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Spatial distribution of soil under the influence of infiltration rate

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Abstract
The infiltration capacity of soil influences the occurrence of overland flow. Further, the prediction of runoff has a crucial role in designing hydraulic structures as well as water resources planning and management. The study was conducted to determine infiltration rate by double ring infiltrometer, to compare the observed infiltration rates with the calculated infiltration rates, to study the suitability and validity of Horton's equation and Kostiakov's equation and to examine the spatial variability of infiltration rates of different agricultural plots. Puriya park, K. K. Wagh COAET, Nashik, was selected for the study area. Infiltration rate was measured by double ring infiltrometer. Further, it was observed that infiltration rate was higher in loamy sand soil than sandy loam for same condition. Soil without vegetation has lower infiltration rate as compare to soil with vegetation. Kostiakov's equation was suitable than Horton for calculating the infiltration rate of sandy loam and loamy sand soil.

Keywords: infiltration, infiltration rate, textural classification, kostiakov's equation

Introduction
Infiltration is the process of water entering soil and generally referred to as the downward movement of water from the soil surface (Bouwer, 1986; Hillel, 1998) [4, 6]. This process affects the transport route of chemicals, the water quality of agricultural drainage, and the uniformity and efficiency of surface irrigation (Berehe *et al*., 2013; Rashidi *et al*., 2014) [3, 16].
The infiltration rate is the rate at which water penetrate the surface of soil expressed in cm/hr. or inches/hr. The infiltration rate is of prime importance to the irrigation engineers as it influences the application rate of irrigation. It is difficult to design an irrigation system without proper knowledge of infiltration characteristics of soil. 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. This is useful for mitigation of hydrological risk. The infiltration capacity of soil influences the occurrence of overland flow. Further, the prediction of runoff has a crucial role in designing hydraulic structures as well as water resources planning and management.
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 replenishment 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 process of infiltration can continue only if there is space available for additional water at the soil surface.
Infiltration rates are measured by using some of the well - known methods such as Single Ring Infiltrometer and Double Ring Infiltrometer. The single ring involves driving a ring into the soil and supplying water in the ring either at constant head or falling head condition. Constant head refers to condition where the amount of water in the ring is always held constant whereas Double ring infiltrometer requires two rings: an inner and outer ring. The purpose is to create a one dimensional flow of water from the inner ring, as the analysis of data is simplified.
Soil factors that control infiltration rate are vegetative cover, root development and organic content, moisture content, soil texture and structure, porosity and permeability, soil bulk density and compaction, slope, landscape position, topography.
The infiltration models were assessed for finding best fitting model to observed field infiltration rate data are Horton's Equation (Hortan, 1940) [7], Kostiakov Equation (Kostiakov, 1932) [14], Modified Kostiakov Equation, Green Ampt Equation (Green and Ampt, 1911) [5], Philip's Two- Term Model.

The objectives of these study were to compare the observed infiltration rates with the calculated infiltration rates and to study the suitability and validity of Horton's equation and Kostiakov's equation.

Materials and Methods

Determination of physical properties of soil samples

Textural classification

The textural classification of ten different points from two different plots were carried out by using sieve shaker method. The triangular classification of U.S.D.A. based on the percentage of sand, silt and clay sizes making up the soil (Fig.1). Such a classification is more suitable for describing coarser grained rather than clay soils whose properties are less dependent on the particle size distribution.

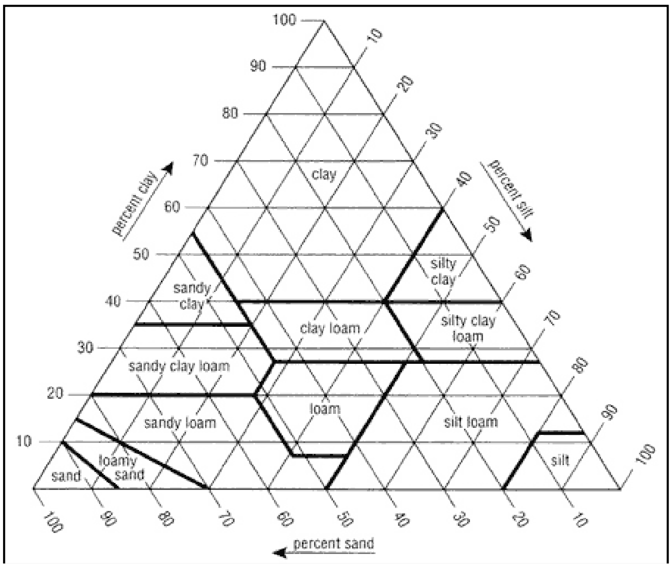

Fig 1: Textural classification chart

Determination of infiltration rate

Infiltration rate was measured by double ring infiltrometer (fig. 2). The diameter of inner and outer cylinders of double ring infiltrometer was 30 and 60 cm respectively and are formed of 2mm rolled steel with a standard height of 25 cm. Infiltration rate was determined as follows, The cylinders were driven into the soil up to 10 cm depth by light blows with an ordinary hammer and using a short iron plank for smooth insertion of metal cylinders. The water level in the inner cylinder was recorded with the measuring tape. Known quantity of water was added at the beginning and afterwards at certain time intervals into the inner cylinders. Same water level was also maintained in the outer buffer cylinder. Water infiltrated as a function of time was measured with the help of measuring cylinder. The difference between the quantities of water added and the volume of water in the cylinder at the instant was taken as the quantity of water that infiltrates during time interval between start of filling and first measurement.

After the initial reading, measurements were made at frequent intervals to determine the amount of water that was infiltrated during each time interval. Constant head of water was maintained by pouring the known quantity of water frequently and after each measurement, approximately equal water level in the inner and outer cylinder was maintained every time. The experiments were continued beyond the estimated time the water would stand in inner and outer cylinder during infiltration test.

Fig 2: Double ring infiltrometer

Infiltration rate equation

Several equations that simplify the concepts involved in the infiltration process have been developed for field applications. The empirical models generally relate infiltration rate or volume to elapsed time modified by certain properties. Parameters used in these models were commonly estimated from measured infiltration rate-time relationships for a given soil condition. For determination of values different parameters from observed field infiltration rate data, following infiltration models were used for different plots.

Kostiakov Model

Kostiakov (Kostiakov, 1932) [14] proposed the simple infiltration rate relating the infiltration rate fp to time t, which was given as,

$$f = at^{\alpha} \quad \ldots (1)$$

Where,
f = cumulative infiltration at any time t.
t = time in min.
a and α are constants
Taking log of equation (1), we have,

$$\log f = \log a + \alpha \log t \quad \ldots (2)$$

The observed values of 'f' and 't' were substituted in equation (2). From the set of these N equations, n and N-n equations n= (N-1)/2 were added to get two simultaneous equations. Solving these two simultaneous equations the value of 'α' and 'log a' were determined and then 'a' was determined.

Horton's Model

Horton (Horton, 1940) [7] expressed decrease of infiltration capacity with time as an exponential decrease as,

$$f = fc + (fo - fc)\, e^{-kt} \quad \ldots (3)$$

Where,
f = infiltration capacity at any time t.
fc = final steady state infiltration capacity.
fo = initial infiltration capacity.
k = Horton's constant representing rate of decrease in infiltration capacity.
t = time in hours.
Taking log of equation (3), we have,

$$\log (f-fc) = \log (fo - fc) - kt \quad \ldots (4)$$

The observed values of ‘f’, ‘fo’, ‘fc’ and‘t’ were substituted in equation (4). From the set of these N equations, n and N-n equations n= (N-1)/2 were added to get two simultaneous equations. Solving these two simultaneous equations, the value of ‘k’ was determined.

Results and Discussion

Particle size distribution

Table 1: Textural classification of different plots

Sample Plot	Observation points	%Sand	%Silt	%Clay	Soil class
Plot No.2	P1(bare)	63.4	23.2	13.4	Sandy loam
	P2(bare)	68.5	18.3	13.2	Sandy loam
	P3(bare)	54.9	25.4	19.7	Sandy clay loam
	P4(vegetation)	74.3	14.5	11.2	sandy loam
	P5(vegetation)	70.6	20.3	10.1	Sandy loam
Plot No.6	P1(bare)	70.8	20.2	9.0	Sandy loam
	P2(bare)	77.2	15.8	7.0	Loamy sand
	P3(bare)	78.6	14.3	7.1	Loamy sand
	P4(vegetation)	51.3	31.7	17.0	Loam
	P5(vegetation)	55.6	30.1	14.3	Sandy loam

In Plot No.2, Sandy loam texture of soil was found while in Plot No. 6 loamy soil was found. Point P1,P2, P4, P5 form plot No. 02 have same soil class i.e. sandy loam and point P1 and P5 from plot No. 06 have same soil texture i.e. sandy loam while point P2 and P3 were loamy sand type.

Determination of Infiltration Rate

Infiltration rate was determined for five different points, three with bare land and two with vegetation, and the observations of different plots were tabulated below,

Table 2: Infiltration test results for Plot No -2

Point	Elapsed time(min)	Time (min)	Infiltration rate(mm/hr)	Depth of water infiltrated (mm)	Cumulative Depth of water infiltrated (mm)
P1	0	0	0	0	0
(bare)	5	5	228	19	19
	10	5	84	7	26
	15	5	48	4	30
	20	5	36	3	33
	25	5	36	3	33
P2	0	0	0	0	0
(bare)	5	5	288	24	24
	10	5	108	9	33
	15	5	48	4	37
	20	5	24	2	39
	25	5	24	2	39
P3	0	0	0	0	0
(bare)	5	5	288	24	24
	10	5	252	21	45
	15	5	216	18	63
	20	5	72	6	69
	25	5	72	6	69
P4	0	0	0	0	0
(vegetation)	5	5	336	28	28
	10	5	108	9	37
	15	5	84	7	44
	20	5	36	3	47
	25	5	36	3	47
P5	0	0	0	0	0
(vegetation)	5	5	312	26	26
	10	5	288	24	50
	15	5	180	15	65
	20	5	132	11	76
	25	5	132	11	87

For Plot No.-2, from textural and infiltration results, it was observed that sandy loam soil without vegetation has lower infiltration rate as compare to sandy loam soil with vegetation. Infiltration rate was higher in sandy clay loam soil without vegetation. From that, it was observed that infiltration rate was higher in sandy clay loam as compare to sandy loam as well as infiltration rate was higher in vegetative soil than bare soil.

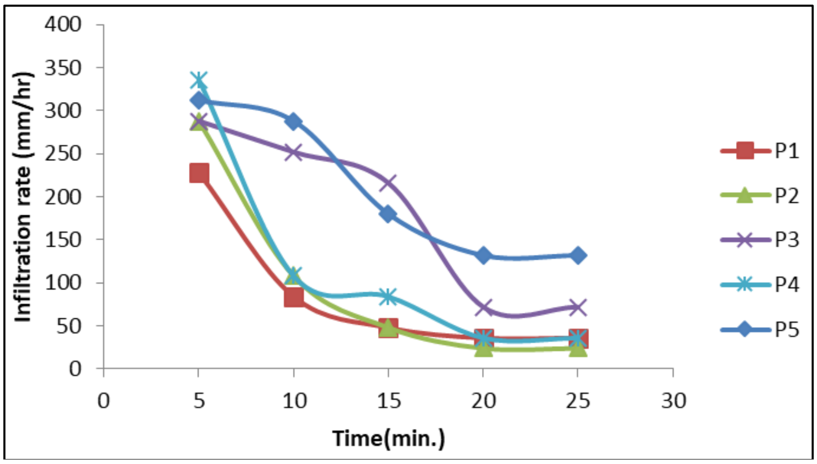

Fig 3: Infiltration rate Vs time graph for Plot No- 02

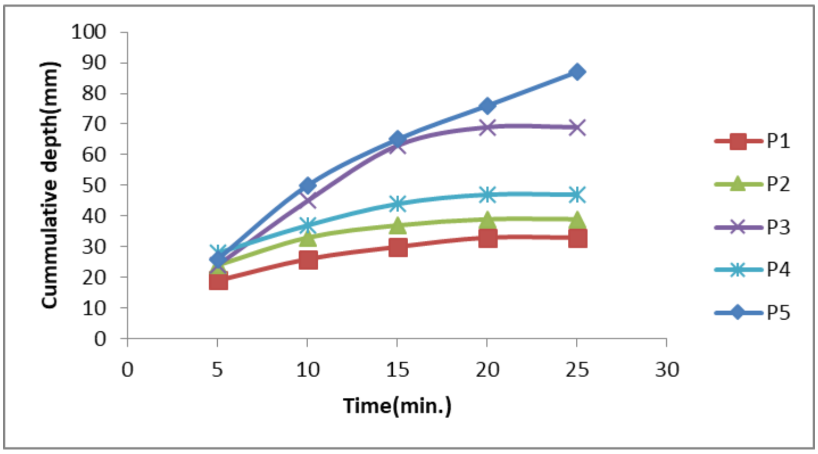

Fig 4: Cumulative depth Vs time for Plot No- 02

Table 3: Infiltration Test results for Plot No -6

Point	Elapsed time(min)	Time (min)	Infiltration rate(mm/hr)	Depth of water infiltrated	Cumulative Depth of water infiltrated (mm)
P1	0	0	0	0	0
(bare)	5	5	732	61	61
	10	5	576	48	109
	15	5	492	41	150
	20	5	432	36	186
	25	5	264	22	208
	30	5	252	21	229
	35	5	252	21	250
P2	0	0	0	0	0
(bare)	5	5	1032	86	86
	10	5	636	53	139
	15	5	528	44	183
	20	5	456	38	221
	25	5	348	29	250
	30	5	324	27	277
	35	5	324	27	304
P3	0	0	0	0	0
(bare)	5	5	600	50	50
	10	5	348	29	79
	15	5	264	22	101
	20	5	300	25	126
	25	5	252	21	147
	30	5	228	19	166
	35	5	228	19	185
P4	0	0	0	0	0
(vegetation)	5	5	612	51	51
	10	5	468	39	90
	15	5	324	27	117
	20	5	276	23	140

	25	5	168	14	154
	30	5	156	13	167
	35	5	156	13	180
P5	0	0	0	0	0
(vegetation)	5	5	1140	95	95
	10	5	924	77	172
	15	5	816	68	240
	20	5	480	40	280
	25	5	444	37	317
	30	5	384	32	349
	35	5	384	32	381

For Plot No.-6, from textural and infiltration results, it was seen that sandy loam soil without vegetation has lower infiltration rate as compare to sandy loam soil with vegetation. Infiltration rate was higher in loamy sand soil than sandy loam for same condition.

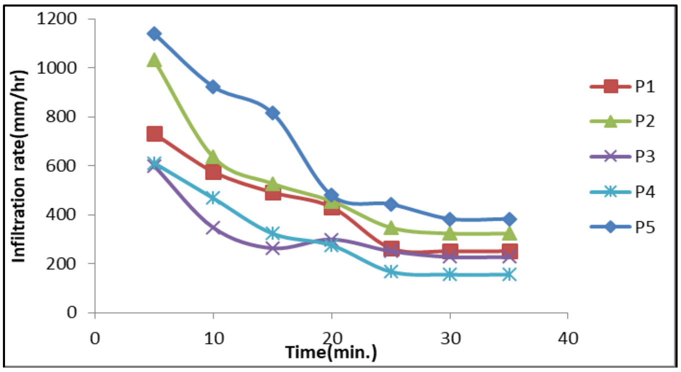

Fig 5: Infiltration rate Vs time for Plot No- 06

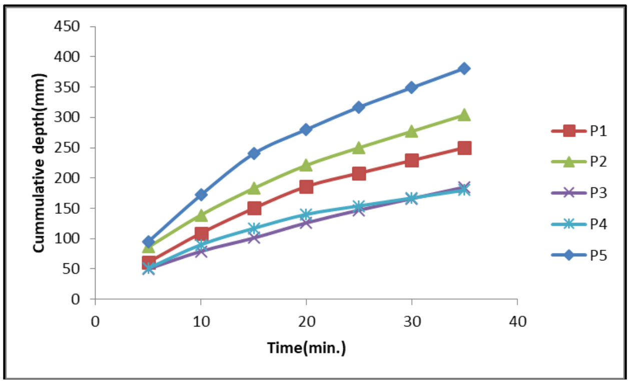

Fig 6: Cumulative depth Vs time for Plot No- 06

Suitability and validity of infiltration equations

For determining the constant of Horton and Kostikov's infiltration equation power and exponential functions were used.

Table 4: Equations for different points for Plot No -2

	Points	Power function equation	R^2	Exponential function equation	R^2
Plot No. 2	P1(bare)	$y=1450x^{-1.208}$	0.97	$y=18.478e^{0.0269x}$	0.84
	P2(bare)	$y=4321.8x^{-1.658}$	0.98	$y=24.073e^{0.0228x}$	0.78
	P3(bare)	$y=1657.7x^{-0.981}$	0.73	$y=23.508e^{0.0508x}$	0.80
	P4(vegetation)	$y=3258.9x^{-1.43}$	0.97	$y=27.194e^{0.0255x}$	0.84
	P5(vegetation)	$y=934.29x^{-0.61}$	0.88	$y=23.997e^{0.0567x}$	0.88

From above table, it was observed that value of correlation coefficient for power function is more than exponential function except the soil with sandy clay loam texture.

Table 5: Equations for different points for Plot No -6

	Points	Power function equation	R^2	Exponential function equation	R^2
Plot No. 6	P1(bare)	$y=2187.5x^{-0.605}$	0.90	$y=65.627e^{0.0432x}$	0.87
	P2(bare)	$y=2744.2x^{-0.617}$	0.99	$y=88.486e^{0.0391x}$	0.90
	P3(bare)	$y=1142.7x^{-0.474}$	0.90	$y=49.193e^{0.0413x}$	0.94
	P4(vegetation)	$y=2427.9x^{-0.783}$	0.94	$y=56.091e^{0.0378x}$	0.85
	P5(vegetation)	$y=3575x^{-0.63}$	0.92	$y=104.0e^{0.041x}$	0.86

From above table, it was observed that value of correlation coefficient for power function is more than exponential function except the soil with sandy loamy sand without vegetation.

Table 6: Constants of Horton and Kostikov's infiltration equation

Plot No.	Point	a	α	R^2	k	R^2
02	P1	1450	-1.208	0.97	0.0269	0.84
	P2	4321.8	-1.658	0.98	0.0228	0.78
	P3	1657.7	-0.981	0.73	0.0508	0.80
	P4	3258.9	-1.43	0.97	0.0255	0.84
	P5	934.29	-0.61	0.88	0.0567	0.88
06	P1	2187.5	-0.605	0.90	0.0432	0.87
	P2	2744.2	-0.617	0.99	0.0391	0.90
	P3	1142.7	-0.474	0.90	0.0413	0.94
	P4	2427.9	-0.783	0.94	0.0378	0.85
	P5	3575	-0.63	0.92	0.041	0.86

From above table, it was observed that, the Kostiakov's equation is suitable equation than Horton equation for calculating the infiltration rate of sandy loam soil as well as loamy sand soil.

Conclusions

The conclusions obtained that the infiltration rate was higher in loamy sand soil than sandy loam for same condition. Soil without vegetation has lower infiltration rate as compare to soil with vegetation and Kostiakov's equation was suitable than Horton for calculating the infiltration rate of sandy loam and loamy sand soil.

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