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Analysing the Infiltration Rate of Different Types of Infiltration Model: A Review

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Abstract

The term "infiltration" refers to the process of water moving in all directions into the soil. The maximum rate at which water is absorbed into the soil at any given time is known as the infiltration rate. The rate of infiltration is measured in centimetres per hour (cm/hr) or millimetres per hour (mm/hr). Before the building can be built, the soil must be stabilized if it has a low infiltration capacity. The lifespan of a building is reduced if water remains stagnant at ground level. As a result, determining the rate of infiltration is critical. This paper makes an attempt to look into infiltrometers and models that are best for determining infiltration rate. The Kostiakov model, Horton model, Philips model, Green-Ampt model, Regression model, M5P model, Modified Kostiakov model, and Branched Modified Kostiakov model were all used by the significant proportion of the authors. The results show that the Kostiakov and Horton models were both effective in estimating the infiltration rate.

Keywords

Branched Modified Kostiakov Model, Green-Ampt Model, Horton Model, Infiltration, Infiltrometers, Kostiakov Model, M5p Model, Modified Kostiakov Model, Philips Model, Regression Model.

INTRODUCTION

The term “Infiltration” refers to the process of movement of water into the soil in all the direction. The infiltration rate is the maximum rate at which water is absorbed into the soil at a given time. The infiltration rate is measured as cm/hr or mm/hr. Infiltration is affected by the texture, structure, and hydrodynamic properties of the soil, as well as the vegetation, topography, and morphology of the slope, rainfall intensity, irrigation flow, temperature, humidity, and soil compaction. Surface run-off, groundwater recharge, evapotranspiration, soil erosion, and chemical transport into the soil most advantage from infiltration. The different types of infiltrometers and models, such as single ring infiltrometers, double ring infiltrometers, Horton model, Kostiakov model, Philip model, Green-Ampt model, and so on, were studied in this paper.

Some of the model have been developed for finding the infiltration rate.

Table 1. infiltration models and functions

MODEL	EQUATION	ABBREVIATION
Horton [29]	$f = fc + (f0-fc)\, e^{-kt}$	f= infiltration rate at time t (mm/hr) f0= initial rate of infiltration (mm/hr) fc= final rate of infiltration(mm/hr) k= constant e= base of the Napierian logarithm t= time from beginning of the storm (hr)
Kostiakov [49]	$F = K_k\, t^{-\alpha}$	F = infiltration capacity t = time after infiltration starts K_k, α = graphical parameter
Philip [22]	$I = Kt + St^{1/2}$	I= cumulative infiltration depth (mm) S= soil water sorptivity (mm/hr) t= time (hr) K= Saturated hydraulic conductivity (mm/hr)
Green-Ampt [26]	$f = m + n/F$	f = infiltration capacity F = cumulative infiltration m and n = Green-Ampt parameter of infiltration

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Infiltrometer have been developed for finding the infiltration rate.

Single ring infiltrometer

The single ring infiltrometer has cylindrical ring of 30cm or larger in diameter that is driven into the soil to find the infiltration rate.

Double ring infiltrometer

The double ring infiltrometer consist of inner ring and outer ring 28/53 cm, 30/55 cm and 32/57 cm in diameter that both the ring is driven into the soil to find the infiltration rate.

LITERATURE REVIEW

1D and 3D flow

David E Elric et al. (1990) Three-dimensional infiltration reaches steady state flow significantly faster than one-dimensional infiltration at first, although one-dimensional infiltration approaches steady state faster at some point near steady flow, depending on soil parameters. [10]

Artificial Neural Networks (ANNs)

Nestor L SY (2006) The contributing factors in utilising ANN to model infiltration include soil moisture and hydraulic conductivity. In terms of cumulative infiltration, ANNs are the most accurate when compared to the classic Philip and Green-Ampt models. [37]

Branched Modified Kostiakov model

L Childs et al. (1933) Because the infiltration pattern was temporally associated across post plant irrigations, representative sites rather than a full field inquiry could be utilised to determine infiltration mean and variability. Using a Branched Modified Kostiakov equation, a cumulative infiltration curve was fitted to the data of each test. [22]

Concentric ring

T R Verma and J A Toogood (1968) To assess infiltration rate variations, they adapted the concentric method: the concentric ring was 10 cm high and made of 14 gauge galvanised ion sharpened at the lower edge. The inner and outer rings were 20 and 30cm in diameter, respectively. Using plywood board 40×40×2cm, the ring was hammered 2 to 4cm into the ground. Infiltration of soil reveals a higher rate in the first half for many soils, which is more than the maximum rainfall reported. [51]

Direct shear test

Shao-Hung Chung (2019) Rainfall infiltration reached a depth of 120cm beneath the surface. The shear strength of the soil decreased as the moisture content of the soil increased. Rainfall would lessen the soil matric suction, lowering the soil's shear strength. When soil was saturated due to rainwater infiltration, the cohesiveness and internal friction angle decreased to extremely low values of 1 kPa and 15°, respectively, based on the findings of the direct shear test. [47]

Double ring infiltrometer

P Anil Kumar et al. They adopted a ring infiltrometer with two rings. Grey ploughed soil and Red ploughed soil have high infiltration rates, while Grey compacted soil and Red compacted soil have low infiltration rates. When compared to ploughed and unploughed soil, compacted soil has a low infiltration rate. [39]

G E Osuji et al. (2010) High infiltration rates are encouraged by bush fallow. It is suggested that lands on the edge that are fragile and prone to soil erosion and other forms of soil degradation be restored to bush fallow for the purpose of accumulating organic matter. [15]

Fig. 1 Double ring infiltrometer (Source: Sunith John David)

Soniya sony et al. (2020) When compared to soil at the location Ambanapoly, soil at Kannady has better infiltration capability and slightly less turn-off. Because of the particle size, fluid density, and water content, there is more infiltration. [48]

J H Gregory et al. (2006) Because of the increased impervious area associated with development, as well as because the previous area effectively approaches the infiltration behaviour of an impervious surface, construction activity in this area increases the potential for runoff and large storm water conveyance networks. [21]

K C Patra & Mrunmayee M Sahoo. In context of the present environmental scenario, the soil becomes compacted, and the infiltration rate remains constant for the coming year, preventing erosion in the area. [6]

Diwan Singh et al. (2014) The link between cumulative infiltration and time was developed using non-linear regression. Due to differences in water content, variable infiltration rates are seen for the same soil. Cumulative infiltration and infiltration rate decrease as water content rises. [13]

Eke Kalu Torti et al. (2013) The results obtained appear to be low in general. Ponding and run-off are common in soils with low infiltration rates. Run-off speeds up the erosion process and adds to flooding in the lowlands of the region. As a result, it is suggested that soil treatment should be used as

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an approach for determining these soil penetration rates. [5]

V M Chowdary & M Damodhara Rao (2006) With a double ring infiltrometer, the lateral component of infiltration is reduced by three to six times. When planning an irrigation system, the extra amount of lateral component estimated with a single or double ring infiltrometer must be considered. A dimensionless equation was also created to forecast cumulative infiltration, and the results were found to be very close to the data that was observed. The wetting zone during the infiltration process has an elliptical shape, and the length of the wetting zone at the central axis of the infiltrometer increases as the infiltrometer diameter and ponding head increases. [53]

Puneet Hiranandani et al. (2017) The soils in the Sher-Umar doab are mostly black clayey soil (black cotton soils), with infiltration rates varying from 0.1 to 4.8 cm per hour. The soils are not suited for irrigation by flooding. If this irrigation method is used (once the Bargi Left Bank Canal is completed), sufficient drainage should be supplied. Excessive irrigation with canal water might result in salinization and waterlogging. [40]

Gayatri Das & Mimi Das Saikia (2016) The infiltration rate is high at first because the soil is dry, but as the soil saturates, it gradually lowers until it reaches a constant value. This is because of the infiltration rates are influenced by soil properties. Following soil testing, we discovered that Eastern Retreat is surrounded by sandy soil, while Bonda is surrounded by loamy soil. Furthermore, it was discovered that the type of infiltration for loamy soil is slow-moderate, the type of infiltration for sandy loam soil is moderate, and the rate of infiltration for sandy soil is moderate-rapid. All of the five research locations, with the exception of DeeporBeel, have Poorly Graded Sand, whereas DeeporBeel has Well Graded Sand. [17]

John Diamond and Thomas Shanley (2003) Infiltration capacity exceeded or equalled the five-year return rainfall rate in summer, except on poorly drained soils, indicating that the risk of overland flow due to infiltration excess is negligible in summer on well drained soils. Infiltration capacity in winter was below the five-year return hourly rainfall at nine of the ten sites (mostly freely drained), indicating a risk of overland flow. [11]

Milad Fatehnia (2015) An Arduino microcontroller, Hall effect sensor, peristaltic pump, water level sensor, and constant-level float valve were used to design and test an automated DRI system. The benefits of the new system were discussed in comparison to previous designed systems. For a better understanding of the setup, the system configuration was illustrated. The equipment was put in a portable, weather-resistant box and used to conduct DRI testing in the field to ensure the portable system's usability and accuracy in field measurements. [34]

B L Maheshwari (1996) An automatic double-ring infiltrometer was created that requires minimum human intervention during data collection and offers an up-to-the-minute overview of result of infiltration while the test is still running. [7]

N sidiras and C H roth (1987) There was a strong positive association between soil cover % and infiltration rate for both techniques of infiltration rate estimation. The infiltration rate of the double-ring infiltrometers was significantly higher than that of the rainfall simulator. The ring infiltrometers produced the highest infiltration rates under conventional tillage, but the rainfall simulator came up with the highest infiltration rates under no-tillage. [35]

Nor Ashikin Binti Shaari & Mohammad Muqtada Ali Khan (2016) Infiltration rate of soil as a factor affecting flood conditions is still a novel concept in the study location, as well as in Malaysia. The findings of this study will be valuable to municipal planners and policymakers in carrying out flood control operations and policies. [38]

J Toama and J Albergel (1991) The data collected by the double ring infiltrometer has a much broader range than the rain simulator data. When the soil surface is prone to crusting, the double ring infiltrometer is shown to be more suitable than the rain simulator for determining soil hydrologic parameters. [23]

Robert Pitt and Janice Lantrip (2000) The soil conditions in metropolitan areas with the greatest infiltration potential. [43]

SelimTarek (2011) The amount of water present in heavy clayey soil affects the rate of infiltration. [46]

GIS & RS

M A Kalam and M Ramesh (2016) It may be deduced that remote sensing and GIS are potentially powerful tools for studying groundwater resources and designing an appropriate exploration strategy.[28]

Horton model

S Mohan and Kumari Sangeeta (2015) Green Ampt model, modified Kostiakov model and Horton model were compared with SWAT model (Soil and Water Assessment Tool). Horton model shows highly correlated to SWAT model when compared to other model. [45]

Katkar namrata et al. (2019) The infiltration rate of black cotton compacted soil is 1.1cm/hr, ploughed soil is 1.34cm/hr, and unploughed soil is 1.49cm/hr. After calculating the correlation coefficient and standard error, it was discovered that the black soil and condition Horton model has the best fit, with a high degree of correlation and the smallest standard error. [25]

Leke Wulan Ayu, Sugeng Prijono Soemarno (2013) The Horton Model's estimated value of soil infiltrability is similar to the value of infiltration measured in the field. Lowland rainfed (rainfed sawah landuse) has the largest infiltration rate, whereas dryland has the lowest rate. [20]

M H Fadadu et al. (2018) By using a semi-log plot and a graphical manner, the Horton model for infiltration rate was created. That the Horton model provides a reliable estimate of soil infiltration. [30]

Bharath Kumar V et al. (2015) Horton's equation is the calculation used in this experiment. According to the

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analysis, the soil in the four selected areas is black cotton soil with a low sand percentage. At KC UNIVERSITY, the infiltration rate is quite consistent. [29]

Gert Aron et al. (1990) The dependence of Horton infiltration rates on time was reduced in particular. It was decided to allow for the regeneration of infiltration capacity during rainless times. For intermittent storm events, the provided equations should be practical. [18]

Jagdale Satyawan Dagadu & Nimbalkar P T (2012) Except for ploughed clay soil, where Green – Ampt model is best fitting, Horton's model is best fitting with a high correlation coefficient and smallest standard error. As a result of the research, it has been shown that Horton's model best fits measured infiltration rates for all types of soils and soil conditions in the region, with the exception of ploughed clay soil. [32]

CH ratnaraju et al. (2015) Except for unploughed circumstances, Horton's model fit all types of soil conditions best with a high correlation coefficient. In addition, graphs of measured infiltration rate and calculated infiltration rate by different models against time were drawn for red soil under various soil conditions, and it was discovered that infiltration rates were initially higher and then decreased with time until they reached a constant rate. [9]

Jean-Claude Mailhol (2003) The applicability of our loamy soil modeling's predictive approach was then successfully applied to a thick clay soil with cracks. Although not proved in this study, the application of this modelling approach to silty soils is doubtful because this soil type has a tendency to produce a surface crust, which reduces infiltration significantly during the advance phase. [31]

Lucas dos Santos Batista & Raimundo Rodrigues Gomes Filho (2020) The soil water penetration rate was determined using a double cylinder infiltrometer and approximated using Kostiakov, Kostiakov-Lewis, Horton, and Philip mathematical models. When comparing the models for calculating soil water infiltration rates, the Horton model best fits than the other models, and the forest type of soil cover had the highest infiltration rate. Higher water infiltration rates in the soil were found in no-till areas, contributing to increased groundwater recharge. [27]

Infiltrometers

Wu et al. (1997) The constant head method ensures that measurements taken shortly after refilling the infiltrometer are nearly equal to the infiltration rate. [26]

Kostiakov model

Adindu Ruth Uloma et al (2014) A toposequential distribution at a valley bottom can be determined using comparative regression analysis, which has highly good economic implications for subsurface drainage. The results reveal that no single infiltration process is suitable for the entire valley. Considering that subsurface drainage pipe spacing is larger and implantation density is smaller as permeability improves, better efficiency and cost savings in valley bottom drainage system design and operation can be realised. [4]

Sunith John David et al. (2018) The best fit model with the measured infiltration rate for the Residential area was found to be Kostiakov model. [49]

Dr. M. P. Rajurkar (2012) The Horton equation showed a lot of fluctuation in Grapes land, but the Kostiakov and Modified Kostiakov equations were almost identical to the measured cumulative infiltration. The Horton infiltration equation showed a lot of variation for Bajra land covers, whereas the Kostiakov equation showed very little variation, although the modified Kostiakov equation coincided with measured cumulative infiltration. With observed cumulative infiltration curves, Horton equation showed a lot of fluctuation, while Kostiakov equation and modified Kostiakov equation showed less variation. [2]

VS Patil et al. (2018) For the same conditions, Loamy sand soil had a higher infiltration rate than sandy loam. In comparison to soil with vegetation, soil which is lacking of vegetation has a lower infiltration rate, therefore Kostiakov equation proved more suitable than Horton's for determining the infiltration rate of sandy loam and loamy sand soil. [54]

Sreejani SP et al. (2017) The infiltration rate near Samatha Hostel is as high as 17.43 cm/h, whereas the rate near Assembly Hall is as low as 1.46 cm/h. [50]

M5P model

Balraj Singh et al. (2019) The M5P tree is a technique for simulating the rate of infiltration for a given set of data. SA suggests that cumulative time is an important parameter for water quality using the M5P model tree for this data set. [8]

Mini Disc infiltration

Vikram Kumar et al. (2021) Because of the maximum soil water table, there is a small IR in the inundated region. The study's infiltration map will be very valuable for decision makers when dealing with flood control; it will also be quite useful in the agriculture field when it comes to strategic and timely irrigation. [55]

Modified Kostiakov model

Manoj Gundalia (2017) Infiltration models have varied parameters for different soil types. This clearly demonstrates that soil types have an impact on infiltration rates. Inceptisols and Vertisols can both benefit from Horton's approach for estimating infiltration rates. In Entisols, a modified Kostiakov model can be utilised to properly forecast infiltration rate. [32]

One Dimensional infiltration model

A Zubair & M. A. Farooq (2008) Infiltration rates vary depending on the soil type, although silty sand performs better in terms of pollution removal from storm water. Because of the huge volume of storm water penetrating media into the basin, the background level of trace metals is reduced, and significant cations can be efficiently kept in the soil. [3]

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Philip model

G Gopi and K Shanmugasundaram (2019) The Philips & Green Ampt model fits the field data nicely. When compared to the Green Ampt Model, the Philips model was best suited to agricultural, barren area, and pond site, with greater correlation co-efficient values. [16]

Adindu Ruth U & Igbokwe Kelechi K (2015) When compared to the simulated data, the filed data revealed a close relationship. Philip's model was able to estimate water infiltration depths for Aba soils, as shown by the results. [52]

Regression model

Marykutty Abraham and Riya Ann Mathew (2018) The amount of water available for a fy percent predictable four year is calculated to be 2.46 MCM, and the total water available in the watershed is 1.23 MCM, even if only half of it can be effectively harnessed. The area's water demand is predicted to be 0.148 MCM for residential use and 0.171 MCM for irrigation, which is significantly less than the available run-off from the watershed. [33]

SCS-CN Method (Soil Conservation Service Curve Number)

Nametso Matomela et al. (2019) The correlation coefficient (r^2) was used to assess the relationship between rainfall and run-off, and the results revealed a positive relationship between the two variables. The SCS-CN approach has proven to be efficient and cost-effective, and it may be used to map out sites for artificial water recharge or abstraction across wide areas. As a result, in order to achieve sustainable development, the method can be used as an integrated aspect of land and water resources. [36]

R Viji et al. (2015) It reveals statically positive correlations and perfect fit between the study's results coefficient determination (SCS-CN = 0.958 and Green-Ampt = 0.97) and t(SCS-CN = 0.979 and Green-Ampt = 0.985). When compared to the Green-Ampt loss approach, the improved SCS-CN yields reduced run-off estimation. [42]

Single ring infiltrometer

Dr. Avinash S Kadam (2015) Four of the seven sites offer a lot of potential, especially for the recharge variable approach, which is most cost-effective and appropriate artificial water recharge methods. Only other artificial water recharge methods should be used for the rest of the site. [14]

A I Johnson (1963) Certain infiltration rate values for a specific type of sediment are unlikely to exist, and recorded rates are largely used for comparison. [1]

Fig 2. single ring infiltrometer (Source: A.I. Johnson)

Sprinkling rainfall simulator

Guoqiang Wang et al. (2015) The comparison of measured and modelled infiltration rates revealed that the model accurately approximated the infiltration process, with an overall N-S coefficient of 0.84. There was a significant negative logarithmic relationship between FIR and the four soil erodibility factors, with the link between USLE-K and FIR demonstrating the strongest correlation. The use of poultry composts would have no effect on the logarithmic relationship between FIR and soil erodibility. The method overcomes the drawbacks of traditional soil erodibility soil, which is both expensive and time-consuming. [19]

Surge infiltration model

Sajid Mahmood & Muhammad Latif (2003) Using limited observed data, the surge infiltration model, which is a modified variation of the Kostiakov equation is used to create data for cumulative infiltration of later surges. [44]

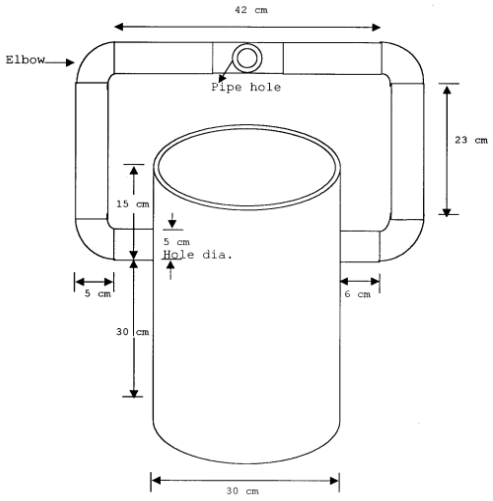

Fig 3. surge ring infiltrometer (Source: Sajid Mahmood)

Tension disc and Pressure ring infiltrometer

Rafael Angulo-Jaramillo et al. (2000) Tension disc and ring infiltrometers have their own set of limitations, the most of which are related to the analysis simplifying assumptions for inferring soil hydraulic parameters from water and solute

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measurements. Other issues emerge from problematic soils, such as hydrophobic, swelling materials, or are inherent in the measurement processes themselves. [41]

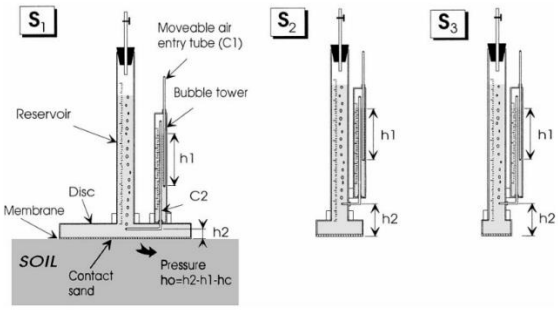

Fig 4.a) disc infiltrometer (Source: Rafael Angulo-Jaramillo)

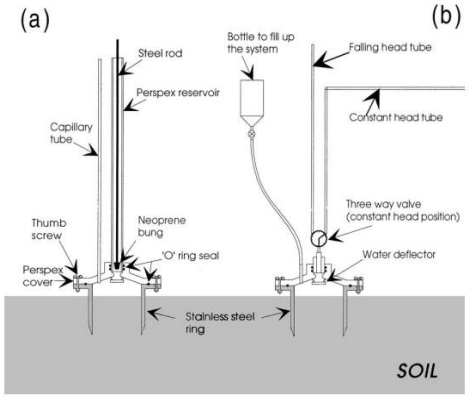

Fig 4.b) pressure ring infiltrometer (Source: Rafael Angulo-Jaramillo)

Turftec Double ring infiltrometer

Fig 5. Turftec Double ring infiltrometer (Source: D Noorvy Khaerudin)

D Noorvy Khaerudin et al. (2019) When compared to Horton's accuracy of 87.2 percent, the Turftec infiltrometer yields no significant results. [12]

Table 2. based on critical review summary of results

Source	Type of soil	locality	methodology	Parameter analysed	conclusion
S Mohan and Kumari Sangeeta (2015) [34]	Sandy loam soil	Neyveli	Green-Ampt model, modified Kostiakov model, Horton model, Swat model	Kostiakov model correlation-0.97, Green-Ampt model correlation-0.9, Horton model correlation-0.95	In comparison to the other models, the Horton model has a strong correlation for all zones except zone 4 and a lower standard error for all zones.
T R Verma and J A Toogood (1968) [51]	Ponaka soil, Angus Ridge loam, Malmo silty clay loam, Peace hill coarse sandy loam, Kavanagh loam, Camrose Loam, Breton loam, Cooking lake loam, Prestille silty clay loam, Dune sand.	Edmonton area	Concentric ring method	in all one hour intensities report were less than 3.7 cm per hour, 79% were less than 1.2 cm per hour, 94-78% were less than 5 cm per hour	They modified the concentric method to show the changes in infiltration rates. Infiltration of soil reveals a higher rate in the first half for many soils, which is higher than the maximum rainfall reported.
P Anil Kumar et	Grey soil, Red soil	Chandragiri Mandal,	Double ring infiltrometer	Infiltration rate	When compared to ploughed and unploughed

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al.[6]		Chittoor district			soil, compacted soil has a low infiltration rate.
katkar namrata et al. (2019) [26]	Black cotton soil	Golapur district, Solapur region of Maharashtra	Double ring infiltrometer	black cotton compact soil-0.95, black cotton ploughed soil-0.98, black cotton harrowed soil-0.99	The Horton model is shown to be the best fitting in the black soil condition, with a high degree of correlation coefficient and the smallest standard error.
Adindu Ruth Uloma et al (2014) [1]	Sandy loam soil	Ikwuano-Umuahia, Nigeria	Kostiakov's model	Infiltration Rate varies from 0.02 – 0.88 cm/min	Kostiakov's infiltration obtained were negative.
Guoqiang Wang et al. (2015) [19]	Fluvo-Acquic soil	china	Sprinkling rainfall simulator	The N–S coefficient of efficiency derived from the last-three, last-two and last time step were 0.89, 0.93 and 0.96, respectively. The averaged deviations for the last-three, last-two and last time step during the validation were 6.34%, 5.94% and 5.14%, respectively	FIR and the four soil erodibility variables have significant negative logarithmic relationships, with the USLE-K showing the strongest association with FIR.
A Zubair & M. A. Farooq (2008) [55]	Silty Sandy gravel, Gravel Silty sand, Sandy silt, silty sand, Silty Gravel sand	Karachi, Pakistan	Infiltrometer	non compacted soil infiltration rate=377 to 634 mm/hr compacted soil infiltration rate=8 to 175 mm/hr	Infiltration rates vary depending on the soil type, although silty sand performs better in terms of pollution removal from storm water.
J H Gregory et al. (2006)	Sandy soil	North Central Florida	Double ring infiltrometer	8-175mm/hr,160-188mm/hr,23mm/hr for the compacted site 377 to 634mm/hr, 637 to 652mm/hr, 225mm/hr for non compacted soil	The least degree of compaction on sandy soils resulted in significantly decreased infiltration rates. Thus, any amount of compaction on these soils must be avoided if runoff from development areas is to be limited.
D Noorvy Khaerudin et al. (2019) [37]	Silty loam soil	Indonesia	Turftec double ring infiltrometer	initial infiltration rate=2667 mm/min infiltration rate constant=0667 mm/min	The Turftec infiltrometer has no significant result
Bharath Kumar V et al. (2015) [7]	Black Cotton soil	Andhra Pradesh	Double ring infiltrometer	infiltration rate of soil in dry condition varies from 13mm/hr to 16mm/hr	The correlation coefficient and standard error analyses revealed that Horton's model fits well with the correlation coefficient and minimum standard error obtained for all types of soils and their conditions.

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CONCLUSION

Based on a review of the journals, The most of the authors have investigated infiltration rates under various soil conditions and soil types. The rate of infiltration varies depending on the soil condition. Because dry soil absorbs water well, the test must be performed on saturated soil to obtain an accurate infiltration rate. Ploughed and unploughed soil has good infiltration when compared to compacted soil. Red soil, Grey soil, Sandy soil, Sandy loam soil, Sandy silt soil has good infiltration when compared to Black cotton soil. It has been found that the double ring infiltrometer gives most accurate measurement of infiltration rate. Kostiakov model and Horton model gives the good value with minuet changes as double ring infiltration. So concluding that double ring infiltrometer, Kostiakov model and Horton model suits best for determining the infiltration rate.

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