
15	228	37
20	356	66
25	504	104
30	668	151
40	862	213
60	1112	300

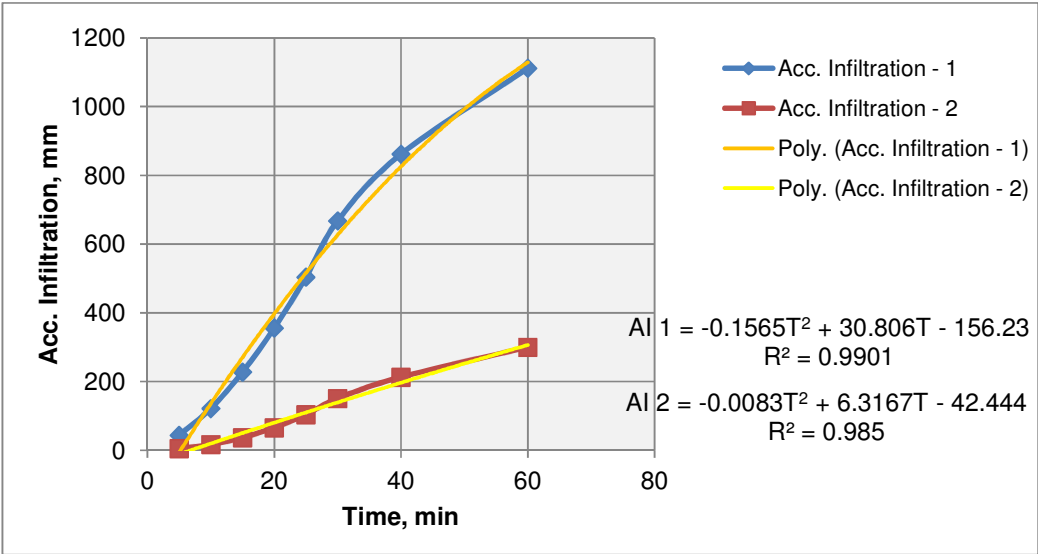


Fig.10. Accumulated infiltration and the obtained equation in two sites with different soil textures

Experimental infiltration measurements are performed at four different locations with various farming lands, [16], using a double ring infiltrometer. Soil texture analyses and land covers are shown in table 11. The raw data for the accumulated infiltration are presented in table 12. Excel approach is applied on the raw infiltration data, where figures 11 and 12 illustrate the accumulated infiltration versus the time, the polynomial regression, and the obtained equations with very high R^2 .

Table 11. Soil texture analysis, [16], and land covers for various farming lands

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Soil Analyses	Land Cover			
	Arable Cropland	Fallow Land	Cultivated Land	Pineapple Farm
% Sand	83	83	81	81
% Silt	2	2	1	2
% Clay	15	15	18	17
Soil Texture	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam

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Table 12. Raw measurements, [16], for infiltration in four different locations with various farming lands

Time, min	Acc. Infiltration - Arable Cropland, mm	Acc. Infiltration - Fallow Land, mm	Acc. Infiltration - Cultivated Land, mm	Acc. Infiltration - Pineapple Farm, mm
3	28	41	27	36
6	52	77	52	68
9	73	111	74	97
12	92	141	94	123
15	110	168	112	147
20	139	211	138	184
25	164	254	164	218
30	188	294	189	250
40	230	368	235	311
50	270	437	280	369
60	306	499	324	423
75	354	585	388	493
90	400	667	451	556
105	444	745	515	615
120	---	818	574	665
125	500	---	---	---
140	---	909	653	730
145	555	---	---	---
160	---	997	730	793
165	609	---	---	---
180	---	1084	807	856

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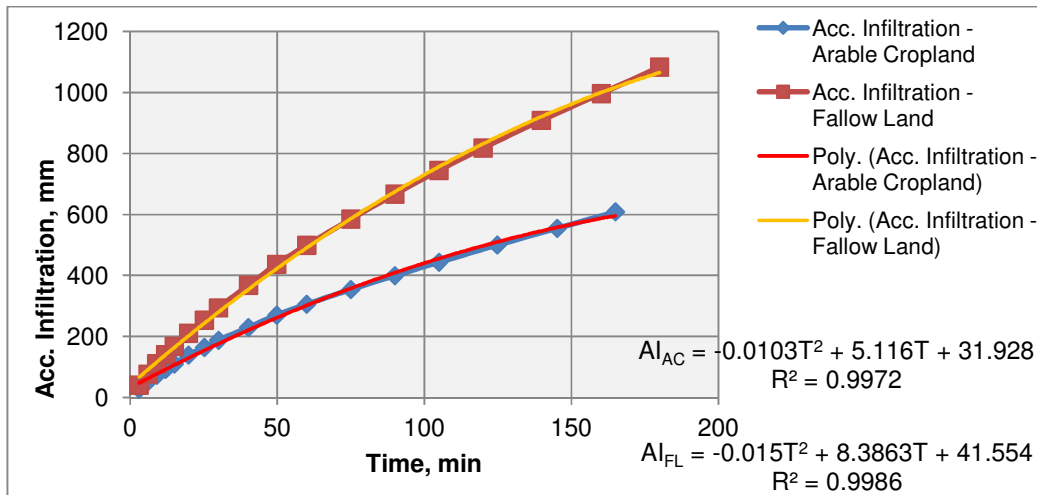


Fig.11. Accumulated infiltration and the obtained equations for two land covers

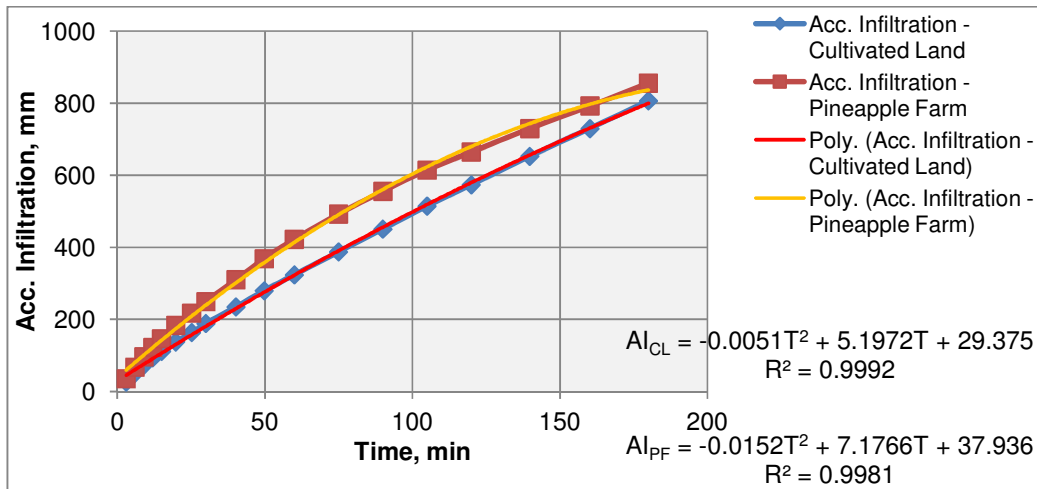


Fig.12. Accumulated infiltration and the obtained equations for other land covers

Experimental infiltration measurements are performed at four different locations with various farming lands, [17], using a double ring infiltrometer. Soil texture analyses and land covers are shown in table 13. The raw data for the accumulated infiltration are presented in table 14. Excel approach is applied on the raw infiltration data, where figures 13 and 14 illustrate the accumulated infiltration versus the time, the polynomial regression, and the obtained equations with very high R^2 .

Table 13. Soil texture analysis, [17], and land covers for various farming lands

Soil Analyses	Land Cover			
	Grazing Land	Secondary Forest	Cultivated Land	Plantain Plantation
% Sand	77	72	83	83
% Silt	7	12	9	11
% Clay	16	16	8	6
Soil Texture	Sandy Loam	Sandy Loam	Loamy Sand	Loamy Sand

Table 14. Raw measurements, [17], for infiltration in four different locations with various farming lands

Time, min	Acc. Infiltration - Grazing Land, mm	Acc. Infiltration – Secondary Forest, mm	Acc. Infiltration - Cultivated Land, mm	Acc. Infiltration – Plantain Plantation, mm
2	3.4	4.1	3.0	4.2
4	7.3	8.4	6.1	8.8
7	11.6	13.5	9.7	14.2
10	16.1	19.1	13.2	19.4
15	22.1	25.8	17.5	26.0
20	27.8	32.6	22.0	33.1
25	33.6	40.0	26.5	40.1
30	39.5	48.0	31.2	47.2
40	46.5	61.0	43.2	58.1
50	53.9	74.6	47.3	69.6
65	63.7	89.9	58.9	82.8
80	73.9	107.0	71.3	95.8
100	86.3	125.1	85.6	110.3
120	98.8	141.4	100.0	125.0
150	112.9	159.8	115.8	141.8
180	127.3	178.5	131.8	158.7

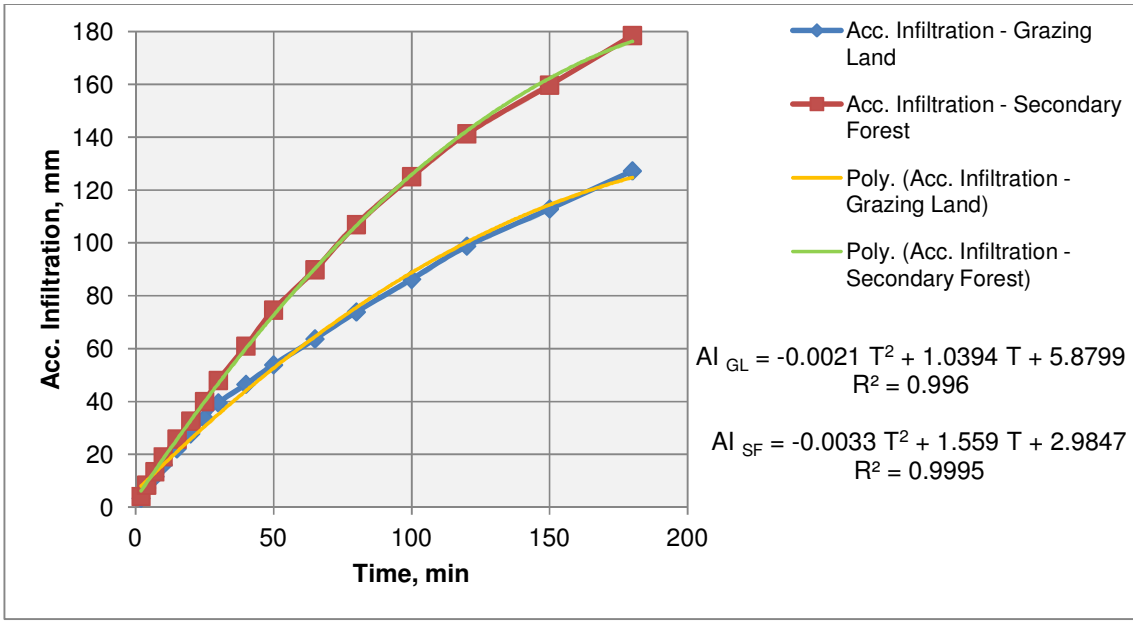


Fig.13. Accumulated infiltration and the obtained equations for two land covers

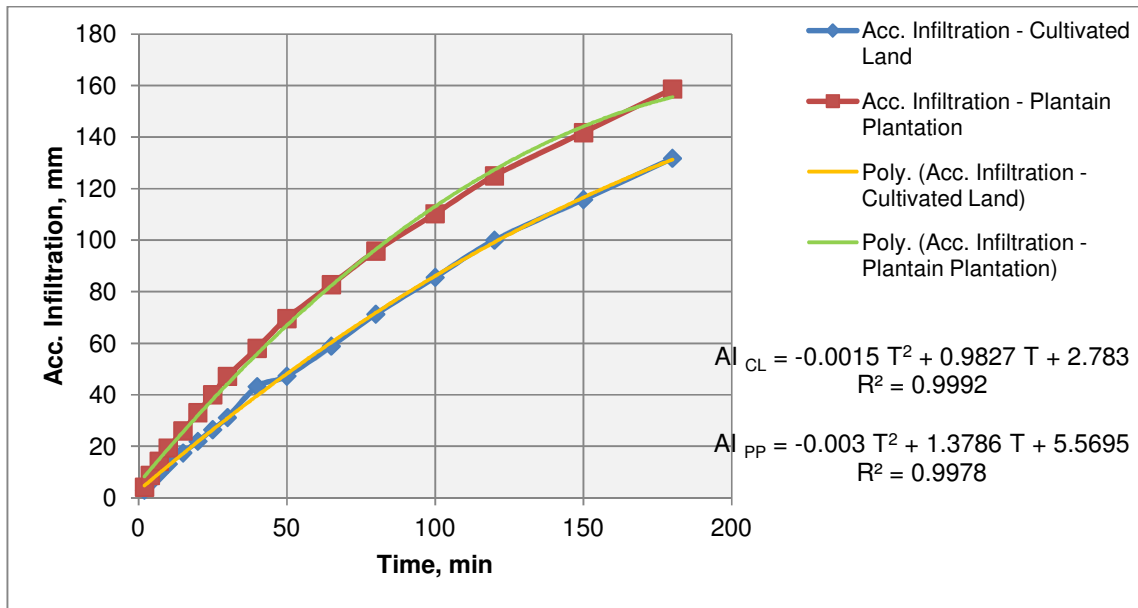


Fig.14. Accumulated infiltration and the obtained equations for other land covers

It is concluded from the last figures 3 through 14 that the Excel approach introduces a polynomial infiltration model, which has a very high accuracy representing the accumulated infiltration versus the time. The infiltration model of Excel approach can be expressed in general formula as in equation 1.

$$AI = A T^2 + B T + C \quad \dots\dots\dots (1)$$

Where: AI = Accumulated infiltration (mm),
T = Time from start (min),
A, B and C = Constants according to specific conditions.

To simplify the infiltration processes, several equations are developed for field applications. These empirical models relate infiltration rate or volume to elapsed time according to certain properties. Parameters used in these models can be estimated from measured infiltration - time relationships for a given soil condition. The empirical infiltration models include the two widely used Horton and Kostiakov models.

Horton infiltration model, [13], expresses the relation of infiltration capacity with time as an exponential function, as shown in equation 2.

$$f = f_c + (f_0 - f_c) e^{-kt} \quad \dots\dots\dots (2)$$

Where: f = infiltration capacity at any time t,
 f_c = final steady state infiltration capacity,
 f_0 = initial infiltration capacity,
k = Horton's constant representing rate of decrease in infiltration capacity,
t = time.

Kostiakov infiltration model, [13], presents a simple power function relating the infiltration with the time t, as shown in equation 3.

$$f = a t^a \quad \dots\dots\dots (3)$$

Where: f = accumulated infiltration at any time t,
t = time,
(a) and (a) are constants.

All the gathered **thirty one** raw experimental infiltration measurements are analyzed employing both Horton and Kostiakov infiltration models. The values of different constants of Horton (k) and Kostiakov (a and α) infiltration models and their **coefficient of determination** (R^2) for all cases are obtained, as illustrated in table 15. Also, table 15 includes R^2 associated with the infiltration model of Excel approach.

Table 15. Analyses of infiltration measurements employing Excel approach, Horton, and Kostiakov infiltration models

Case of Accumulated Infiltration	Polynomial model (Excel approach)	Exponential model (Horton equation)		Power model (Kostiakov equation)		
	R^2	k	R^2	a	α	R^2
Figure 3	0.9979	0.0333	0.7573	5.3206	0.6570	0.9912
Figure 4	0.9988	0.3536	0.8869	15.6810	0.9512	0.9846
Figure 5, A1	0.9948	0.0303	0.9176	10.2570	0.3930	0.9955
Figure 5, A2	0.9861	0.0248	0.8374	14.6390	0.3307	0.9651
Figure 5, A3	0.9958	0.0541	0.8433	8.0339	0.7216	0.9685
Figure 5, A4	0.9971	0.0280	0.8986	15.8010	0.3653	0.9901
Figure 5, A5	0.9964	0.0567	0.8818	8.2933	0.7452	0.9846
Figure 6, B1	0.9987	0.0432	0.8724	19.9910	0.7258	0.9914
Figure 6, B2	0.9991	0.0391	0.9039	30.9240	0.6487	0.9982
Figure 6, B3	0.9996	0.0413	0.9358	16.7430	0.6735	0.9993
Figure 6, B4	0.9968	0.0378	0.8520	19.4940	0.6413	0.9849
Figure 6, B5	0.9967	0.0419	0.8608	32.5460	0.7071	0.9875
Figure 7, AI1	0.9983	0.0244	0.8760	7.8515	0.7331	0.9886
Figure 7, AI2	0.9993	0.0220	0.9341	4.5577	0.6413	0.9992
Figure 7, AI3	0.9958	0.0174	0.8725	5.0249	0.5220	0.9875
Figure 8, AI4	0.9961	0.0128	0.8955	5.6979	0.4248	0.9947
Figure 8, AI5	0.9976	0.0104	0.9805	5.8504	0.3264	0.9748
Figure 8, AI6	0.9980	0.0169	0.9002	3.8234	0.5023	0.9934
Figure 9, AI7	0.9957	0.0232	0.9453	2.0771	0.6721	0.9956
Figure 9, AI8	0.9998	0.0211	0.9626	4.3522	0.6046	0.9960
Figure 9, AI9	0.9995	0.0162	0.9139	4.9529	0.5347	0.9977
Figure 10, AI1	0.9901	0.0536	0.7708	5.5437	1.3611	0.9829
Figure 10, AI2	0.9850	0.0688	0.7869	0.3393	1.7327	0.9862
Figure 11, AI _{AC}	0.9972	0.0151	0.7673	13.8910	0.7503	0.9971
Figure 11, AI _{FL}	0.9986	0.0147	0.8013	19.4030	0.7860	0.9991
Figure 12, AI _{CL}	0.9992	0.0154	0.8013	12.0960	0.8073	0.9991
Figure 12, AI _{PF}	0.9981	0.0141	0.7582	18.0450	0.7592	0.9962
Figure 13, AI _{GL}	0.9960	0.0156	0.6907	2.5024	0.7772	0.9925
Figure 13, AI _{SE}	0.9995	0.0170	0.7094	2.6315	0.8370	0.9967
Figure 14, AI _{CL}	0.9992	0.0172	0.7401	1.8582	0.8302	0.9986
Figure 14, AI _{PP}	0.9978	0.0159	0.6958	2.9510	0.7914	0.9945
Average R^2	0.9967		0.8467		0.9906	

From the results in table 13, it is found that the polynomial infiltration model of Excel approach has higher accuracy, followed by Kostiakov infiltration model, and finally Horton infiltration model. The polynomial infiltration model of Excel approach has an average value of R^2 of **0.9967**, where the values of R^2 range between 0.9850 and 0.9998. Kostiakov infiltration model has an average value of R^2 of **0.9906**, where the values of R^2 range between **0.9651** and 0.9993. Finally, Horton infiltration model has an average value of R^2 of **0.8467**, where the values of R^2 range between **0.6907** and 0.9805.

It is noted that there is only one case where Horton infiltration model has more accuracy than Kostiakov infiltration model. This case concerns experiment 5 shown in figure 8. The reason may be due to inaccurate infiltration measurements, which are performed using a single infiltrometer. For this specific case, the polynomial infiltration model of Excel approach is still associated with higher accuracy.

The developed polynomial infiltration model describes very well all the experimental results within their associated time values. Attention has to be paid when concerning very low or very high time values, which are not employed in the experiment. Employing very low time values in the obtained equations may give false results (negative values) for the expected accumulated infiltration, such as case A3 in figure 5 that gives negative value for time of 1 min. The very high time values may be employed in the obtained equations only when the basic infiltration rate is not known, [6]. If the basic infiltration rate is known, then its value is added to predict the accumulated infiltration. If the basic infiltration rate is not known, the obtained equations are used carefully to avoid false results for the expected accumulated infiltration.

In fact, many factors affect infiltration such as moisture content, soil texture and structure, porosity and permeability, soil bulk density and compaction, vegetative cover, root depth and organic content, slope, and topography. For each specific location, the infiltration depends on some parameters that are commonly got from various measurements.

One or some of the infiltration models are better and appropriate for a specific site, [18], where Horton's model was better than the Kostiakov-Lewis and Philip's models at most sample points in the studied area. Another study was conducted to evaluate Philip and Kostiakov infiltration models on three different soils, [19]. Philip model gave the best prediction of water infiltration in coastal plain sands soil, while the Kostiakov model was best for soils of sandstone and river alluvium. It is noted that this study concerned only with investigating the effect of soil texture on the infiltration, and neglected the effect of other factors such as moisture content, land cover, slope and topography. However, infiltration models have to be tested for the ability to estimate the infiltration of each location and it has to be documented at each site.

4. CONCLUSIONS

It is concluded that the presented polynomial model of Excel approach for the accumulated infiltration is associated with high accuracy, where the values of coefficient of determination (R^2) range between 0.9850 and 0.9998. The obtained equations can help in irrigation processes. It is possible to determine how long it will take to infiltrate a certain amount of water, which is important for irrigation purposes.

It is found that the polynomial infiltration model of Excel approach has higher accuracy, followed by Kostiakov infiltration model, and finally Horton infiltration model.

However, infiltration models have to be tested for the ability to estimate the infiltration of each location and it has to be documented at each site.

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