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A Review on Infiltration Patterns in Different Types of Soils

Kalola Amit Chunilal[1], Parikh Arpit A[2], Gundalia Manoj J[3], Bhuva Prashant K[4]
[1]*Research Scholar, Department of Civil Engineering, Dr.Subhash University, Junagadh, Gujarat, 362001, India*
[2]*Professor, Department of Civil Engineering, Dr.Subhash University, Junagadh, Gujarat, 362001, India*
[3]*Professor and Head, Department of Civil Engineering, C. G. Patel Institute of Technology, UTU, Bardoli, Gujarat, 394601, India*
[4]*Assistant professor, Department of Civil Engineering, Dr.Subhash University, Junagadh, Gujarat, 362001, India*

Abstract: ***A hydrological phenomenon that occurs in nature is infiltration. It is a difficult, nonlinear procedure. The process by which water at the soil's surface penetrates the structure is known as infiltration. The depth of the water layer that may saturate the soil in one hour is typically used as a measurement (in mm or cm). Various models, and methods are used for evaluating the infiltration rate. Significant scientific effort has been put in over the past few decades to improve infiltration process by many researchers across world. Thus, present review gives magnificent information regarding infiltration rates on different types of soil around the world and research work done in India is also discussed as infiltration rate is crucial for drainage and irrigation effectiveness since it maximizes water availability while reducing erosion. Hence, paper focuses on reviewing different infiltration patterns, challenges and future work to overcome these challenges as soil infiltration rate continues to be a subject of interest so many researchers have done a number of research papers on this topic, thus reviewing the study of it.***
Keywords: Infiltration Rate, Soil, Water, Infiltrometer, Infiltration Model, Survey Methodology.

I. INTRODUCTION

The highest IR (Infiltration Rate) were seen in forest ground covers (leaf litter) and forest land covers [1]. External variables initial soil water content, rainfall process, land use type and soil characteristics soil texture, structure, bulk density are the two primary categories that influence infiltration . In soil technology, the term "infiltration rate" refers to a measurement of how quickly soil can absorb rainwater [2]. Infiltration rates are maximum close to stems and quickly decrease as distance increases. A pattern of radially declining infiltration refers to the fact that the infiltration rates of the soil surface inside groves display a broad range of variation and are often identical to those of intergrove soils. To evaluate the field infiltration rate on sandy loam and different kinds of soils, researchers are evaluating the infiltration models. By comparing the soils' actual and expected infiltration rates, the Kostiakov, modified Kostiakov, and Horton infiltration models were determined [3, 4]. For Aba region soils, Philip's model was able to predict the depths of water infiltration [5]. Infiltration is frequently higher beneath plant canopies than beneath interspaces in both grassland and shrubland. Canopies are oases with increased soil moisture [5]. The volcanic soil with ponderosa pine vegetation had the biggest variation in IR with a ratio of steady-state IR in burnt locations to unburned soils [6]. A thorough understanding of the soil's spatial water infiltration characteristics, which vary from site to site and are more complicated due to non-uniformity, might improve agricultural water usage effectiveness and reduce water-related problems [7]. Further, Compacted soils due to the motion of agricultural technology have low IR which to runoff generation. Preparation and creation of water resource systems as well as for comprehending the rainfall-runoff process, and IR data for innumerable soil types are crucial. For the motive of calculating infiltration rate, a model primarily based totally on complementary error characteristic peak ERFC is used [8].

In order to compare the empirical equation depending on different models which are used for evaluating IR [9] and to find the best soil IR model based on specific physical soil features and to validate the model, multiple linear regression analysis (MLR) was used to compare the estimated rate with the field-measured rate of infiltration [10]. The impact of different soil conditions on infiltration rate helps developing a better knowledge of the variations and local soil infiltration rate [7, 11] Hence, present review paper focuses on reviewing different state-of-art approaches for soil infiltration in India and around the work. Thus, the primary objective of the review paper includes,

- To review different pattern used to estimate soil infiltration in India and world.
- To perform comparative analysis for identifying different infiltration patterns used across India
- To encounter challenges faced by the existing works and deliberate on future recommendation of the model.

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II. SURVEY METHODOLOGY

Different traits are explored for selecting relevant papers, which includes fetching content, scrutinizing the references, searching in different journals and many more. Numerous keywords such as “infiltration”, “infiltration methods”, “Soil types”, “infiltration pattern of soil in India”.

A. Inclusion Criteria

- Articles with relevant content for soil infiltration must be fetched.
- Articles with appropriate aim and methodology needs to be considered.

B. Exclusion Criteria

- Papers with irrelevant abstract, title should be omitted.
- Papers in Non - English must be omitted.

Articles with duplicated findings need to be eliminated.

III. INFILTRATION CHARACTERISTICS

Numerous elements, such as gravity, capillary forces, adsorption, and osmosis, contribute to infiltration. The formation of the soil, its colour, thickness, chemical, and other physical and chemical characteristics can all have a significant impact on how quickly infiltration takes place. Infiltration properties and runoff factors of land surface are transformed by cultivation, which has a significant impact on evapotranspiration, the stream of water and residue to surface-water bodies, and groundwater rejuvenation. Thus, these processes play a vital role in providing an impact on how surface rate and ground water act together, be it directly or indirectly. Thus, Figure.1 shows the characteristics of infiltration process.

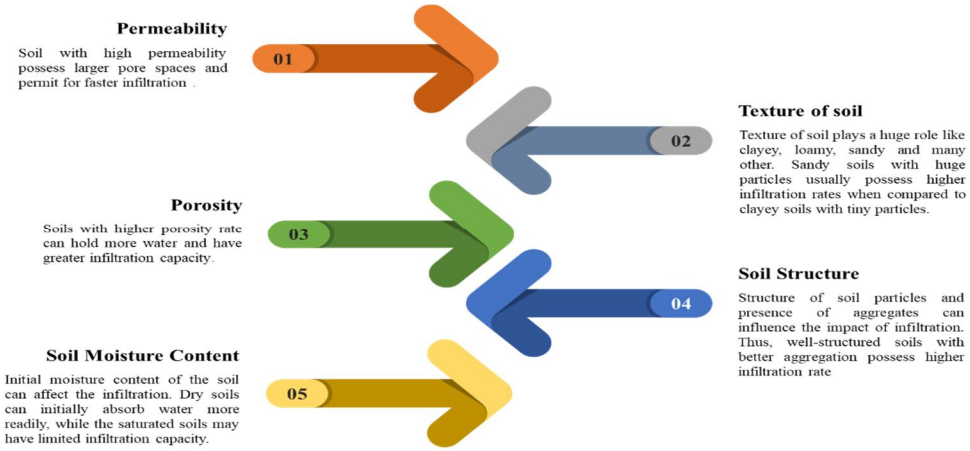


Figure.1. Infiltration characterises

Figure.1 deposits some of the characteristics of infiltration which includes permeability, porosity, texture of soil, soil structure and soil moisture content. The subsequent section deals methods and techniques used for estimating soil infiltration.

IV. METHODS AND TECHNIQUES

Different methods have been developed to estimate soil infiltration. In order to calculate the infiltration rate, different researchers has used different approaches which includes,

1) Double-Ring Infiltrometer Technique
2) Artificial Precipitation Simulator,
3) Run-Off-On Ponding Method
4) Straight Source Method
5) Adjusted Double Ring
6) Single Ring,
7) Altered Precipitation Simulator
8) TDR (Time Domain Reflectometry) method. Figure.2 and Figure.3 shows the techniques used for Estimating infiltration rate.

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Figure.2. Double Ring Infiltration [12]



Fgiure.3. TDR method [13]

From the studies, the world's researchers used infiltration models, and were measured for detecting the best fitting model to observed field infiltration rate data. The majority of researchers trusted on Double ring infiltrometer which has a wooden plank placed on top of the ring with a falling weight type hammer without disturbing the soil, two rings are driven into the ground at a depth of around 15 cm. To maintain a consistent depth of between 5 and 12 cm, water is introduced into both rings. Water occupying the inner ring is given a water jacket by the outer ring. During the monitoring period, the water depth in the inner and outer rings is kept constant. Only the inner ring is used for the water volume measurement. Up until a steady penetration rate is attained, the experiment is conducted.

V. SCENARIO OF STUDY INFILTRATION RATE OF SOIL IN THE WORLD

IR technique has been evaluated in central North Carolina, USA [14] in which, information has been gathered based on properties of soil like texture of the soil, bulk density of the soil and context (time, usage of land) at 89 points throughout the 102 ha Walnut Creek watershed in Raleigh, USA. However, all observations show that metropolitan soils present in Walnut Creek watershed possess the ability to captivate most precipitation events and are probably proficient of entering extra urban stormwater and eventually examined that, leaf litter and Forest land covers have the uppermost infiltration capabilities. The Walnut Creek watershed's urban soils, on the other hand, appear to be able to infiltrate extra urban stormwater runoff and can absorb the majority of precipitation events, according to all of the data. Estimates from the rainfall-runoff model and measurements are in agreement, indicating that rates of urban soil infiltration were both overestimated. Study has recommended that regardless of whether the model have undeviating connections to pipe or stream networks, studies of stormwater management should broaden definitions of impervious connectedness for including surface flow pathways that are completely impermeable and frequently cause floods.

To examine the connection between soil moisture and IR in the process of rainfall infiltration, a research study [15] has determined a mathematical equation based on the Horton equation. The study conducted 42 tests that involved various rainfall intensities and initial soil moisture contents. To obtain highly accurate data on IR and changes in soil moisture at different depths, an artificial rainfall infiltration research was devised. Study has conducted 3 different experiments. The first section involved a test chamber constructed with loam soil, where a sustained and uniformly distributed rainfall event occurred at intensities ranging from 0.5 to 3.5 mm/min. Simulating the infiltration process accurately proved challenging when considering various initial soil moisture content scenarios using traditional empirical infiltration equations. This difficulty arose from the substantial impact of initial moisture content of soil disparities on the infiltration process. To address this issue, the study presented a more refined version of the equation through the Horton equation, along with physical infiltration equations like the Philip equation. These equations established the connection between moisture content of soil and IR, as demonstrated in the study.

Study [16] has emphasized on measuring the infiltration rate using double infiltration method. Different infiltration models such as Green-Ampt, kostiakovs, Philips and Horton's were conducted and the performance of the models were assessed using R^2 value. However, from the experimental outcome, it was identified that Horton's model outclassed other prevailing methods for predicting IR. Moreover, it was detected that, green ampt model was identified to be worse than all the existing works under different soil for prediction of IR.

Research on the validity of infiltration models in a sandy loam soil was conducted by the existing work [17]. By contrasting the measured and anticipated IR of the soils, the Kostiakov, modified Kostiakov, and Horton infiltration models were tested in this study.

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Ponding water into the double-ring infiltrometer that was used to conduct the tests resulted in fifteen infiltration runs. From obtained infiltration data and laboratory examinations of soil samples, parameters were created. With the strong overall agreement and RMSE values of 0.0372 and 0.0365 and R^2 values of 0.999 and 0.998, respectively, the Horton and Kostiakov models accurately predicted the measured infiltration rate.

VI. TYPES OF SOILS IN INDIA

Soils of India are considered to be assorted and have resulted rich mosaic of agricultural practices, with various cropping systems and different types of crops which are appropriate to particular soil and climatic conditions. Thus, soil management and maintenance practices are important for food security and sustaining agricultural productivity in the country. India has a diverse range of soils due to its vast climatic variations and geographical disparities. Hence, Table-1 shows different types of soil in India.

Table-1. Soil types and description

Soil Types	Description
Black Cotton Soil	Approximately 30,000 square kilometers of central India and a portion of southern India, including South Gujarat, Maharashtra, Karnataka, Tamil Nadu, and Uttar Pradesh, are covered. It is the term used by the Indians to describe the vast dirt deposits.
Laterite soil	Contains silica and oxides of iron and aluminum that are created by the disintegration of rock, covering an area of around 100,000 square kilometers included West Bengal, Orissa, Kerala, Karnataka, and Maharashtra.
Alluvial soil	Found in extensive portions of north India and extends from Assam in the east to Punjab in the west. It has alternating layers of sand, silt, and clay.
Coastal soil	Marine clay is soft and flexible. It has been found all along India's southwest coast in deep deposits of soft marine clays that are covered in thick layers of sand.
Desert soil	Usually in a loose form, it has to be consolidated to increase its strength, and it covers a significant amount of Rajasthan (approximately 5,000 square kilometers). includes dry soils

Table-1 depicts different types of soil in India along with its description and function. In the subsequent section, different infiltration patterns used in India are depicted.

VII. DIFFERENT INFILTRATION PATTERN OF SOIL IN INDIA

Various techniques are used for soil infiltration in India. The existing works of these infiltration technique's are discussed as follow. Field tests at three separate locations in the Haknakawadi, Latur area has conducted in the research [1]. These include the lakeshore, a forest area, and Mundewasti's agricultural land. The constant IR of various soil types under various soil conditions have been searched after. The examination is performed using double ring infiltrometer. The infiltration rate at Lake Side was 10.73 cm per hour, whereas in Mundewasti it was 1.73 cm per hour. The type of infiltration for sandy loam soil is determined to be moderate; for sandy soil, the IR is moderately quick; for loamy soil, the IR is moderately slow. Study has discovered that the soil research region is often covered by badly graded soil from the sieve size analysis test. The plastic and liquid limits showed that the sediments often had a low medium plasticity index. Similarly,various infiltration models were evaluated in the current study [11] under a variety of land uses, including forest land , grassland , and paddy field. The double-ring infiltrometer was utilized in the testing, which were carried out at several locations. The basis for the applicability of the chosen infiltration models used in the study is their empirical to physical underpinnings. Study has estimated the infiltration capability or total infiltration of the experimental field. The field's characteristics influence the parameters of the models. Using nonlinear regression fitting, the infiltration model's parameters are generated. Models of infiltration were evaluated using RMSE and coefficient of determination R^2. Study has used minimum RMSE and maximum R^2 values to select the most suitable model,from result it showed that Modified Kostiakov's model is suggested for forest land use, Re-Modified Kostikov's model works best in grassland, and Modified Kostiakov's model performs better in paddy fields.

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Characteristics of field infiltration using a minidisc infiltrometer made in the United States in all 24 blocks of the Gaya district in Bihar was conducted in the paper [7], which includes a variety of soil types. All 24 blocks, measurements of soil infiltration were made in the months of Dec 2019 and Jan-Feb 2020 (3 months). The cumulative infiltration (in cm) must be plotted against the square root of time and by using the equations proposed by Zhang and Philip models, curve must be fitted. For each value of the Gaya infiltration rate measured, a box and whisker graphic has been created. For all of the values of the Gaya district's measured infiltration rate, a box, and whisker diagram has been created. According to study, the average penetration rate for forest land is up to 1.32 cm/min, whereas it is up to 0.8 cm/min for mixed-use, semi-urban, and agricultural land. From high to low, the infiltration rate is influenced by forest land use, semi-urban areas, grasslands, and finally urban settlement. The average constant infiltration rate, according to the study's results based on data gathered in the field, is 1.16 cm/min minus 0.485 cm/min. In order to clarify hydrological issues, additional research is needed to assess the effects of rainfall infiltration in the study area.

Empirical equation-based models was conducted on study [18] which predicted the IR of different places in Kurukshetra, India. Using a small disc infiltrometer, infiltration tests were carried out at 20 distinct sites. The equation parameters and IR of 3 independent experimental techniques—the Kostiakov, modified Kostiakov, and models—were estimated for each location separately using the least square fitting approach. These pragmatic performance of infiltration techniques was also contrasted with that of the RF (Random Forest Regression) and ANFIS (Adaptive Neuro-Fuzzy Inference System) based on machine learning. Figure.4 depicts the small disc infiltrometer.

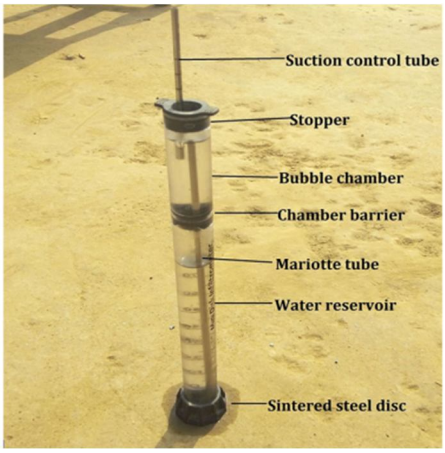


Figure.4. Small Disc Infiltrometer [18]

The performance of RF is clearly within 15% of error range and the performance of the model resulted to be worst when compared with all the models because its scattering of predicted data is moderately superior and many of the data points are outside of the 15% error line due to its high MAE rate of 7.34 and RMSE value of 11.8 and values in comparison to other infiltration models. As a consequence, it was discovered that ANFIS suggests that triangular-shaped membership functions are better to other types of membership functions with respect to providing good outcomes. The ANFIS and RF methods' performance comparisons indicate that RF is a powerful tool for estimating IR of soil.

Double ring infiltrometer field measurements were carried out [10] in Gangtok, Sikkim, India utilizing 25 locations that were located at 10m grid intervals. The study area's soil textural classes include loamy sand at 6 locations and sandy loam at 19 stations. Sandy loam soil was found to have higher IR in the research area than loamy sand, which possess slightest and concentrated value of 13.80 cm/h and 0.30. Likewise [19] examined the rates of soil infiltration in the Andhra Pradesh state's Karishma district. Grey soil and red soil, two distinct soil types with compact soil, ploughed soil, and unploughed soil conditions, respectively, were chosen. By using a double-ring infiltrometer to assess the infiltration test, it was found that the infiltration rates for Red and Grey ploughed soils were low and the infiltration rates for Grey and Red compacted soils were high. As opposed to ploughed and unploughed soil, compacted soil will have a lower rate of infiltration.

An effort is made to use field data from an agricultural area, Chengannur, for validating the Horton's model, Green ampt model, and Kostiakov's infiltration model [20]. By applying decision factor analysis, model has the ability to select the significant model from their study for the specific site. Infiltration of water into the soil is assessed using Double ring infiltrometer. Infiltration models are the empirical equations built utilizing infiltration principles which are utilized for calculating the IR of the soil. By using the oven-dry technique, the original moisture content of the chosen region was ascertained to be 10.71%.

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Further, classification of soil was based on USDA categorization. To determine the significance of the infiltration models, a one-way ANOVA test was used. The allowable limit of consequence was 0.05 and the data which was collected were surrounded by the tolerable sorts. Persistent infiltration rate for Agricultural space was attained as 20.45 cm/hr and eventually, experimental outcome has shown that Kostiakov's model was identified to be the suitable model with better infiltration rate for agriculture.

Constant infiltration rates from a paddy-growing region of a micro watershed in India's mountainous Sikkim state were estimated in the study [3]. The infiltration rates were measured in the field using the double ring infiltometer test. The projected values from the Horton, Philip model, Green-Ampt and Kostiakov infiltration models were contrasted with the actual infiltration rates. For the assessment of soil moisture content, bulk density, and soil texture analysis, soil samples were gathered. Within the micro watershed, the soil's texture ranged from sandy loam to loamy sand. The models' suitability was assessed using the coefficient of determination, a statistical approach, and the best model for the paddy fields of the hill topography was discovered. The analysis's findings showed that the Kostiakov model provided the greatest fit and the highest coefficient of determination for the micro watershed's paddy field area. Correspondingly, determination of constant infiltration rates, with double ring infiltrometer [21] was explored in the existing work, under different soil conditions like black cotton, clay, and sandy soil and compared it with the IR obtained by 4 different models at four locations near Junagadh, from the experiment, it was analyzed that Horton's model is better suitable for Soil IR.

Like double infiltration rate [4], both single and double ring infiltrometer has used for evaluating the infiltration characteristics of soils on the Andhra University campus. On the campus, experimentation work is carried out at five distinct locations. Using both infiltrometers and the infiltration models developed by Kostiakov, Philip, and Horton as well as Green-Ampt, the purpose of the study is to compare the constant infiltration rates of these soils to one another. Using a graphical method, the models' various constant values are calculated. Using correlation coefficient and customary error as tools, the results of various infiltration models are compared to observed field data to determine the best model for a given soil condition. Their research revealed that the state of the soil has an effect on the IR, with rates as high as 17.43 cm/h observed close to Samatha Hostel and as low as 1.46 cm/h observed in the Assembly Hall area. Study has concluded that, vegetal cover, kind of soil medium, Soil moisture, permeability, surface fines, compaction of soil, water holding capacity, temperature of water, and other factors affect infiltration rates.

VIII. COMPARATIVE ANALYSIS

Different studies have been compared with different aspects like location, type of infiltration method and outcome and tabulated in table.

Table-2. Comparative Analysis

Sl.No	Location	Type of infiltration method	Outcome	References
1	Haknakawadi, Latur	Double Ring Infiltrometer	➢ Discovered that the soil research region is often covered by badly graded soil from the sieve size analysis test. The plastic and liquid limits showed that the sediments often had a low medium plasticity index.	[1]
2	Kurukshetra, India	Small disc infiltrometer	➢ RF and ANFIS based on machine learning. ➢ It was discovered that ANFIS suggests that triangular-shaped membership functions are better to other types of membership functions with respect to providing good outcomes. The ANFIS and RF methods' performance comparisons indicate that RF is a powerful tool for estimating soil IR.	[18]

3	Sikkim state	Double ring infiltometer test	➢ The models' suitability was assessed using the coefficient of determination, a statistical approach, and the best model for the paddy fields of the hill topography was discovered. The analysis's findings showed that the Kostiakov model provided the greatest fit and the highest coefficient of determination for the micro watershed's paddy field area	[3]
4	Papumpare district of Arunachal Pradesh	double-ring infiltrometer	➢ Calculating the infiltration capability or total infiltration of the experimental field. The field's characteristics influence the parameters of the models. Using nonlinear regression fitting, the infiltration model's parameters are generated. ➢ Result showed that Modified Kostiakov's model is suggested for forest land use, Re-Modified Kostikov's model works best in grassland, and Modified Kostiakov's model performs better in paddy fields.	[11]

From the table-2, it can be identified that, double-ring infiltrometer method have been used in most existing works due to its ability to control over boundary effects, further, double infiltrometer offers precise outcome when compared to other methods. Thus, double-ring infiltrometer is used over methods in state-of-art approaches.

IX. CHALLENGES AND FUTURE RECOMMENDATION

1) Soil compaction is considered as one of the common problems due to different agricultural practices, human activities and urbanization. Impacted soil can reduce the infiltration rates and lead to poor water absorption and increase the surface runoff.
2) Degraded soils often have abridged water-holding capacity and augmented surface sealing, deterring infiltration, thus soil degradation can substantially influence the patterns of infiltration.
3) Diverse soil types is one of the challenges as each soil type possess different infiltration aspects in terms of water absorption and drainage.

Despite the ability of the state-of-art approaches, performance of the models still lacked in delivering better accuracy, which is considered as one of the drawbacks, that can be overcome by employing different IR methods with AI approaches for better prediction performance of soil infiltration in future.

X. CONCLUSION

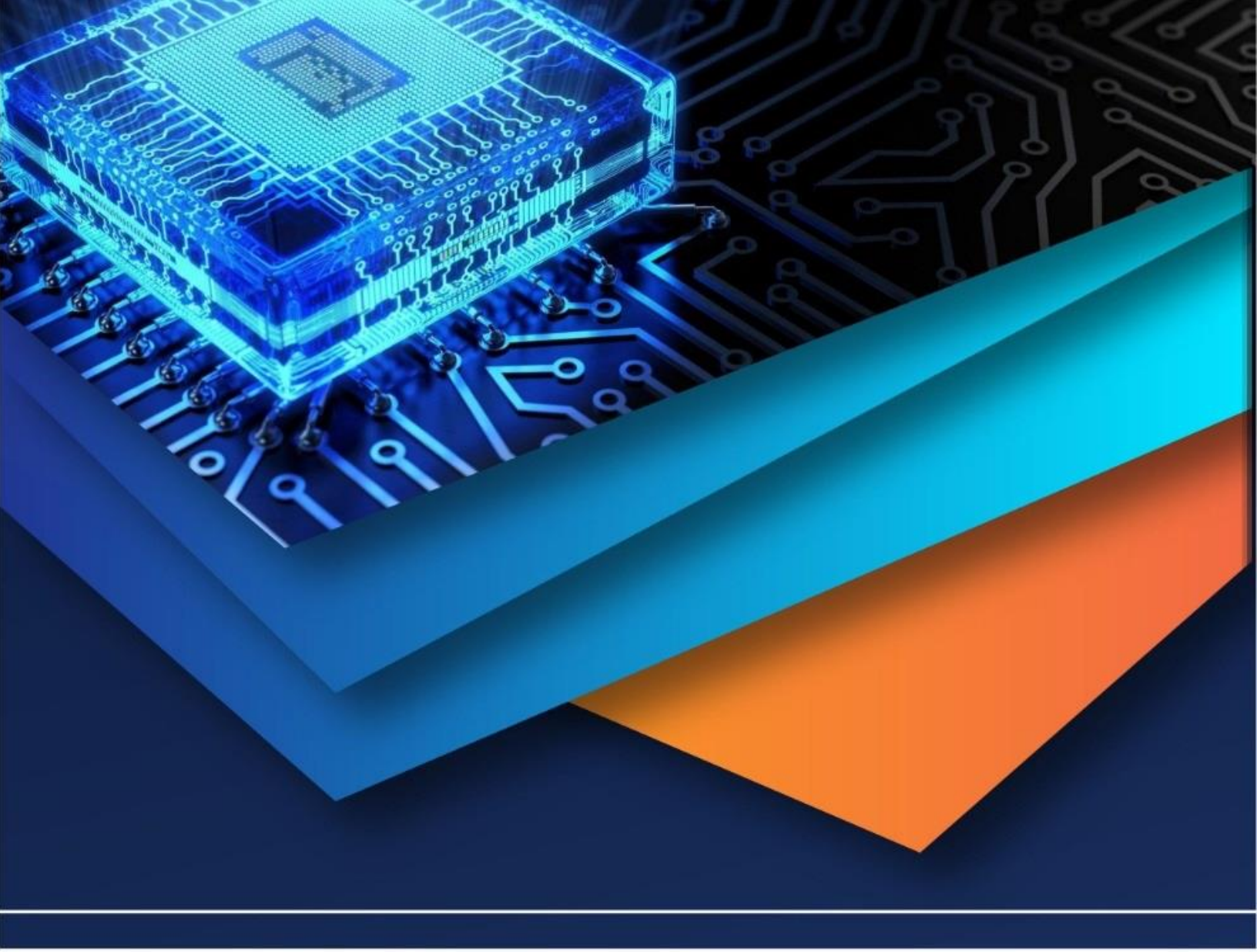
From countless research articles, it is found that soil infiltration is a very interesting topic in all around the world and Researcher gives valuable information about their research work. Infiltration rate is varied from soil to soil and depend upon soil characteristics and land condition. Initially, it was high and decreased with time up to a constant infiltration IR and the rate is high for ploughed soil when compared to the compacted soil and unploughed soil. Some Researcher also compared their IR data with different models but which model is fitted and gives accuracy depends upon soil profile, and movement of water through the soil and double ring method is better than other to determine IR due to minimum error arising from the lateral flow of water when distinguished with single ring method. Despite the superior performance of the model, there are few challenges which needs to be overcome in future by employing better approaches, which improves the soil infiltration process.

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