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A Comparative Study to Assess the Suitable Models for Predicting the Infiltration Rate in an Arid Region

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A B S T R A C T

Surface infiltration plays an important role in watershed management and flood forecasting; Furthermore increase the efficiency of irrigation system and reduce water losses during the irrigation process. Experiments carried out on the Wadi AL-Ratga of the western desert, Iraq during 2019; which had been selected as a study area. The infiltration rate data were collected using double ring infiltrometer at selected ten points of the selected study area. The duration of double ring test ranged between 30 minutes to one hour based on the infiltration speed in the soil, about 6 to 12 readings were recorded for the infiltration rate at each points. The aim of this paper is to check the ability of the common infiltration models such as Horton's, Kostikov's and Philip's to accurate estimated infiltration rate. These models were fitted to the observed infiltration data for estimation of models parameters and to find appropriate model for this region. Horton's infiltration model's parameters such as infiltration decay constants 'k' And the value of infiltration capacity at onset of infiltration (*fo*) had been calculated in the ranges of 3.38-6.97 hr^{-1} and 21 to 47.8 $cm.hr^{-1}$; respectively; for all the ten points. Philip's infiltration model's parameters such as the values of conductivity constant 'A' and sorptivity 'S' were obtained in the ranges of 3.48-12.49 $cm.hr^{-1}$ and 9.96 to 17.2 $cm/hr^{0.5}$; respectively. Similarly; the Kostikov's model's parameters 'a' and 'b' were obtained in the range of 8.85-24.38 and 0.732-0.829; respectively. Based on results of infiltration models at the selected points the predicated parameters have realistic capability predication. The results showed that all models provided the acceptable values for Root Mean Square Error (RMSE) as1.45, 2.01, 1.88 $cm.hr^{-1}$ for Horton's, Kostikov's and Philip's model; respectively; The highest model efficiency (ME) as 99% for all models; and the maximum Relative Error (RE) values as 16% at all points except point 2 was calculated as 21%. This indicated that infiltration can be well-described by the Horton's model little more than other models at the study area.

1. Introduction

The hydrological cycle consists many elements in its formation, water is the main component of it, which takes several patterns depending on its environmental conditions and climatic factors. Surface infiltration is considered one of the most important of these elements, which is known as the process of transferring or entering the rain or irrigation water from the soil crust to the internally (Essig et al., 2009; Feki et al., 2018). Soil and hydrology scientists have focused on this process in particular because of its fundamental importance in surface and groundwater hydrology, irrigation and agriculture systems (especially in arid areas such as the Western Iraqi Desert where they are located). Infiltration is considered as one of the primary issues for water conservation and give a decent irrigation system, through which it is conceivable to know the amounts of water that will be lost during precipitation or irrigation (Rahman et al., 2016; Patle et al., 2019).

Anticipating soil infiltration rates is one of the most significant viewpoints in arranging planning and overseeing of groundwater energize frameworks, flood retainers, and other infiltration frameworks. Information on soil infiltration rates decides the soil ability to absorb surface water and eventually how much of the field or land surface is needed to meet the infiltration requirements of the engineering system.

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Furthermore, during the utilization of the irrigation water to the field of farming, infiltration phenomenon was found as one of the most basic process to effectively control on the surface irrigation during the irrigation process consistency and expanded the irrigation effectiveness (Walker et al., 2006; Rashidi and Seyfi, 2007)

The amount of water that reaches the ground vertically down per unit time is called the infiltration rate (Haghiabi et al., 2011). On the other hand, the amount of water that enters the soil at a certain time and expressed in terms of length is called cumulative infiltration whereas, the rate at which the infiltration becomes constant during certain time periods is called the final (or constant) infiltration rate. There are a various factors that influence the water infiltration in the soil, the most significant of these variables are initial soil water content, porosity, texture, construction, the presence of cracks and the rate of addition of water to the soil(Hagnazari et al., 2015). The inherent factors that influence soil infiltration, for example, the fraction of clay, silt and sand (soil texture) cannot be changed. The (USDA, 1993) reported that soil texture is the main factor influencing infiltration). Water moves faster through big pores of sandy soil than through little pores of clay, especially when the soil is compacted and has almost no aggregation or structure.

Commonly, infiltration measurements are performed in situ. The double rings inflometers are often utilized to measure infiltration because the process is simpler and the instrumentation is easy (Reynolds et al., 2002). They comprise of two simple concentric cylinders and a simple grip; double rings inflometers are generally economical and can be effectively manufactured. Nonetheless, Simple specifications, including internal and external cylinders, height, and structure material must be followed. Information can be effortlessly gathered with a DRI utilizing a stop watch and ruler under falling head conditions. The methodology necessitates that the client records the water level inside the internal ring at various time interims while keeping up the water level in the external ring at a comparable level as in the inward ring (Reynolds et al., 2002). Another method can be utilized to determine the infiltration rates are the cylinder infiltrometer (Bouwer, 1986). cylinder infiltrometer is packed with water and maintained a constant water level in the cylinder; at the same time as measuring the flow of water into the cylinder. The primary source of blunders in single-ring cylinder infiltrometer measurements is divergence of water leakage in the soil because of lateral unsaturated leakage (Bouwer, 1986; Bouwer, 1960). This divergence leads to overestimated of the infiltration measurements in the cylinder, especially if the soil has a finer texture. Double-ring infiltrometers limit the mistake related with the single-ring method because the height of the water in the external ring powers vertical infiltration of water in the internal ring (Bouwer, 1986). Fig.1 Shows the installation method of double ring infiltrometer and its geometries (Raghunath, 2006).

In the present study, measurements of soil infiltration were carried out at ten sits of the study area during August 2019 by using double ring infiltrometer. These data were collected in the summer season, when the soil was completely dry and have homogenous conditions. Double ring infiltrometer consists of two parts, one of which is an outer ring with a diameter of 50 cm and the other is an inner ring with a diameter of 30 cm. The infiltrometer ring is pushed 10 cm into the ground (Fig.2). The mallet should strike consistently on steel plate which is put on the highest point of the rings without upsetting the bottom surface. Water is filled to the same level in both rings. The infiltrometer water depth is recorded regularly until a constant infiltration rate is reached. At each site a three trials of infiltration test was performed, then the average values of infiltration readings were taken. To identify the soil texture; about 5-6 kg of soil sample was brought from the near site of infiltration test.

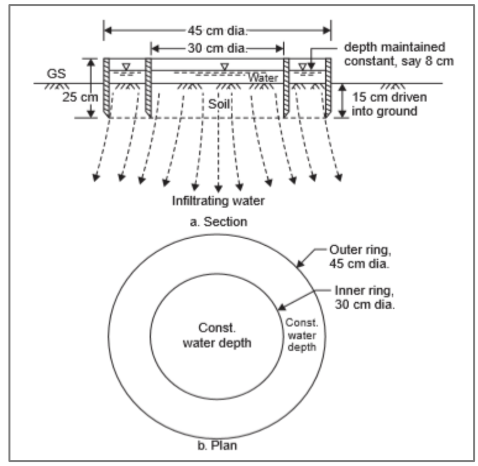


Fig.1 Double Ring Infiltrometer

Fig.2. Field infiltration test

There were several models for infiltration prediction (Horton, Mezencey, Kostikov, Green-Ampet, Soil Conservation Services, Philip and others) had been created in order to identify the infiltration rate of the soil and qualities. Because the infiltration rate depends mainly on the soil texture, not all models may applicable to all types of soils(Haghighi et al., 2010; Fashi et al., 2014). Many research studies were carried out to evaluate the parameters of the infiltration model and to approve these models for various soil conditions. (Roohian et al., 2005) recommended that Horton's model provides estimates of the final infiltration rate that is acceptable under certain soil texture conditions. However, complex factors that impact the final rate of infiltration are the main reasons for the different application of the model. (Musa et al., 2010) found that Kistove model was the best performer compared to the Philip and Horton model. (Sihag, et al.,(2017) examined the different infiltration models (SCS, Novel model, Kostiakov, and Changed Kostiakov) for the NIT Kurukshetra site. Unlike the other models with field infiltration data, Novel model are generally suitable. In a study in Taleghan watershed of Tehran Province, (Roohian et al., 2005) suggested that under a certain conditions of soil texture, the Horton model give good estimations of final infiltration rate.

The limitations of hydrological measurement data for deferent infiltration parameters needed to predict water runoff make managing water resources in the Iraqi desert in the western Iraq zone a challenge because of the very large catchments areas. Therefore; the objective of the present study is to find out the best suitable model among the Horton, Kostyakov and Philip models for estimation the soil infiltration and determine the parameters of these models in this region.

2. Materials and methods

2.1. Study area

The proposed research was conducted at wadi Al-Ratga, which is located in Anbar province(longitude 34o 17’ 41” to 32o 47’ 7”°, latitude 39o 38’ 11” to 40^o 46’ 46” , Area : 5579 km2 , elevation 268 to 836 m above mean sea level). This valley is considered one of the main valleys in the western desert of Iraq (Fig.2). The study area characterized by arid climate with an average annual rainfall of 150 mm. during the winter The maximum and minimum temperature were recorded as 7.5°C and 4.8°C; respectively. Similarly, the maximum and minimum temperature were observed during the summer as 47°C and 26°C; respectively (Husam, 2015). The present study was carried on the northern part of the Wadi Al-Ratga basin (about 320 km^2 from the total area). Based on the specific criteria, i.e. land cover, slope, soil roughness, topography, roads, and farmland areas; ten sits were selected for the field survey as shown in figure 3.

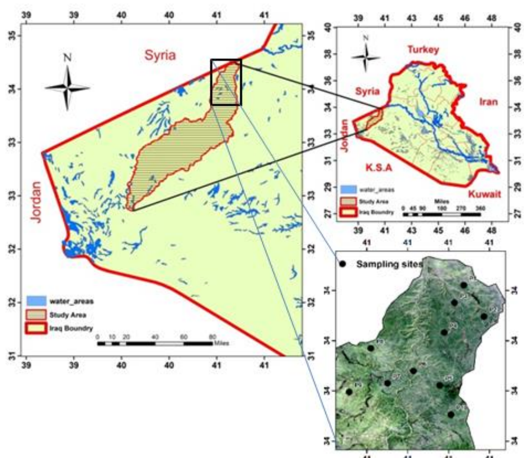


Fig.3. Description of the study with selected points

2.2. Infiltration models and parameters

Several models have been developed for field applications that Simplifying the concepts related to the soil infiltration process. three popular reference models were selected in this study, and model parameters were determined using data from the measurement field. Infiltration models; Philip, Horton and Kostikov were used for assessment. A concise description of above the selected models can be found below.

2.2.1. Horton’s model

(Horton, 1940) obtained an equation based on principle of energy and work to estimate the infiltration rate. Relation (equation (1) is given as:

$$f_p = f_c + (f_o - f_c)e^{-kt} \quad (1)$$

where f_o is the initial infiltration rate (cm/hr), f_c is the final infiltration rate (cm/hr) and t is time (hr), f_p is the infiltration rate at any time, k is the infiltration decay factor(1/hr). Horton model applicable for various soil that have homogenous conditions (Horton, 1940).

2.2.2. Kostikov’s model

(Kostikov, 1932) Suggested a simple experimental infiltration model based on the observed data at the site or in the laboratory. This model ties infiltration as an exponential function, as in Equation (2):

$$i = at^b \quad (2)$$

where, a and b are the empirical parameters, i is cumulative depth of infiltration depth (cm) and t indicate to the time elapsed for infiltration(hr).

2.2.3. Philip Model’s

(Philip, 1957) suggested an experimental model of infiltration by truncating the solution series from a pounded area. The resulting equation (3) is expressed as

$$f_p = 0.5St^{-0.5} + A \quad (3)$$

where: f_p is the infiltration rate (cm/hr), S is a sorption (cm/hr$^{0.5}$), t is a time (hr), A is the gravity component which is depending on hydraulic conductivity on saturation (cm/hr). The assumptions of this model are homogeneous soil condition and uniform water content as possible(Philip, 1957).

Appendix A represents an example arithmetic model for each equation in which it clarifies the method for calculating the constants of the above-mentioned equations.

2.3. Particle Size Distribution Test(PSD)

After soil samples gathered from 25cm depths in the field (fig.3), soil particle size distribution was conducted in the laboratory; where processed in the Soil Mechanics Laboratory in the college of Engineering-University of Anbar; to determine the texture of the these samples. The test is separated into three sections which are the destruction of organic matter, sieve analysis to collect the samples with particle size >20 µm, and silt and clay sampling using hydrometer analysis (ASTM D 422 –63 , 2007) Soil textural classes are categorized based on the ASTM system.

3. Results and discussions

3.1. Soil texture analysis

Based on the selected points at 10 locations in study area, results were analyzed. Soil properties of all sites showed slight difference among the ten sites selected (Table1). Soil textures at all points were mostly sandy loam and loam having sand fraction of 38% -69%, 27.1% -44.4% of silt fraction and 3.9-19.4 of clay fraction (Table1).

Table 1 – Soil texture of selected points.

points	Sand%	Silt%	Clay%	Texture class
P1	42.0	40.1	17.9	Loam
P2	69.0	27.1	3.9	Sandy loam
P3	53.0	33.7	13.3	Sandy loam
P4	55.0	37.6	7.4	Sandy loam
P5	55.0	34.4	10.6	Sandy loam
P6	44.0	44.4	11.6	Loam
P7	45.0	41.6	13.4	Loam
P8	38.0	42.6	19.4	Loam
P9	55.0	35.6	9.4	Sandy loam
P10	50.0	38.9	11.1	Loam

Overall analysis showed that all selected points had similar soil surface conditions and homogenous soil. sieve analysis for each ten points of the Hydrometers test was listed in Appendix B.

3.2. Models estimated parameter

The infiltration model's (Horton's ,Kostikov's, Philip's) parameters have been summarized in Table 2. According to the Horton's model's, at all of ten points the parameters such as decay factor 'k' was obtained in the range of 3.38 to 6.97 hr^{-1}. The values of initial infiltration capacity '*fo*' were is measured from double ring infiltrometer as 21 to 47.8 cm/hr. These parameters values can reflected the influences of physical properties of the soil on infiltration as well as initial soil moisture and surface conditions (Ogbe et al., 2011). The results indicated that Horton parameters k (decay factor) are related to the measured final infiltration rate (R^2 =0.748) at selected sample points(fig.4). The parameters a and b of Kostikov's model was estimated and found in range of 8.85-24.38 and 0.732-0.829 respectively. The decay constant values (b) are a positive value and less than unity, furthermore they indicated that these values ranged from 0.2 to 0.9 (Ogbe et al., 2011). The results indicated that correlation between Kostikov's parameters a and b was found (R^2=0.550) at selected sample points(fig.5). Similarly in the Philip's model, the infiltration parameters of sorptivity 'S' factor were estimated in the range of 9.96-17.2 $cm/hr^{0.5}$ and conductivity constant 'A' values were found as 3.48 to 12.49 cm/hr. For all selected points, the correlation between parameters of the Philip's model parameters S and A was very good and the relationship between them was significant (R^2=0.817) as shown in Fig.6.

Table 2 – Estimated parameter values for infiltration models

Points	Horton's model		Kostikove'smodel			Philip'smodel	
	K	Fo	Fc	a	b	S	A
P1	5.19	39.1	15.6	19.64	0.832	11.77	9.47
P2	3.71	47.8	16.8	24.38	0.827	15.47	11.03
P3	4.91	36.2	14.4	18.90	0.822	11.25	8.48
P4	5.61	39.5	16.8	20.14	0.829	12.06	9.88
P5	6.32	29.4	13.2	15.00	0.829	8.65	7.80
P6	5.86	34.8	14.4	17.27	0.821	10.67	8.27
P7	6.55	28.8	10.8	12.44	0.784	8.97	5.23
P8	6.97	32.7	13.2	14.94	0.786	10.90	5.96
P9	3.38	47.3	19.2	26.52	0.818	17.20	12.49
P10	7.28	21	8.4	8.85	0.732	6.96	3.48

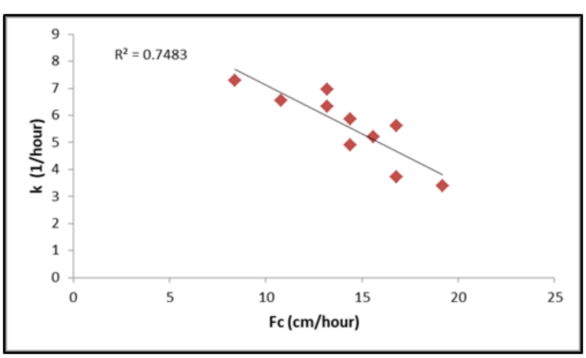


Fig.4 Correlation between decay factor(K) and Final infiltration rate (Fc)

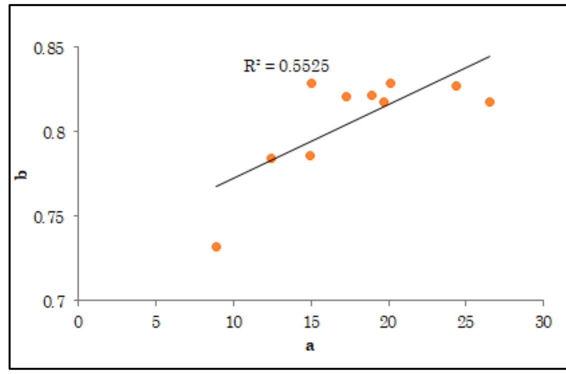


Fig.5 correlation between Kostikov's parameters a and b.

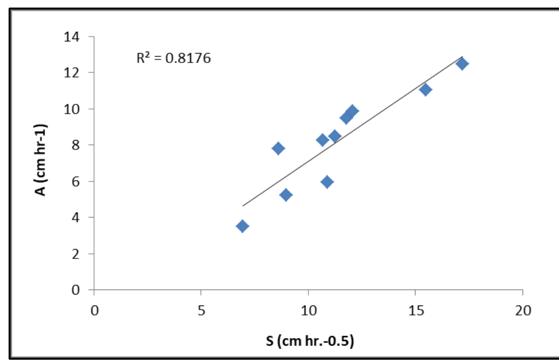


Fig.6 Relationship between sorptivity factor and parameter A obtained and by Philip's

3.3. Prediction of infiltration rate

Based on field measurements of infiltration rate at ten-locations of the study area, results were analyzed and individual curves at each points have been generated. At each location; three experiments were carried out to take the average values of infiltration readings, all experiments was carried in two weeks. Fig.7 summarized the results of measured and estimated infiltration rate, which is estimated by above-mentioned models. The values of the infiltration rate is observed to be closely agreement to the fields measured for the selected sites. However; the Kostikov model was under-estimated at Point 10 and over-estimated at Points 2, 3 for the final experimental stages. In the Philip's model; the analysis shows that the estimated infiltration value for all points except for point 2 close to the measured value. At this point the infiltration rate at the first period up to 45 min of the model predicated was over-estimated and after the period of 45 min the model matched the observed infiltration rate. The possible reason for this action to occur in point 2 only is that the soil at this point is near to sand (69%) more than sandy loam as given in Table 1. The estimated infiltration rate by the Horton's model also matched observed infiltration rate for all points excepted point 2 (because the same reason above mentioned) which slightly difference to the observed values (Fig.6).

the analysis of all models shows that this infiltration model, using infiltration parameters, has satisfactory predictability at all points selected because the model's performance indicators are within plausible limits, as explained in the next section. Table 4 illustrate the estimated and observed infiltration rate values.

Table 4 - estimated and observed infiltration rate values.

Points		Time/min											
		5	10	15	20	25	30	35	40	45	50	55	60
P1	f_m	28.80	24.60	22.80	20.4	18.60	17.40	16.80	16.20	15.60			
	f_H	30.85	25.49	22.02	19.76	18.3	17.35	16.74	16.3	16.08			
	f_K	30.87	23.55	21.40	20.12	19.21	18.52	18.00	17.50	17.11			
	f_p	29.86	23.89	21.25	19.67	18.59	17.80	17.18	16.68	16.27			
P2	f_m	36.00	31.20	27.60	25.80	24.00	22.80	21.60	20.40	19.20	18.00	17.40	16.80
	f_H	39.55	33.50	29.06	25.80	23.40	21.65	20.36	19.41	18.72	18.21	17.83	17.56
	f_K	37.47	29.00	26.48	24.97	23.90	23.08	22.42	21.87	21.40	21.00	20.64	20.31
	f_p	36.28	28.43	24.95	22.88	21.46	20.24	19.60	18.95	18.41	17.95	17.56	17.21
P3	f_m	27.60	22.80	20.40	19.20	18.00	16.80	15.60	15.00	14.40	14.40		
	f_H	28.87	24.01	20.78	18.64	17.21	16.27	15.64	15.22	14.95	14.76		
	f_K	29.41	22.59	20.57	19.36	18.51	17.86	17.33	16.89	16.52	16.20		
	f_p	27.97	22.26	19.73	18.22	17.19	16.43	15.84	15.37	14.98	14.64		
P4	f_m	30.00	25.20	23.40	20.40	19.20	18.00	17.40	16.80	16.80			
	f_H	31.03	25.72	22.4	20.30	19.00	18.18	17.66	17.34	17.14			
	f_K	30.80	23.92	21.86	20.63	19.75	19.08	18.55	18.10	17.71			
	f_p	30.87	24.75	22.04	20.42	19.32	18.50	17.87	17.36	16.94			
P5	f_m	22.80	18.00	16.80	15.60	14.40	13.80	13.20	13.20				
	f_H	22.77	18.85	16.54	15.17	14.36	13.89	13.61	13.44				
	f_K	22.94	17.81	16.28	15.36	14.71	14.21	13.81	13.48				
	f_p	22.76	18.38	16.44	15.28	14.49	13.91	13.45	13.09				
P6	f_m	26.40	21.60	19.20	18.00	16.80	15.60	15.0	14.40	14.40			
	f_H	29.92	220.8	19.11	17.29	16.18	15.50	15.07	14.81	14.65			
	f_K	29.94	20.66	18.8	17.69	16.91	16.31	15.83	15.43	15.08			
	f_p	26.75	21.34	18.94	17.51	16.53	15.81	15.26	14.80	14.43			
P7	f_m	20.40	16.80	14.40	13.20	12.00	11.40	10.80	10.80				
	f_H	21.23	26.84	14.30	12.83	11.98	11.48	11.20	11.03				
	f_K	21.28	15.36	13.71	12.74	12.06	11.55	11.14	10.80				
	f_p	20.77	16.22	14.20	13.00	12.18	11.57	11.10	10.72				
P8	f_m	25.20	19.20	16.20	15.00	14.40	13.80	13.20	13.20				
	f_H	24.11	19.31	16.62	15.11	14.27	13.80	13.53	13.39				
	f_K	25.43	18.42	16.46	16.30	14.50	13.88	13.39	12.99				
	f_p	24.84	19.31	16.86	15.40	14.40	13.67	13.10	12.63				
P9	f_m	42.00	33.60	30.00	27.60	26.40	24.60	24.00	22.80	21.60	20.400	19.20	19.20
	f_H	40.40	35.20	31.27	28.31	26.07	24.38	23.11	22.15	21.43	20.88	20.47	20.16
	f_K	41.69	31.80	28.90	27.17	28.94	25.01	24.26	23.63	23.10	22.64	22.23	21.86
	f_p	42.28	33.56	29.69	27.39	25.81	24.65	23.75	23.02	22.40	21.91	21.47	21.09
P10	f_m	15.60	12.00	10.20	9.60	9.00	8.40						
	f_H	15.27	12.14	10.44	9.51	9.01	8.73						
	f_K	17.23	11.38	9.89	9.02	8.43	7.99						
	f_p	15.45	12.00	10.44	9.51	8.87	8.40						

Note: f_m=measured infiltration rate(cm/hr); f_H = estimated infiltration rate by Horton's model(cm/hr); f_k = estimated infiltration rate by Kostikov's model(cm/hr); f_p = estimated infiltration rate by Philip's model(cm/hr)

4. Model perfomance

Comparison of the difference between the estimated and observed infiltration rate value are done to evaluate the infiltration rate based on performance evaluation parameters. Evolution of these models to select the best performance was carried out based on the model efficiency (ME) (also called Nash-Sutcliffe (NSE) efficiency)and root mean square error (RMSE) (Nash and Sutcliffe, 1970; Farid et al., 2019) In addition to the relative error (RE), maximum absolute error and mean bias error (MBE) have been considered; as described in (Kennedy and Neville, 1986)

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i-\hat{y}_i)}^2 \quad (4)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}(y_i-\hat{y}_i) \quad (5)$$

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{|y_i-\hat{y}_i|}{yi}\right) \quad (6)$$

$$ME = 1-\frac{\sum_{i=1}^{n}(\hat{y}_i-y_i)^2}{\sum_{i=1}^{n}(\bar{y}_i-y_i)^2} \quad (7)$$

$$RE = \frac{y-\hat{y}}{\hat{y}} \text{ x } 100\% \quad (8)$$

Where n is the number of samples, y_i is the measured values, $\hat{y}$ is the estimated values and $\bar{y}_i$ is mean of measured values.

The calculated values of performance indices such as MBE, ME ,MAE and RMSE for the all models showed a high realistic agreement (Table 5). At the selected points, all the models have great capacities for estimation of infiltration rate. The values of RMSE were calculated and found between 0.23 - 1.45 cm/hr for Horton's, 0.34 - 2.01 cm/hr for Kostikov's and 0.12 - 1.88 cm/hr for Philip's infiltration models. Whereas, The values of ME were found in range of 93.4% to 99.1% for Horton's , 87.3% to 99.2% for Kostikov's model and from 88.9 to 99.4 for Philip's model . Point 2 was recorded least values of ME compassion with other points because the soil at this point is near to sand (69%) more than sandy loam . However, the ME values at each points for all models were considered in acceptable limitation (Ritter and Muñoz-Carpena, 2013). MBE values also demonstrated the satisfactory estimation at all the selected points by the infiltration models. It was ranged between -0.008 to 0.554 for Horton, -0.146 to 0.98 for Kostikov's and from -1.93 to 0.470 for Philip's model. In the other hand, the MAE values fonud in range of 0.331 - 3.554, 0.612 -3.513, 0.24 -2.955 for the (Horton's, Kostikov's and Philip's model), respectively. Similarly; the comparison between measured and estimated average infiltration rate (i.e.; the cumulative infiltration depth divided by total period of the infiltration measured from begging of the test) for all tested models is further verified the prediction capability of these infiltration models (figure 8). For more assessment of the performances of these models, the predicted infiltration rate was estimated and compared with the observed data based on the Relative Error (%RE) values; as shown in Figure 9, It is obvious that the calculated values of RE at all selected points does not exceed 10 % for the Horton's, 21 for Kostikov's and 12% for Philip's for both case over-under of RE.

Table 5 - performance indices values between the observed and estimated

Points	Horton model's				Kostikov model's				Philip model's			
	RMSE	ME	MAE	MBE	RMSE	ME	MAE	MBE	RMSE	ME	MAE	MBE
P1	0.84	96.0	2.046	0.192	1.26	91.0	2.071	0.562	0.79	96.5	1.553	0.000
P2	1.45	93.4	3.554	0.354	2.01	87.3	3.513	0.980	1.88	88.9	2.925	-1.393
P3	0.70	97.0	1.275	0.216	1.38	88.3	2.121	1.103	0.57	98.0	0.977	-0.156
P4	0.57	98.2	1.027	0.171	1.05	93.9	1.538	0.356	0.64	97.8	1.363	0.097
P5	0.39	98.4	0.852	0.104	0.37	98.5	0.612	0.102	0.24	99.4	0.378	0.000
P6	0.43	98.7	0.707	0.022	0.68	96.7	1.026	0.249	0.31	99.3	0.490	-0.002
P7	0.36	98.7	0.831	0.136	0.68	95.4	1.440	-0.146	0.30	99.1	0.584	-0.005
P8	0.44	98.7	1.088	-0.008	0.34	99.2	0.784	0.019	0.37	99.1	0.660	0.001
P9	0.97	97.7	1.598	0.203	1.56	94.0	3.029	0.570	1.02	97.5	2.272	0.470
P10	0.23	99.1	0.331	0.051	0.81	88.8	1.625	-0.143	0.12	99.8	0.240	-0.007

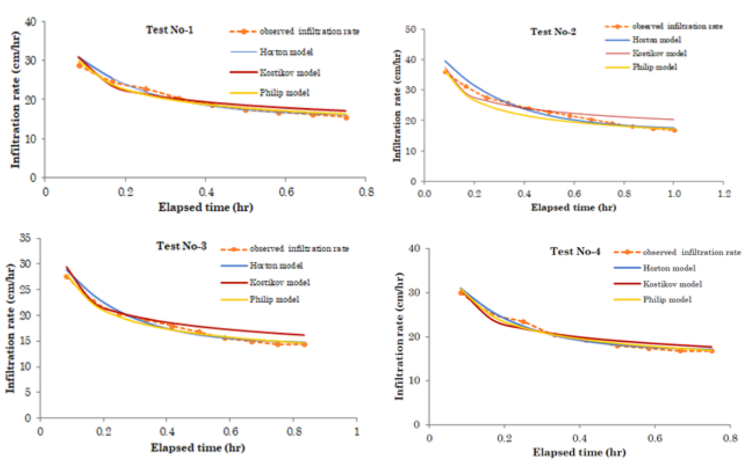


Fig.7 comparison of the predicated values of infiltration rate to the observed values of the study area

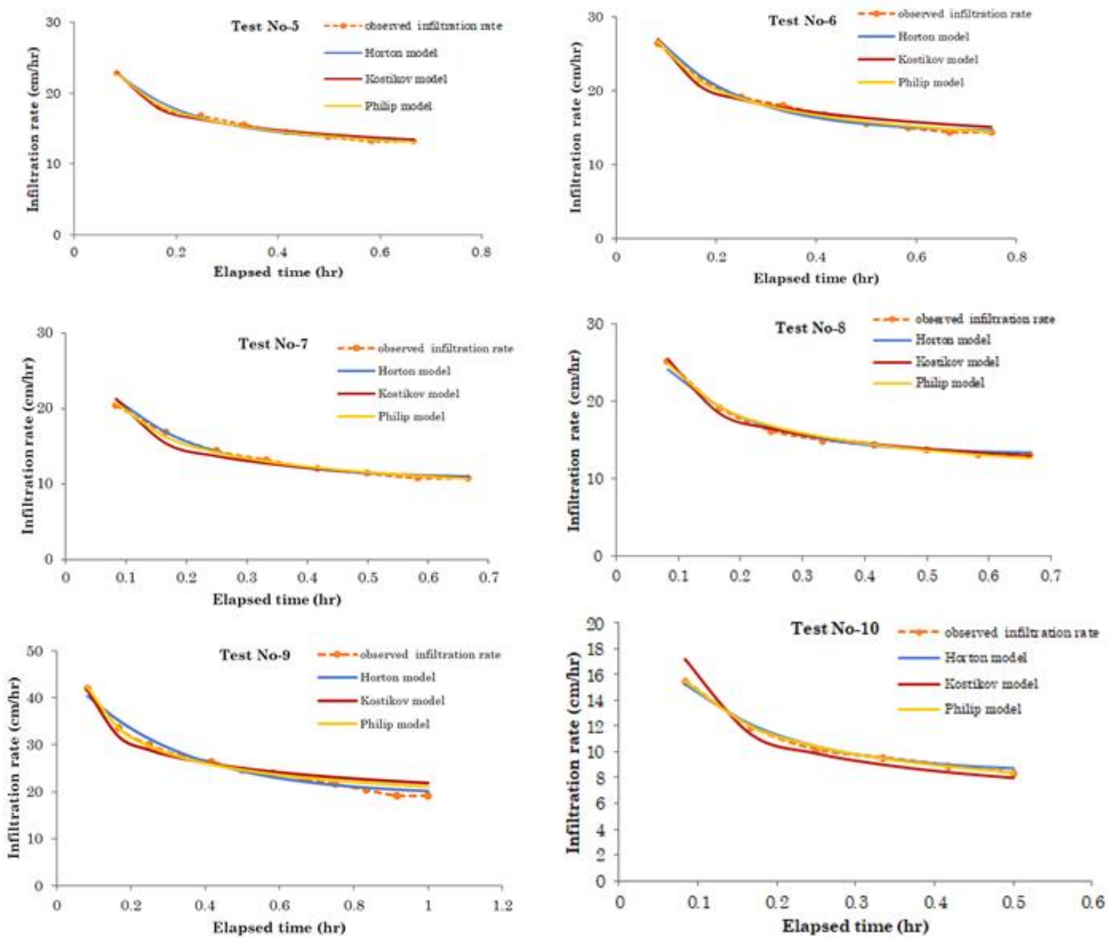


Fig.7 comparison of the predicated values of infiltration rate to the observed values of the study area(continue..)

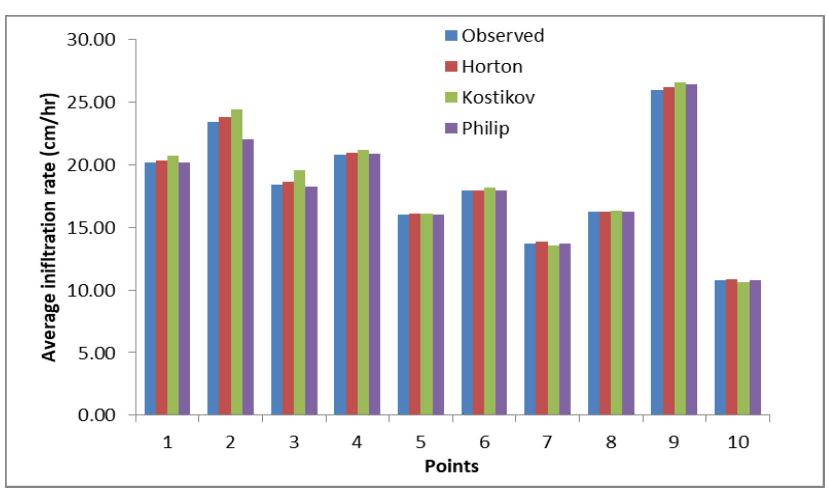


Fig.8 Comparison between observed and estimated average infiltration rate at each point

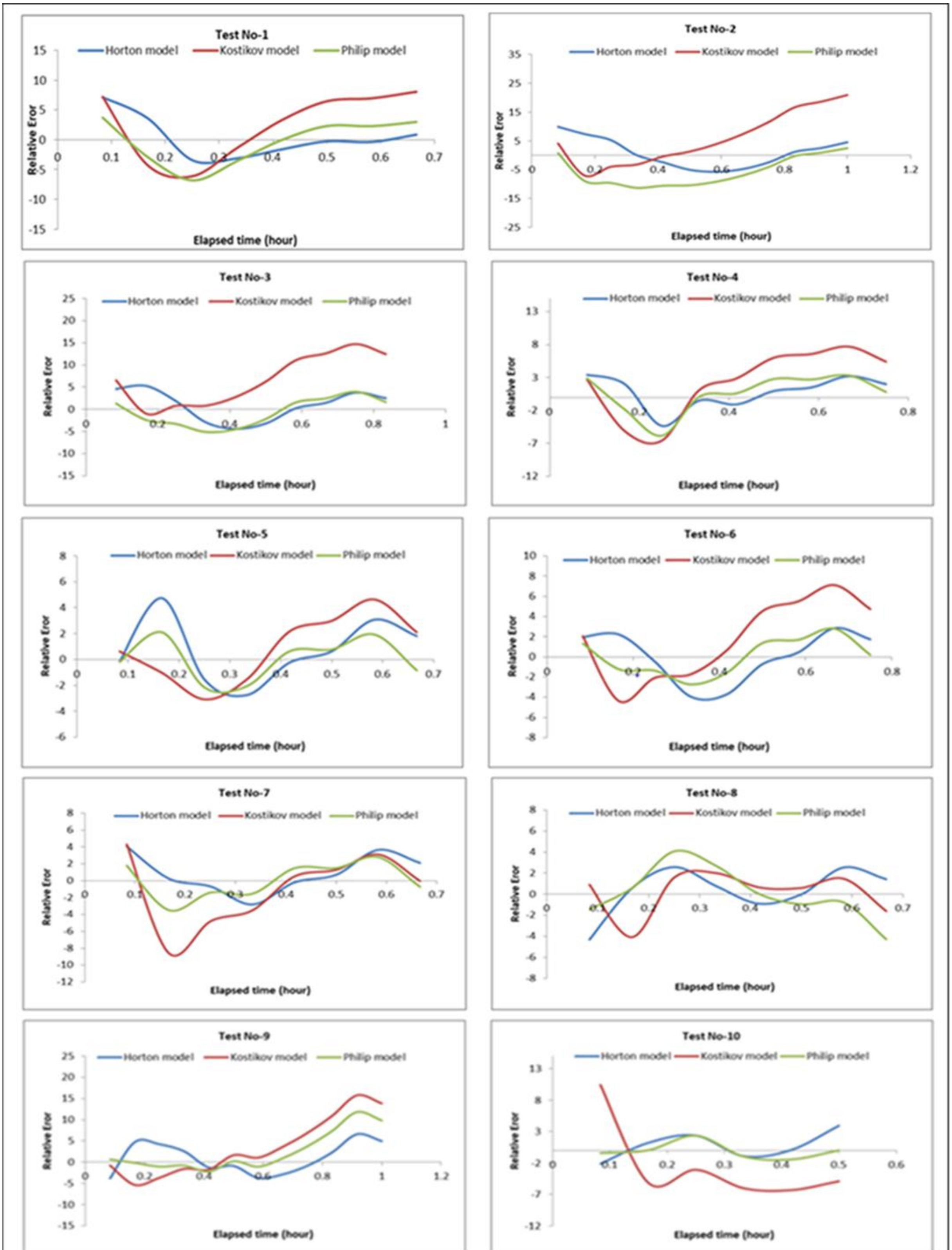


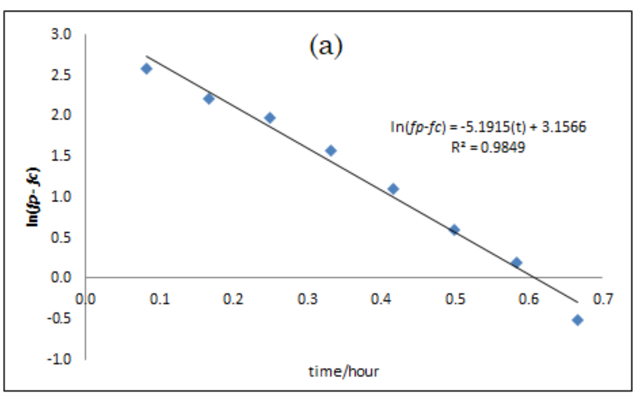
Fig.9 distribution of the relative error of different infiltration model for the study area.

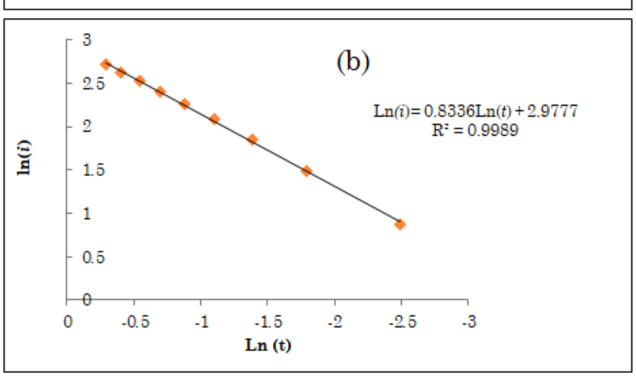
5. Conclusion

Depending on the results of evaluation, all models showed close agreement with the field data using the predicated model's parameters. The models predicated showed that performance indicators such as ME, MAE. MBE, RE and RMSE give acceptable range. This means a realistically simulate of the infiltration rate at field conditions of this selected study area. Also; the accurate forecasting of the infiltration rate based on the model's parameters demonstrated that infiltration model's parameters need to adjusted in the local soil states. based on the performance indices of tested models; Horton's and Philip's model slightly gave a better match of the observed infiltration rate than the Kostikov's models as noted in table 5 for the values of RMSE, MBE and MAE. All models provided a good simulation of the field data which showed a high value of ME reached to more than 99% and low values of MBE, MAE, RMSE for all models. Under site verified conditions, application of these models leads to simulate the infiltration rate. It was found that the measured final infiltration rate has a good correlation (R2 = 0.748) to the calculated Horton parameters (k) for all sites. Moreover, the determined sorptivity factor related to permeates (A) with (R2 = 0.817) and this relationship between them was significant. Also the correlation between Kostikov's parameters a and b was found (R^2=0.550).

Appendix A.

An example an arithmetic model for each equations.





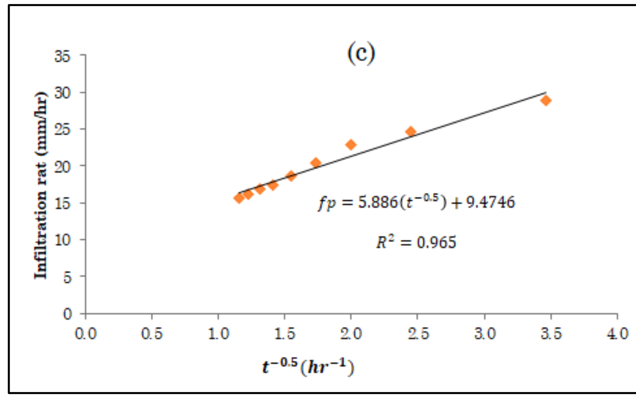


Fig. A1 example of an arithmetic model at point 1 for: (a) Horton's model; (b) Kostikov's model; (c) Philip's model.

Appendix A. example of an arithmetic model at point 1 for: (a) Horton's model; (b) Kostikov's model; (c) Philip's model (continue...).

Appendix B.

TableB1- sieve analysis for each ten points of the Hydrometers test

Points	%Passing on sieve size				
	0.075 mm	0.03 mm	0.01 mm	0.005 mm	< 0.001 mm
1	100	86	42	31	10
2	100	82	25	13	6
3	100	83	41	28	11
4	100	74	29	17	6
5	100	80	36	24	10
6	100	80	41	21	10
7	100	85	38	24	13
8	100	93	51	31	17
9	100	80	38	21	10
10	100	86	40	22	19

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