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FIELD EVALUATION OF INFILTRATION MODELS

Infiltration has a great importance in the watershed management and prediction of flood. Infiltration is defined as a physical phenomenon, in which water penetrates into the soil from surface sources such as precipitation, snowfall, irrigation etc. Information of infiltration is necessary in hydrologic design, watershed management, irrigation, and agriculture. It is, therefore, necessary to have a detailed understanding of infiltration characteristics for a given land use complex. Infiltration is a vital component process of the hydrologic cycle. It is one of the main abstractions accounted for in the rainfall-runoff modeling. In the hydrological process, infiltration divids the water into two parts surface flow and groundwater flow. Soils of different types have different infiltration characteristics. Infiltration rates are affected by a number of factors of which antecedent soil moisture texture of the soil, density and behaviour of the soil. Knowledge of infiltration is essential for any beneficial durable study of hydrological evaluations. In this investigation, the performance of the various infiltration models (Mezencev, Philip's, Horton's, Kostiakov, Modified Kostiakov and Lewis and Milne) was evaluated by using double ring infiltrometer on five different locations in National Institute of Technology, Kurukshetra. The aim was to study the ability of the models in accurately predicted cumulative infiltration. The performance of various models was evaluated using evaluation parameter Sum of Squared Error (SSE), Model Efficiency and Root Mean Square Error (RMSE) criteria. The results show that Modified Kostiakov model and Mezencev model are most efficient models with SSE, Model Efficiency and RMSE that are 2. 352, 99.621, 0.400 and 2.483, 99.619, 0.491 (average values) respectively. Hence, Modified Kostiakov and Mezencev model could be used successfully to evaluate the cumulative infiltration of soil for the study area.

Keywords: cumulative infiltration; prediction of flood; root means square error; sum of square error.

1. Problem statement.

Infiltration is the process in which the water moves down to the earth through the surface soil. It has the dominant role of irrigation planning and scheduling. It is necessary to calculate the exact values of cumulative infiltration in the planning and design of irrigation scheduling. This study compares the six conventional models (Mezencev, Philip's, Horton's, Kostiakov, Modified Kostiakov and Lewis and Milne) to find out the most efficient model for the given study area (National Institute of Technology, Kurukshetra). Very few researchers study the infiltration rate in this study area but with models other than Mezencev, Philip's, Horton's, Kostiakov, Modified Kostiakov and Lewis and Milne models. Therefore, it is necessary to compare these conventional models to find out the best fit models that can be used to calculate the cumulative infiltration in any instance for a given study area.

2. Analysis of the recent researches and publications.

Infiltration has a vital role in subsurface and surface soil erosion, runoff generation, irrigation rate and hydrology. Moreover, the cumulative infiltration of the soil is affected by a large number of factors such as the condition of the soil surface and its physical and chemical properties [1]. The infiltration characteristics of soil can be measured by direct measurement from the data and field cumulative infiltration data which fitted to mathematically to various infiltration models [2, 3]. Lili et al. [4] reviewed the commonly used direct method for measuring infiltration characteristics of soil, which include: Single ring infiltrometer, double ring infiltrometer, mini disc infiltrometer, disc parameter, rainfall simulator, run off-on-out, run off-on-pounding and linear source methods, the results got from the various field infiltration test are used for infiltration modeling.

Many infiltration models have been evolved to evaluate hydrologic process from about 1911 [5, 6]. Several researchers were able to successfully compare and evaluate those available soil-infiltration models in different frameworks under field conditions [7-11]. Mirzaee et al. [12] thought about the capacity of eight diverse infiltration models (i.e. Green and Ampt, Philip, Horton, Kostiakov, Modified Kostiakov, Swartzendruber, Revised Modified Kostiakov models and SCS (US-Soil Conservation Service)) which were assessed by least squares fitting to measured soil infiltration. Sihag et al. [13] has compared the various infiltration models (Kostiakov, SCS, Novel model and Modified Kostiakov) for the NIT Kurukshetra campus. Novel model was most suited as compare to others with field infiltration data. Sihag et al. [14], Singh et al. [15] and Sihag et al.[16] utilized the various soft computing techniques to predict the infiltration rate of the soil. Singh [17] studied the cumulative infiltration and gave a non-linear relationship between cumulative infiltration and time.

In this exploration work, an attempt was made to appraise the cumulative infiltration of soil and assess the execution of six infiltration models. Statistical parameter examination was completed to contemplate the execution of six infiltration model [18]. The general objective of this investigation is to simulate water cumulative infiltration of soil. The particular objective is to assess the model parameters and to look at the cumulative infiltration by the models with measured information in the field.

3. Statement of the problem and its solution.

3.1. Infiltration models to be evaluated.

In this study, six infiltration models were selected and model parameters are driven by using the data obtained from field measurement. These entire models are tabulated in table 1.

Table 1 – Details of the infiltration models

Sr. No.	Model Name	Equations	Parameters
1	Philip's model [19]	$M = S_p t^{0.5} + A_p t$	S_p and A_p
2	Horton's model [20]	$M = Z - Z(\exp(-Ut)) + V$	Z, U and V
3	Kostiakov model [21, 22]	$M = wt^x$	W and x
4	Modified Kostiakov model	$M = w_1 t^{x1} + k_s t$	w_1, x_1 and k_s
5	Mezencev model	$M = m_f t + \alpha \frac{m_f}{1-\beta} t^{(1-\beta)}$	m_f, α and β
6	Lewis and Milne [23]	$M = L - L(\exp(-nt))$	L and n

Where M is the cumulative infiltration, A_p is the transmissivity factor, S_p is the, ks is hydraulic conductivity of soil, if is the final infiltration rate, Z, U and V, w and x, α & β, L, n, Z, U, V, w, x, w_1, x_1, α, β, L and n are constant.

3.2. Study area.

The experiments were carried out at Kurukshetra in Haryana region. The investigation area comes under upper-Ghaggar basin. Total area of Kurukshetra is 1530 km^2 and lies 260 m above the sea level. It is situated about 160 kilometres from New Delhi and 93 kilometres from Chandigarh. The geographical coordinates of study area is 29.9655° N latitude and 76.7106° E longitude. The five different locations were selected for experimentation in NIT Kurukshetra campus to study the variation in the cumulative infiltration. The details of the all the location have been available in figure 1.

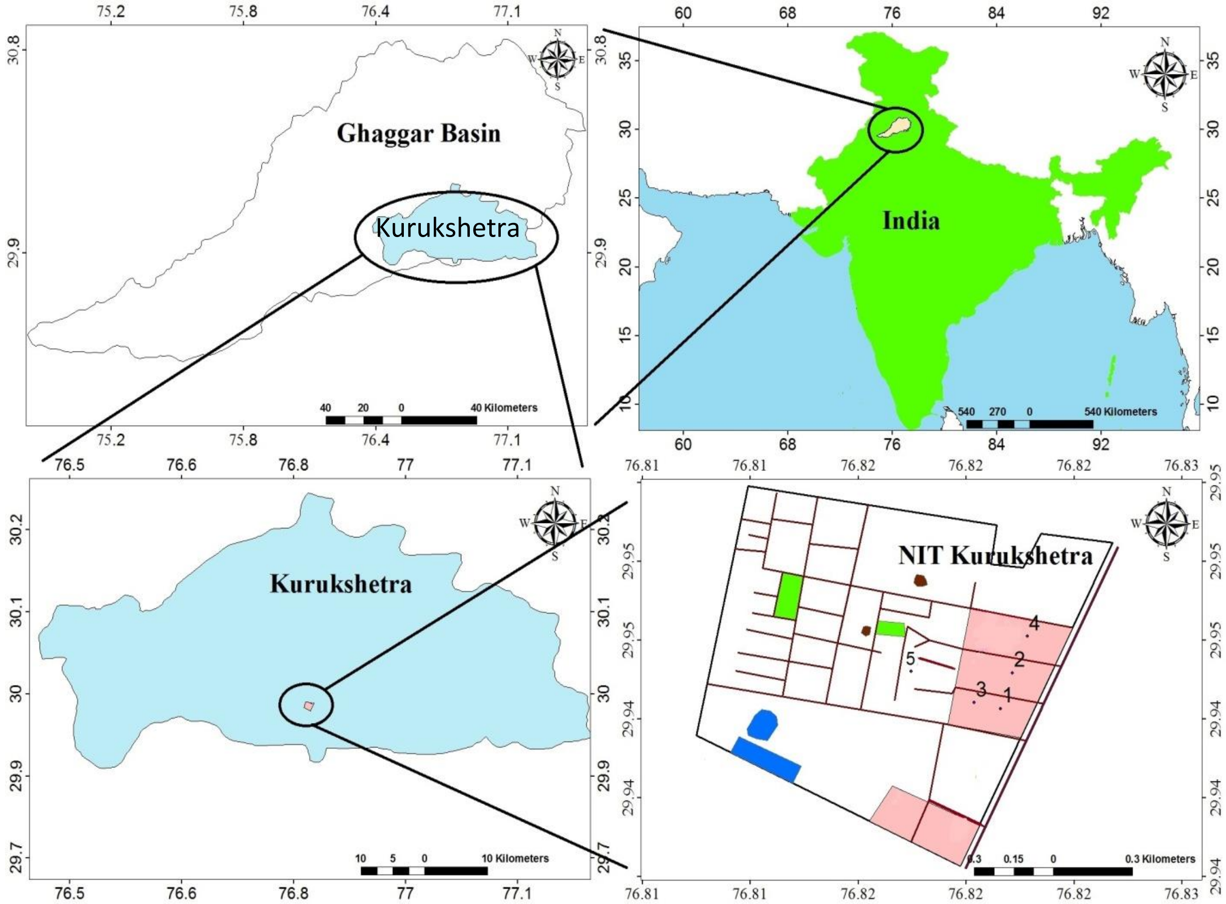


Figure 1 – Locations of the study area

3.3. Methodology.

The infiltration data were conducted from March 2015 to June, 2015 on the campus of NIT Kurukshetra by using double ring infiltrometer [24]. As shown in figure 2, the double ring infiltrometer has two parts, one was outer ring whose diameter was 450 mm and second was inner ring whose diameter is 300 mm. The rings of infiltrometer were driven 100 mm depth into the soil. The hammer should strike uniformly on steel plate which is placed on the top of the ring without disturbing the top soil surface. The water was filling at the same level of both rings. The profundity of water in the infiltrometer was recorded at regular interims until the steady infiltration rate was achieved. The soil sample (about100-150 gm) for calculating moisture content was collected from a site nearest to the location chosen for experimentation.

Figure 2 – The Double ring infiltrometer having 300 mm inner diameter and 450 mm outer diameter for measuring infiltration rate

4. Model Evaluation.

Comparison of difference between the predicted infiltration rate values and measured values was done to evaluate the infiltration rate on the basis of the performance evaluation parameters. Those model performances are addressed below:

4.1. Sum of square error (SSE). The sum of squared error (SSE), which is the difference between the measured cumulative infiltration and the predicted cumulative infiltration.

$$[\mathrm{SSE}]{\downarrow}\mathrm{i}=\sum{\downarrow}(\mathrm{j}=1)^{\uparrow}\mathrm{z}\equiv[\{\mathrm{P(o)j}-\mathrm{P(c)j}\}]^{\uparrow}2\,. \quad (1)$$

4.2. Model efficiency. It can be express as:

$$\text{Model efficiency}=\left(1-\frac{\mathrm{A}_1}{\mathrm{A}_2}\right)\cdot 100\,, \quad (2)$$

where

$$\mathrm{A}{\downarrow}1=\sum{\downarrow}(\mathrm{j}=1)^{\uparrow}\mathrm{z}\equiv[\{\mathrm{P(o)j}-\mathrm{P(c)j}\}]^{\uparrow}2\,, \quad (3)$$

$$\mathrm{A}_2=\sum_{\mathrm{j}=1}^{\mathrm{z}}\{\mathrm{P(o)j}-\overline{\mathrm{P(m)j}}\}^2\,. \quad (4)$$

4.3. Root means square error (RMSE). It can be calculated:

$$\mathrm{RMSE}=\sqrt{\sum_{\mathrm{j}=1}^{\mathrm{z}}\frac{\{\mathrm{P(c)j}-\mathrm{P(o)j}\}^2}{\mathrm{z}}}\,, \quad (5)$$

where $\mathrm{P(o)j}$ is the measured cumulative infiltration for soil (i), $\mathrm{P(c)j}$ is the predicted cumulative infiltration by the soil infiltration models for soil (i), $\overline{\mathrm{P(m)j}}$ is the mean of the observed data, j is the number of the j-th infiltration measurement in one set of soil infiltration measurement for soil (i) with total of n infiltration reading, and z is the number of cumulative infiltration measurement.

4.4. Single factor ANOVA.

The single factor ANOVA is used to determine whether there are any statistically significant differences between the means of two or more independent groups. Specifically, it tests the null hypothesis ($\mathrm{H}{\downarrow}\mathrm{O}$):

$$\mathrm{H_o}:\ \mu_1=\mu_2=\mu_3=\mu_4\ \ldots\ \ldots\ =\mu_k\,, \quad (6)$$

where μ – group mean and k – number of groups. If, however, the one-way ANOVA returns a statistically significant result in Excel sheet, single factor ANNOVA provides us the value of F, F-critical and P values. It has been compared F critical with the F statics and P values with the significance level value, α (= 0.05).

Reject Null Hypothesis: If F value is greater than or equal to the F-critical value, $F \geq$ F-critical (significant results).

Accept Null Hypothesis: If F value is less than or equal to the F-critical value, $F \leq$ F-critical (insignificant result).

5. Results and discussions.

Every infiltration test was carried in the field in order to deal with the spatial variability of cumulative infiltration. Based on the field tests at 5 locations in NIT Kurukshetra area, results were analyzed. Table 2 indicates the values of initial cumulative infiltration, final cumulative infiltration, properties (percentage of sand, silt, clay, dry density and moisture content) of the soil samples from different locations. The average values of % clay, % silt, % sand, dry density and moisture content were 68.78, 16.13, 15.49, 1.61 and 4.74 respectively.

Table 2 – Detailed of observed cumulative infiltration and properties for the study area

Site No.	Initial cumulative infiltration (t = 1 min.), mm	Final cumulative infiltration (t = 180 min.), mm	Sand, %	Silt, %	Clay, %	Dry density, g/cc	Moisture content, %
1	5	71	69.62	15.01	15.37	1.57	2.65
2	4	46	63.12	19.08	17.80	1.63	1.93
3	8	30.5	71.28	14.30	14.42	1.66	7.98
4	7	34	70.18	16.32	14.50	1.60	7.65
5	4	37.5	69.71	15.93	15.36	1.59	3.51
Average	5.6	43.8	68.78	16.13	15.49	1.61	4.74

A number of infiltration models are projected to find out field infiltration rates. The projected models Philip's, Horton's, Kostiakov, Modified Kostiakov, Mezencev and Lewis & Milne models were chosen for evaluation in the study. To study these models, actual field infiltration data have been used. Attempt was made to evaluate these infiltration equations on the basis of experimental data of the study area and to obtain numerical values for the parameters of the models. For the analysis of infiltration data and find out the parameters of the above model using least square techniques, XLSTAT software has been used. The parameters for six infiltration model were summarized in table 3.

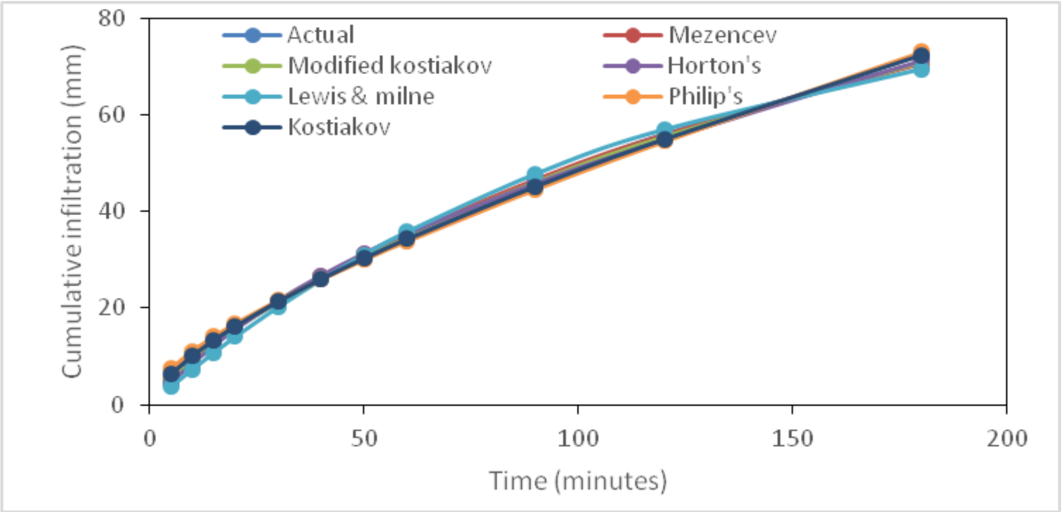
Table 3 – Parameters of the different selected models

Equation with parameters		1	2	3	4	5
Philip's	S_p	2.902	2.216	3.508	4.263	1.794
	A_p	0.190	0.094	-0.100	-0.132	0.074
Horton's	H	24.386	12.499	14.516	13.674	8.927
	A	0.027	0.051	0.124	48.552	0.067
	C	0.262	0.189	0.090	0.135	0.160
Kostiakov	a	2.120	1.747	5.072	5.820	1.433
	n	0.680	0.631	0.341	0.347	0.626
Modified Kostiakov	a_1	3.538	1.629	5.239	4.077	1.623
	n_1	0.934	0.692	0.327	0.522	0.551
	k_s	-2.115	-0.073	0.008	-0.155	0.050
Mezencev	i_f	32.041	0.002	0.008	0.995	0.050
	α	-30.900	1.126	1.713	0.991	0.894
	β	-0.006	0.308	0.673	5.988	0.449
Lewis & Milne	L	87.673	-35510.164	25.447	30.243	-26832.380
	M	0.009	0.000	0.039	0.038	0.000

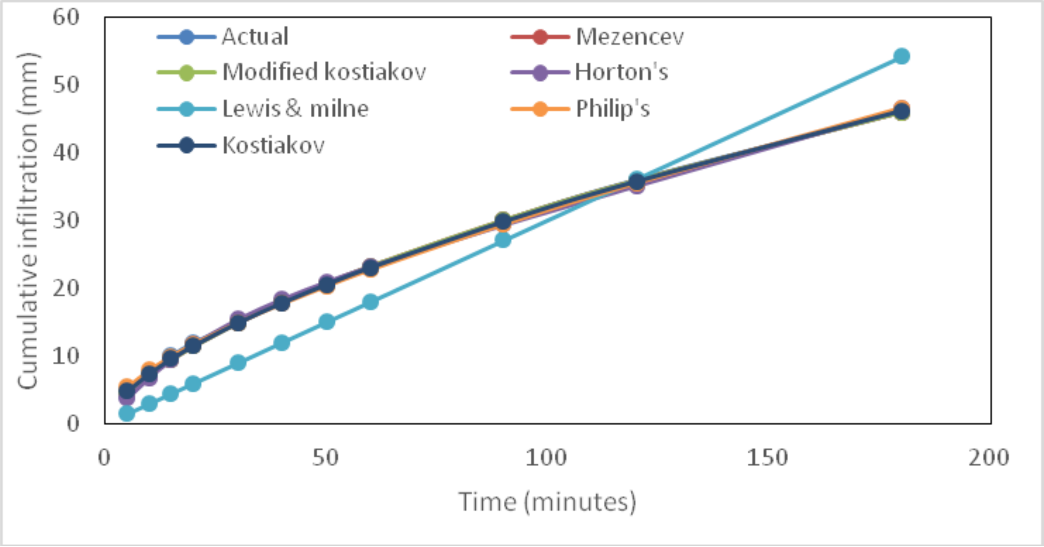
It was found that in the Phillip's model, the values of Sp and Ap varies from 1.794 to 4.263 and -0.132 to 0.190 respectively. In the Horton's model, the values of Horton's constant H, A and C varies from 8.927 to 24.386, 0.027 to 48.552 and 0.135 to 0.262 respectively. In the Kostiakov Model, the values of a and n varies from 1.433 to 5.820 and 0.341 to 0.680 respectively. In the Modified Kostiakov model, the values of a1, n1 and ks varies from 1.623 to 5.239, 0.327 to 0.934 and -2.115 to 0.050 respectively. In the Mezencev model, the values of if, α and β varies from 0.002 to 32.041, -30.900 to 1.713 and -0.006 to5.998 respectively. And in the Lewis &Milne model, the value of L and M varies from -35510.164 to 87.673, 0.000 to 0.039 respectively.

The comparison was carried out between models' measured cumulative infiltration and field measured cumulative infiltration.

The graphs between cumulative infiltration and time were plotted in figure3.



Site 1



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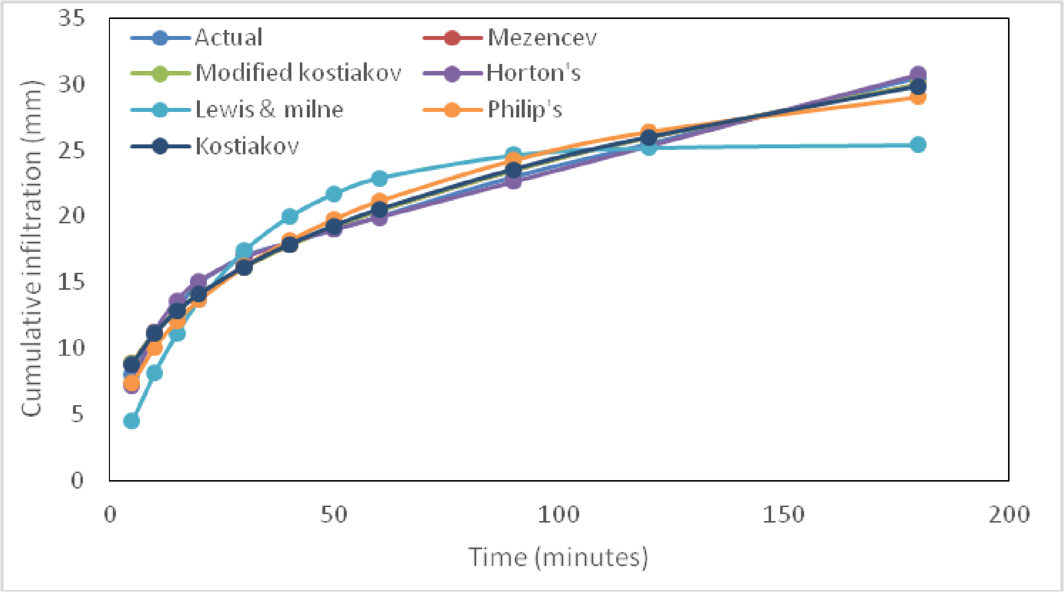

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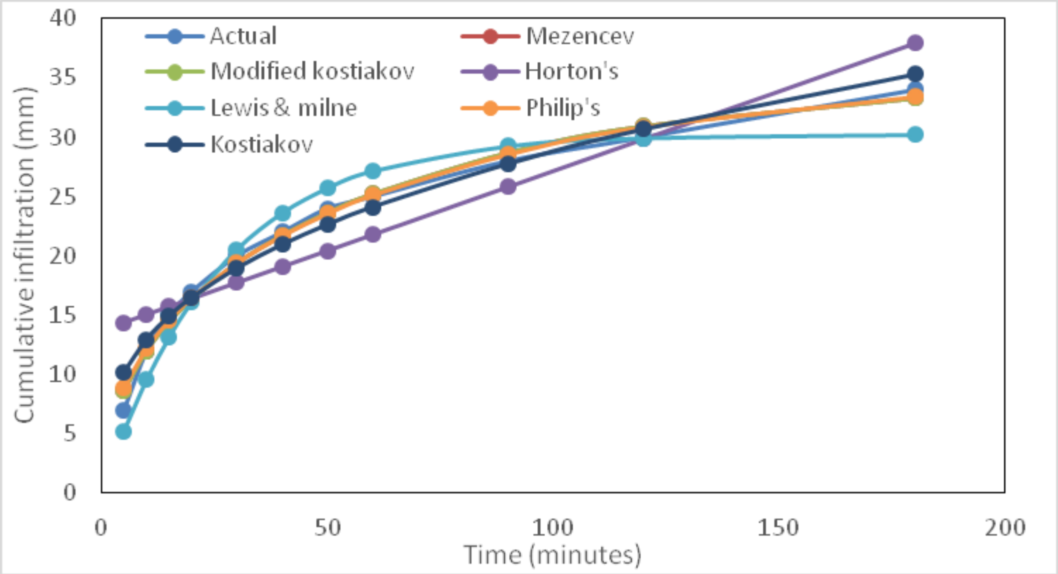

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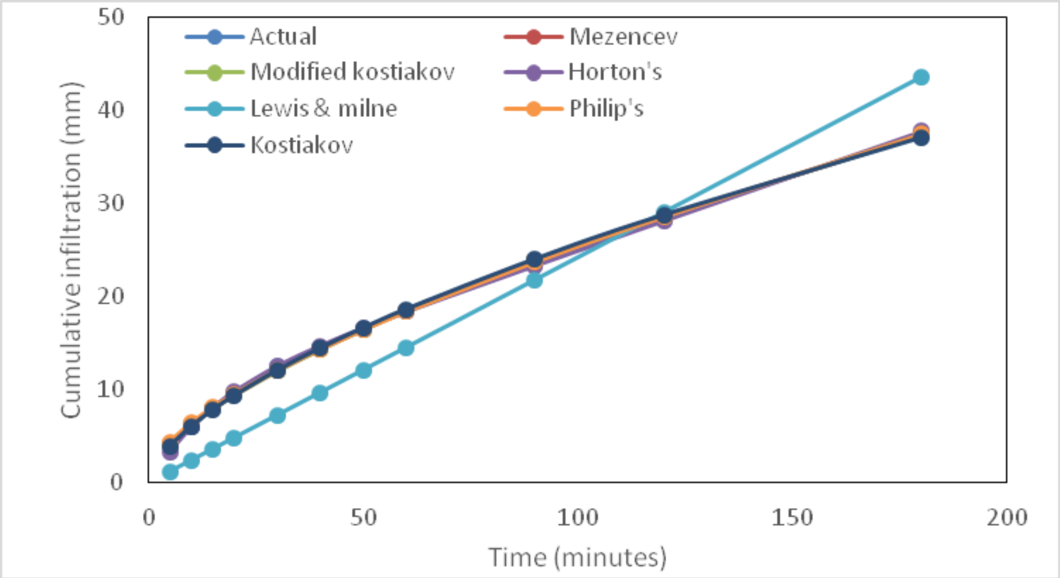

Site 5

Figure 3 – Performance of Field infiltration rates and various models predicted cumulative infiltration for 5 Sites

Sum of Squared error (SSE), Model efficiency and Root means square error (RMSE) were used to evaluated the six infiltration models. The best fit model was selected on the basis of minimum values of SSE & RMSE and maximum values of Model Efficiency. Findings of these errors were tabulated in table 4.

The estimated average values of the SSE were 8.966, 26.008, 6.546, 2.352, 2.483, 122.367; Model Efficiency were 98.563, 95.331, 99.541, 99.641, 99.619, 91.735 and RMSE were 1.039, 1.003, 0.667, 0.400 0.491, 3.062for Philip’s model, Horton’s model, Kostiakov model, Modified Kostiakov model, Mezencev model and Lewis & Milne model respectively. Table 5 gave the ranking of the various infiltration models for every test and suggests that Modified Kostiakov and Mezencev are the best suitable models for the given study area. Results from Table 6 suggests that the F-value (0.092573) was less than f-critical (2.12275) and P-value (0.99706) was greater than 0.05 suggesting that the difference in predicted values was insignificant for all the models.

Table 4 – Performance evaluation parameters of different infiltration models

Test No.	Evaluation parameters	Infiltration equations					
		Philip's	Horton's	Kostiakov	Modified Kostiakov	Mezencev	Lewis & Milne
1	SSE	23.035	3.903	8.129	0.769	1.425	20.483
	Model Efficiency	99.424	99.910	99.805	99.982	99.967	99.553
	RMSE	1.447	0.596	0.860	0.264	0.360	1.365
2	SSE	3.969	2.414	1.368	1.093	1.093	289.151
	Model Efficiency	99.753	99.856	99.917	99.934	99.934	89.114
	RMSE	0.601	0.468	0.353	0.315	0.315	5.127
3	SSE	11.042	1.384	3.481	3.418	3.418	74.711
	Model Efficiency	94.689	99.682	99.172	99.185	99.185	86.137
	RMSE	1.002	0.355	0.562	0.557	0.55	2.606
4	SSE	6.149	121.511	18.355	5.988	5.988	39.883
	Model Efficiency	99.012	77.1884	98.888	99.050	99.055	94.795
	RMSE	1.903	3.324	1.292	0.738	0.738	1.903
5	SSE	0.635	0.829	0.796	0.490	0.491	187.606
	Model Efficiency	99.939	99.921	99.924	99.953	99.953	89.078
	RMSE	0.240	0.274	0.269	0.211	0.211	4.130
Average	SSE	8.966	26.008	6.546	2.352	2.483	122.367
	Model Efficiency	98.563	95.331	99.541	99.621	99.619	91.735
	RMSE	1.039	1.003	0.667	0.400	0.491	3.062

Table 5 – Ranking of infiltration models on the basis of performance evaluation parameters

Test No.	Ranking of infiltration model					
	Philip's	Horton's	Kostiakov	Modified Kostiakov	Mezencev	Lewis & Milne
1	6	3	4	1	2	5
2	5	4	3	1	2	6
3	5	1	4	2	3	6
4	3	6	4	2	1	5
5	3	5	4	2	1	6
Overall	3	5	4	1	2	6

Table 6 – Result of ANOVA Single Factor Test

Infiltration Model	F values	P values	F critical
All Model	0.092573	0.99706	2.12275

Figure 4 represented the plot between estimated cumulative infiltration using the models above and observed cumulative infiltration and suggests that all the plots of the Modified Kostiakov model and Mezencev model lies within +10 % error line from the line of the perfect agreement.

Results from table 6 suggest that the difference in observed and predicted values was insignificant for all above infiltration model.

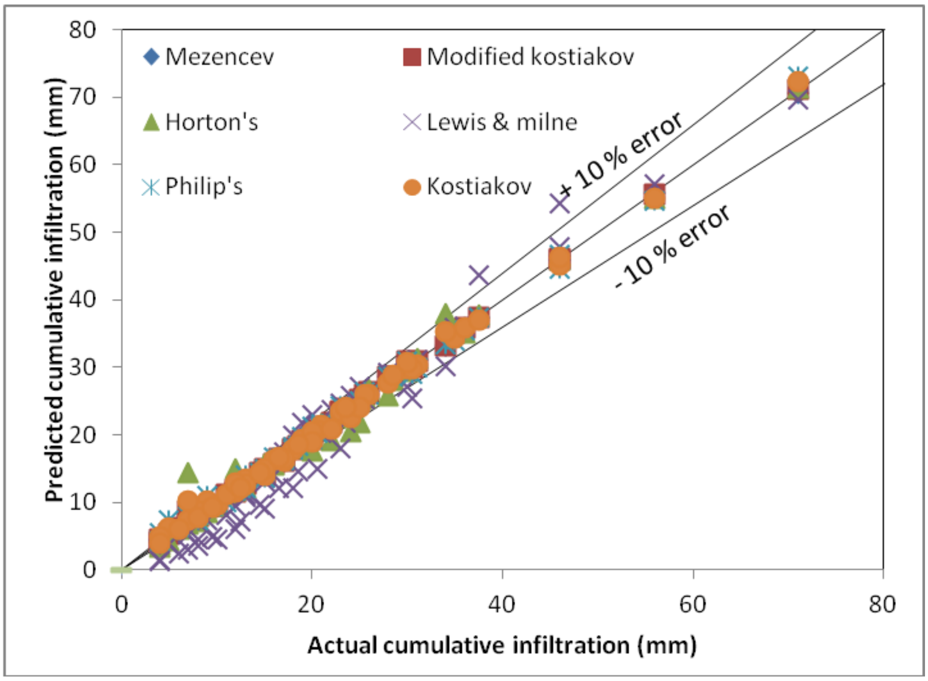

Figure 4 – Actual vs predicted cumulative infiltration using various model

Statistical evaluation parameters i.e. SSE, Model Efficiency and RMSE also suggests that the performance of Modified Kostiakov model and Mezencev model is good as compare to the others model and it may be used to assess the infiltration rate with similar field characteristics of the study area.

Conclusions.

In this study, the infiltration model investigated and compared the induced theoretical based model Philips's model and five empirical based model Horton's, Kostiakov, Modified Kostiakov, Mezencev and Lewis & Milne models. Among these model Modified Kostiakov model and Mezencev model performed better than the other four infiltration models with consideration of validation indices, including sum of squared error (SSE), model efficiency and root mean square error (RMSE). Table 4 shows the values of SSE, Model efficiency and RMSE 2.352, 99.621& 0.400 and 2.483, 99.619& 0.491 for Modified Kostiakov model and Mezencev model respectively. These values are closely fitted with the actual dataset than other four infiltration model. From this research, it can be included that Modified Kostiakov model and Mezencev model can be used more appropriately for simulation of cumulative infiltration in the study area.

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ОЦІНКА ОБЛАСТІ ДІЇ ІНФІЛЬТРАЦІЙНИХ МОДЕЛЕЙ

Інфільтрація має велике значення для управління водозбірними басейнами і прогнозування повеней. Інфільтрація є життєво важливим компонентом процесу гідрологічного циклу, що враховуються при моделюванні зливових стоків. У гідрологічному процесі інфільтрація виділяє поверхневий потік і потік підземних вод. Ґрунти різних типів мають різні характеристики проникнення. На рівень проникнення впливає ряд факторів, з яких первісна вологість ґрунту, щільність і поведінка ґрунту. Знання інфільтрації має важливе значення для будь–якого корисного довготривалого вивчення гідрологічних оцінок. У цьому дослідженні наведені результати різних інфільтраційних моделей (Mezencev, Philip's, Horton's, Kostiakov, Modified Kostiakov й Lewis й Milne), які оцінювалися з використанням подвійного кільцевого інфільтрометра в п'яти різних місцях у Національному технологічному інституті Курукшетра. Мета полягала в тому, щоб вивчити здатність моделей точно прогнозувати сукупну інфільтрацію. Точність прогнозування різних моделей оцінювалася параметрами Sum Squared Error (SSE), Model Efficiency и Root Mean Square Error (RMSE). Результати показують, що вдосконалена модель Kostiakov і модель Mezencev – найбільш ефективні за параметрами SSE, Model Efficiency і RMSE, які дорівнюють відповідно 2,352; 99,621; 0,400 і 2,483; 99,619; 0,491 (середні значення). Отже, вдосконалена модель Kostiakov і модель Mezence можуть бути успішно використані для оцінки кумулятивної інфільтрації ґрунту для досліджуваної території.

Ключові слова: кумулятивна інфільтрація; прогнозування повеней; основна квадратична помилка; сума квадратичної помилки.

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ОЦЕНКА ОБЛАСТИ ДЕЙСТВИЯ ИНФИЛЬТРАЦИОННЫХ МОДЕЛЕЙ

Инфильтрация имеет большое значение для управления водосборными бассейнами и прогнозирования наводнений. Инфильтрация является жизненно важным компонентом процесса гидрологического цикла, который учитывается при моделировании ливневых стоков. В гидрологическом процессе инфильтрация разделяет поверхностный поток и поток подземных вод. Почвы разных типов имеют разные характеристики проникновения. На уровень проникновения влияет ряд факторов, из которых первоначальная влажность почвы, плотность и поведение почвы. Знание инфильтрации имеет важное значение для любого полезного долговременного изучения гидрологических оценок. В этом исследовании приведены результаты различных инфильтрационных моделей (Mezencev, Philip's, Horton's, Kostiakov, Modified Kostiakov й Lewis и Milne), которые оценивались с использованием двойного кольцевого инфильтрометра в пяти разных местах в Национальном технологическом институте Курукшетра. Цель состояла в том, чтобы изучить способность моделей точно прогнозировать совокупную инфильтрацию. Точность прогнозирования различных моделей оценивалась параметрами Sum Squared Error (SSE), Model Efficiency и Root Mean Square Error (RMSE). Результаты показывают, что усовершенствованная модель Kostiakov и модель Mezencev – наиболее эффективные по параметрам SSE, Model Efficiency и RMSE, которые равны соответственно 2,352; 99,621; 0,400 и 2,483; 99,619; 0,491 (средние значения). Следовательно, усовершенствованная модель Kostiakov и модель Mezence могут быть успешно использованы для оценки кумулятивной инфильтрации почвы для исследуемой территории.

Ключевые слова: кумулятивная инфильтрация; прогнозирования наводнений; основная квадратичная ошибка; сумма квадратичной ошибки.