Infiltration studies for varying land cover conditions

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Abstract — Procedures adopted for infiltration calculations vary greatly in sophistication right from the application of reported average rates for specific soil types and vegetal land covers to the use of differential equations governing the flow of water in unsaturated porous media. In this work attempt is made to determine infiltration rates of soil under different land cover conditions and to compare validity of different infiltration equations viz. Kostiakov, modified Kostiakov, Horton and Philip. The various land covers such as Grapes, Gram, Bajra, Weeds and Cucumber were selected at a location Brahmangaon in Tq. Kopargaon, dist. Nagar (M.S.). Observations were taken by using double ring infiltrometer for two seasons' winter and summer. The field observations, analysis of data and graphical representations indicates that the infiltration rate in summer was around twice the infiltration rate in winter. Suitability of the infiltration model under different conditions has been indicated. Further, the Kostiakov equation was found to be the best for almost all cultivated land covers.

Keywords- infiltration, double ring infiltrometer, land cover, season, Horton, Kostiakov, Philip, modified Kostiakov

I. INTRODUCTION

The infiltration rate is of prime importance to the irrigation engineers as it influences the application rate of irrigation. [2], [6], [13] It is difficult to design an irrigation system without proper knowledge of infiltration characteristics of soil. [5], [11], [12]. In dry-land agricultural infiltration characteristics will also be required for proper water management. It is useful for determination of availability of water for plants, runoff rate and percolation. Accurate determination of infiltration rates is essential for reliable prediction of surface runoff. [1],[7],[9] This is useful for mitigation of hydrological risk. The infiltration capacity of soil influences the occurrence of overland flow. [3], [4] An evaluation of the risk of overland flow is needed in order to minimize the risk of transferring pollutants from soil to rivers and lakes. Further, the prediction of runoff has a crucial role in designing hydraulic structures as well as water resources planning and management. [2], [6], [11]

II. OBJECTIVES

The present infiltration study is undertaken with the following main objectives:

i) To evaluate the infiltration capacity of the soil and to evaluate the reliability of infiltration tests,
ii) To determine the infiltration rate for summer season and winter season and
iii) To study the suitability and validity of various commonly used infiltration equations

III. INFILTRATION PROCESS

Infiltration on pervious surface is controlled mainly by three mechanisms, namely initial entry of water through the soil surface followed by the movement of water through infiltration zones and finally.repenishment of soil water storage The Infiltration rate usually shows a sharp decline with time from the start of the application of water. The constant rate approached after a sufficiently large time is referred to as the steady Infiltration rate. The surface entry rate of water may be affected by the presence of a thin layer of silts and clay particles at the surface of the soil and vegetation.

The infiltration process is influenced by various factors such as: i) Soil texture and structure; ii) Sealing of surface or crust formation; iii) Initial moisture content; iv) Aggregation and Structure; v) Frozen Surface; vi) Organic Matter; vii) Pores; viii) Land cover and evaporation; and ix) Compaction due to rain. The initial moisture content has pronounced effect on the initial infiltration rate though the basic infiltration rate is not appreciably affected. A dry soil reaches the basic infiltration rate latter than the wet soil. This is an important aspect from the irrigation point of view.

IV. LITERATURE REVIEW

A number of Literatures and research papers have been studied, which deals with infiltration through different types of soils and related investigations. The findings of these papers have been presented here.

Vardhan Ravi, Ying Ouyang and Joseph R. Williams, [1]. 1998 carried out an investigation on Estimation of Infiltration Rate in the vadose zone. In this study a compilation of simple mathematical models has been presented for quantifying the rate of soil- water movement due to infiltration. This paper discusses the techniques for characterizing goals for their chemical, physical and hydraulic properties. It also provides a list of available field and laboratory measurement techniques and look-up methods for these parameters. In addition to the identification of parameters, a document provided a table of common unsaturated zone models and their parameter requirements. An extensive survey of unsaturated zone models was provided by Van Der Hiejde (1994). A related effort is the release of the Soil Screening Guidance (U.S.EPA, 1996). This Guidance provides the public with a tool for determining risk-based site-specific, soil screening levels (SSLs) for the evaluation of the need for further investigation at NPL (National Priority List) sites.

Robert Pitt Janice L. [3]. (1999), carried out an extensive experimental study on infiltration through Disturbed Urban Soils and Compost. This study examined a common, but poorly understood, problem associated with land development and the modifications made to soil structure. The project was divided into two tasks namely, testing infiltration rates of impacted soils, and Enhancing soil by amending with compost to increase infiltration and prevent runoff. This project evaluated a widespread problem, decreased infiltration due to disturbed soils, and a potential solution, soil amendment with compost. A large number of infiltration tests were conducted to identify the factors significantly affecting infiltration parameters

John Diamond and Thomas Shanley, [4]. (2003), carried out infiltration rate assessment (spatial and temporal variability) of some extensive soils in Ireland at Castle Research Centre, Wexford. The objectives of investigations were to evaluate the infiltration capacity of the dominant component of major soil associations and to evaluate the reliability of infiltration tests. Infiltration capacity was measured by using double ring infiltrometers at one poorly drained, one imperfectly drained and eight freely drained sites for both winter and summer seasons. The study indicated a significant relationship between infiltration capacity and the antecedent soil water content, which contributed to the seasonal effect.

Jean-Claude and Mailhol, [5]. (2003), carried a study to validate a predictive form of Horton infiltration for simulating furrow irrigation. An operative modeling approach for predicting the advance- infiltration process under furrow irrigation through the irrigation season was proposed. The applicability of the model was then extended to heavy clay soils where the parameters λc (capillary length) and K_s (hydraulic conductivity) agreed with the values proposed in the study.

Sharma D.C., Dubey O. P., and Chhabra S. S., [9]. (2004), worked on determination of infiltration rate in Chitaurgarh dam command area (U.P.). In this study authors used radio-active tracer method and double-ring infiltrometer method for determination of average infiltration rate. For implementing the technique, tritiated water was injected into the ground at a certain depth between root zones. The tracer as a result of subsequent rainfall or irrigation moves downward. Infiltration tests were carried out at 12 sites in the canal system of dam. The study concluded that the results of radio-active tracer technique are comparable with double-ring infiltrometer and therefore can also be used for determination of infiltration rate.

Singh R.V. and Bhakar S.R. [8]. (2004), reported a study on comparison of infiltration equations for different land covers. A comparison of various infiltration equations e.g. Kostiakov equation, modified Kostiakov equation, Green Ampt and Horton equation were made. The various land covers in a sandy loam, soils e.g. cultivated land, fallow land, Pasture land and farm pond bed were considered.

Mohan S. and Kumari S., [10]. (2005), presented an experimental study on Recharge Estimation Using Infiltration Models. Different infiltration models were tested at 50 locations in a basin based on the soil type and land use variations at Neyveli. The Infiltration models namely Green Ampt Model, Modified Kostiakov model and Horton model were found to be statistically fit to the observed field data. The results were compared with that of the standard SWAT (Soil and Water Assessment Tool) Model developed by the USDA, agricultural research service (ARS). The study concluded that Horton Model is the most appropriate infiltration model for estimating recharge in Neyveli region.

Nestor L. Sy, [12]. (2006), carried out investigation for Modelling the in the Infiltration process with multi-layer perceptron artificial neural network in Netherlands. In this study, the ANN multilayer perceptron was used for the model the infiltration process. The data derived from plot scale simulator experiments conducted was used for analysis purpose. The networks were trained using physically measurable data from rainfall simulator experiments. The simulator produced 3.7mm average sized raindrops. At a height of 1.5m above the ground. The simulator produced an average velocity of 7.8m/s. Test plots of one square meter size were chosen. A vertical trench was dug at the downstream end of the test plot and a trough was positioned to catch the runoff water. The experiments usually lasted between one and three hours and runoff was recorded every 5 minutes. Total 80 experiments were conducted. The data was divided into two sets, 56 samples were used in the ANN training and 24 for testing.

The infiltration parameters of the Green–Ampt, Kostiakov, Horton and Philip infiltration models using field rainfall simulator data were determined by empirical filling using linear regression. The cumulative Infiltration by different infiltration model was compared with ANN model. The ANN model provided the highest accuracy. Therefore one can estimate Infiltration from easily available physical data using ANN.

V. LOCATION DETAILS

The location of sites is at Village Brahmangaon, 10 Km away from Kopargaon, Dist. Ahmednagar. The measurements were made in winter and summer at four land covers having different crops in it. The sites were chosen to represent the dominant component of major soil associates.

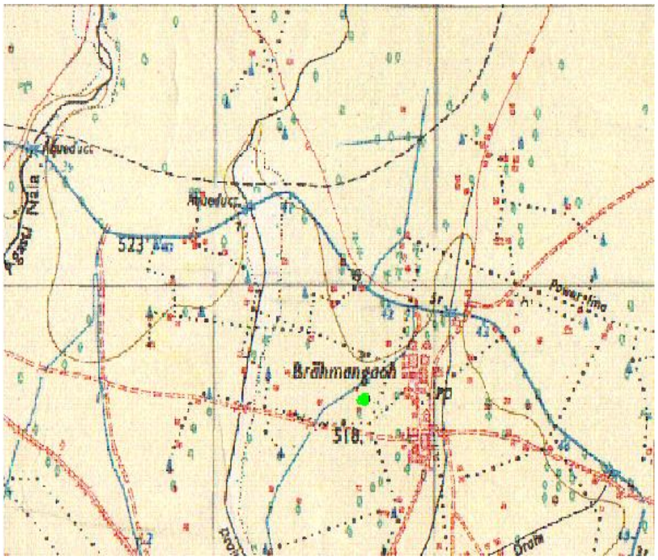


Figure 1. Map of the Study Area

VI. CLIMATIC CONDITIONS

Usually the temperature in Kopargaon and adjoining areas is quite high in months of March, April and May. The temperature variation was from 20°C to 40°C from morning to afternoon.

TABLE 1. Commonly Used Infiltration Equations

Sr. No.	Name of Equation	Expression	Method of Determination of Constants
1	Horton's Equation	$f = f_c + (f_o - f_c)\, e^{-kt}$	Graphical and Numerical
2	Kostiakov Equation	$Y_c = at^{b}$	Experimental
3	Modified Kostiakov Equation	$Y_c = at^{b} + c$	Method of average
4	Green Ampt Equation	$f_p = K_s (L+S)/L$	Field measurement
5	Philip's Two-Term Model	$q(t) = 1/2\, S\, t^{-1/2} + A$ $I(t) = S\, t^{1/2} + A\, t.$	Field measurement

VII. MEASUREMENT OF INFILTRATION

Infiltration rate was measured by double-ring infiltrometer, consisting of two concentric rings. The rate of fall of water level was measured in the inner ring while a pool of water was maintained at approximately the same level in the outer ring to reduce the amount of lateral flow from the inner ring. The diameter of the inner ring is 300mm $\pm$ 10mm and the outer ring diameter is 600mm $\pm$ 10mm. The slight variation in diameter allowed nesting of the rings during transport. Rings are 250 mm deep and were made from 6 mm thick steel plate with sharpened bottom edge. They were driven into the ground to 100 mm depth. Generally the water level was kept at 50 mm depth; the difference in height between the inner and outer rings was kept to a minimum. Other equipments used were water container, a measuring flask, wooden plank, hammer, plastic sheet, stop watch, hook gauge and scale. The rate of fall of the water level in the inner cylinder water was measured at 1, 2, 3, 5, 10, 15 and 30 minute intervals. The process was stopped once a steady infiltration rate had been found. The duration of each test was 4 to 7 hours.

VIII. RESULTS AND DISCUSSION

Cumulative infiltration is calculated for the observed time intervals with evaluated infiltration equation. Then comparison between measured cumulative infiltration and cumulative infiltration by evaluated infiltration equation is carried out. The same is tabulated and compared graphically. Table 2 indicates a sample comparison.

TABLE 2: GRAPES GARDEN- 01(WINTER SEASON)

Tim min	Kosti-akov Eqn. (cm)	Modified Kostiakov Eqn. (cm)	Horton's equation		Measured Yc (cm)
			Rate (cm / hr)	Yc (cm)	
0	0	0	0	0	0
2	1.06	1.11	5.848	0.19	1.45
4	1.39	1.46	5.846	0.39	1.63
9	1.93	2.00	5.841	0.876	1.88
14	2.30	2.38	5.837	1.36	2.16
19	2.60	2.68	5.832	1.85	2.42
24	2.85	2.94	5.830	2.33	2.67
29	3.08	3.16	5.823	2.81	2.92
34	3.28	3.36	5.818	3.30	3.15
44	3.63	3.72	5.809	4.26	3.50
54	3.95	4.03	5.799	5.22	3.89
64	4.22	4.30	5.790	6.176	4.27
74	4.47	4.55	5.780	7.13	4.64
89	4.82	4.89	5.767	8.55	5.04
104	5.13	5.20	5.750	9.97	5.39
119	5.41	5.48	5.739	11.38	5.77
149	5.92	5.98	5.710	14.18	6.21
179	6.37	6.43	5.684	16.96	6.59
209	6.78	6.83	5.657	19.70	6.89
239	7.15	7.19	5.629	22.42	7.01
269	7.50	7.53	5.600	25.118	7.12
299	7.82	7.85	5.575	27.785	7.22
329	8.13	8.15	5.549	30.42	7.30
359	8.42	8.43	5.522	44.04	7.37

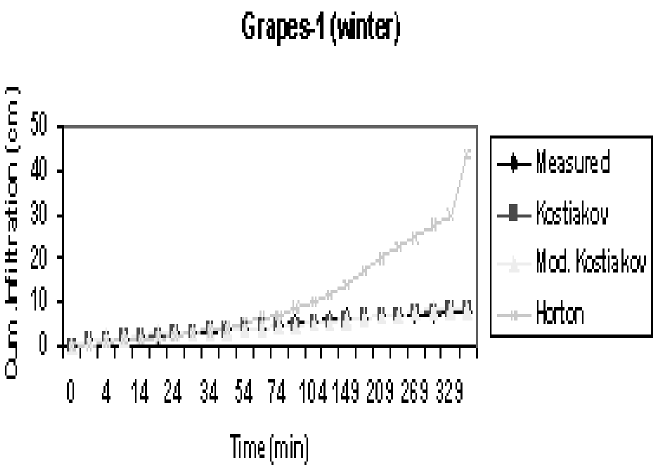


Figure 2. Measured Vs. Estimated Cumulative Infiltration for Grapes- I

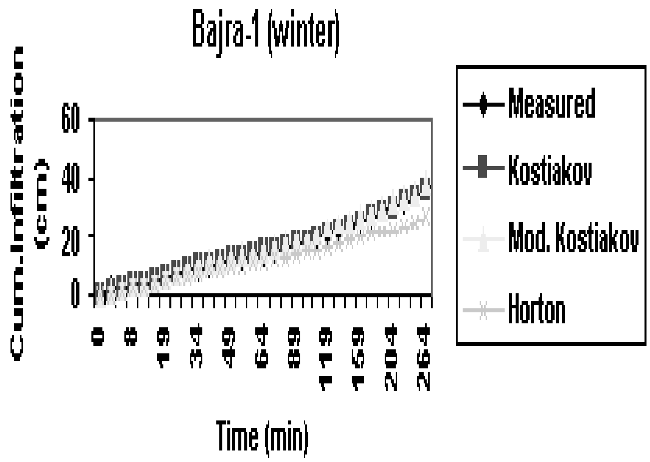
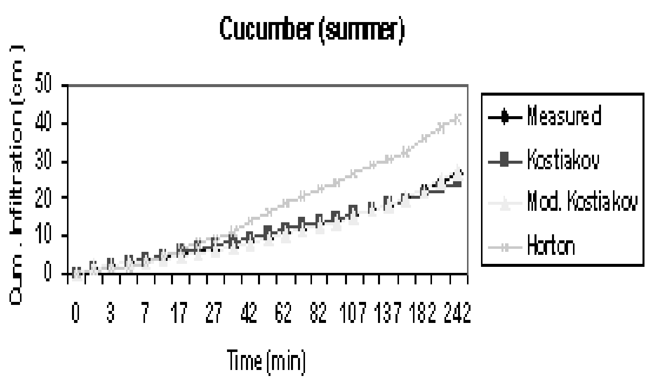


Figure 3. Measured Vs. Estimated Cumulative Infiltration for Bajra- I



Figurer 4. Measured Vs. Estimated Cumulative Infiltration for Cucumber

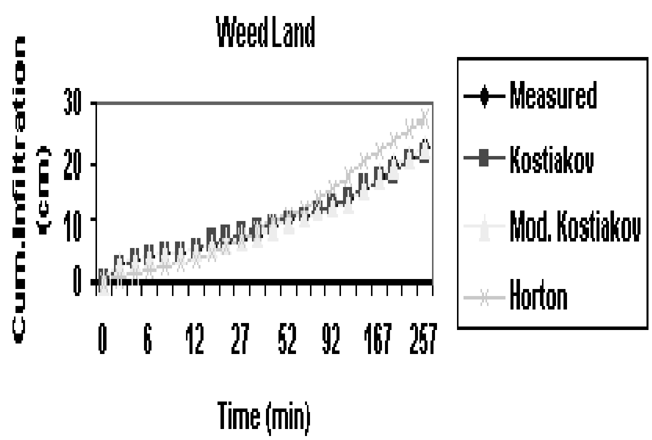


Figure 5. Measured Vs. Estimated Cumulative Infiltration for Weed Land (summer)

IX. ANALYSIS AND DISCUSSION

The study was undertaken for the determination of infiltration rate and evaluation of different infiltration equations stated earlier under different land covers, like Grapes garden, Bajra land, Gram land, Cucumber land and Weed's land in winter season and summer season.

The infiltration depth at the selected time intervals was measured in all the land covers based on double-ring infiltrometer field observations. Total fourteen experiments were conducted, six in winter season and eight in summer season. The infiltration curves were plotted for infiltration rate vs. time and cumulative infiltration vs. time separately for each land cover and for both seasons.

The infiltration observations indicated that for almost all land covers in winter season the infiltration rate was low and it requires more time to reach to constant infiltration rate. For almost all land covers in summer season the infiltration rate was more and it requires less time with compare to winter season to reach to constant infiltration rate. The total depth of cumulative infiltration in winter season and in summer season was near about same for grapes garden. The total depth of cumulative infiltration in summer season for Gram land was about 1.5 times the cumulative infiltration in winter season for Bajra crop on the same land.

Analysis was carried out for Kostiakov equation, modified Kostiakov equation, Horton equation and Philip equation for different land covers, in winter season and in summer season. In Kostiakov and modified Kostiakov for obtaining soil constant a, b and c by conventional approaches. Davis method was adopted to find out soil constants. In case of Horton's equation, analysis was carried out graphically for all the land covers in winter season and summer season. In Philip equation analysis was carried out by using Philip Two Term model, which is in the form of Taylor power series solution.

The relationship of measured cumulative infiltration and estimated cumulative infiltration with time under different land covers was determined and tabulated in table 1. The relationship of measured cumulative infiltration and estimated cumulative infiltration is also represented graphically. The infiltration rate shows much variation for the same land covers which may be due to the presence of pores below the crust or variations in soil texture and structure. Observations show that, the rate of infiltration for different land covers in summer season was about twice the infiltration rate in winter season. Based on the observations and analysis the following conclusion can be drawn.

X. CONCLUSIONS

In winter season-

- For Grapes land Horton equation shown much variation but Kostiakov equation and Modified Kostiakov equations were almost coinciding with measured cumulative infiltration.
- For Bajra land covers the Horton infiltration equation shown much variation, Kostiakov equation shown very little variation but modified Kostiakov equation was coinciding with measured cumulative infiltration.

- For weeds land Horton equation shown much variation and Kostiakov equation and modified Kostiakov equation shown little variation with measured cumulative infiltration curve.

In summer season

- For Grapes garden Horton equation shown much variation but Kostiakov equation and modified Kostiakov equation shown little variation with measured cumulative infiltration.
- For Cucumber land Horton equation shown too much variation but Kostiakov equation and modified Kostiakov equations were almost coinciding with measured cumulative infiltration curve.
- For Gram land Horton equation, Kostiakov equation and Modified Kostiakov equation all were suiting best with measured cumulative infiltration.
- For Weed land Horton equation shown variation but Kostiakov equation and Modified Kostiakov equation were coinciding with measured cumulative infiltration curve. Philip equation shown much variation for all the land covers.
- From the foregoing discussion it can be concluded that, Kostiakov equation was found to be the best for all the land covers In Brahmangaon area of Kopargaon Taluka.

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