Chapter

A Revisit of Rainfall Simulator as a Potential Tool for Hydrological Research

Felix Gemlack Ngasoh, Constantine Crown Mbajiorgu, Matthew Boniface Kamai and Gideon Onyekachi Okoro

Abstract

Different means of hydrological data collection have developed and used. However, they are constraint in one way or other. This paper therefore revisited the rainfall simulator as potential tool for hydrological research. The research disclosed that there are three different types of rainfall simulators; drop former simulator, pressure nozzle simulator and hybrid simulator. It can further be classified as indoor model and outdoor. The research also showed that precipitation is the driving force in hydrological studies. Consequently, in the design of rainfall simulator, the following should be taken into consideration: nozzle spacing, pump size, nozzle size, nozzle type, nozzle spacing, plot size and pressure. Meanwhile, intensity, distribution uniformity, kinetic energy, rainfall drop size and rainfall terminal velocity should be noted in its evaluation. Factoring-in the aforementioned design considerations, data collection is made easy without necessarily waiting for the natural rainfall. Since the rainfall can be controlled, the erratic and unpredictable changeability of natural rainfall is eliminated. Emanating from the findings, pressurized rainfall simulator produces rainfall characteristics similar to natural rainfall, which is therefore recommended for laboratory use if natural rainfall-like characteristics is the main target.

Keywords: rainfall-simulator, intensity, uniformity, kinetic-energy, drop-size, runoff, hydrology, research-tool

1. Introduction

Disintegration of the soil are impelled by the effect of rain drops on plain or almost plain soils, which detaches and splash soil particles and transports them downslope as a feature of surface flow. The net disintegration rate (sediments mass/unit zone) is an element of both rain sprinkle and surface flow. Runoff from earth surface conveys with it the most erodible sediment and fine sand particles from the dirt surface as the water streams downhill. At that point, rills are shaped; they start little channels, inevitably framing gaps, which can bring about enormous soil losses [1]. These processes are regularly studied in the field with normal precipitation which may be moderated by uncontrolled factors such as irregularity of the precipitation events. This paper therefore reviewed rainfall simulator as a potential tool for hydrological research.

2. Rainfall simulator

Rainfall simulators (RS) are device designed to model the characteristics of natural rainfall to the nearest possible. It can be used to determine inter-rill erosion rates and their dependent rainfall and soil parameters [1]. It has been a tool for agricultural research and has been used for different studies ranging from determination of soil characteristic, such as infiltration rate, surface runoff, storage or erosion process studies [2]. Yakubu and Yusop [3] pointed out two most important aspects to note while using rainfall simulator; the method used to simulating rainfall and runoff from plot. Consideration was not given to infiltration.

3. Rainfall simulator classifications

There are three classification of rainfall simulator: drip, pressurised nozzle (PN) [3–5] and hybrid [6] rainfall simulator.

Drip simulator: also known as drop former (DF) [4] uses hanging yarn or hypodermic needles to produce drops of necessary size at zero velocity. Its impact velocity is attained by free fall which made others defined it as non-pressurised simulator [7]. The drilled holes and drop height determines the diameter of the raindrop and kinetic energy respectively [3] (see **Figure 1**).

It is capable of producing drops which ranges from 3 to 6 mm depending on the diameter holes [8]. Main advantage of the drip simulator is that it has the ability to produce relatively large drops at low application rate [5, 9]. It has the following disadvantages [10]:

i. It is impractical for field since it requires huge distance of at least 10 m height to attain terminal velocity.

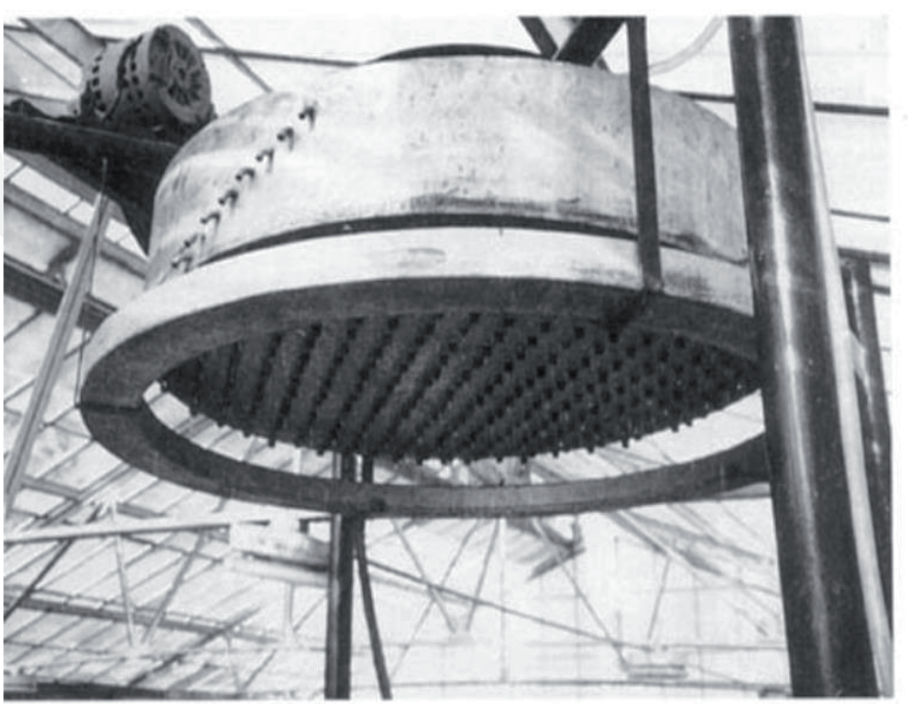

Figure 1.
Drop formers simulator [11].

ii. Another constraint of this simulator is that simulation is only carried out on a limited plot depending on the size of the hanging yarn.

iii. It does not produce distribution drops unless a variety of drop forming sized tubes are used.

Pressurised Simulator (PN): produces drop distribution that includes both small and large range of drop sizes with nonzero initial velocity and an impact velocity similar to terminal velocity of raindrops. In order to obtain drops of suitable sizes while upholding high velocity, high discharge nozzles are required [7]. The application rates are reduced by means of an intermittent moving object which intercepts the rainfall. An example of this type of simulator was developed by [12]. The authors found out that it utilises the best nozzle known as "yet-for-rain simulation" (spraying system 80,100-veejet nozzle). But problem with the 80,100-veejet nozzles was that it did not simulate rainfall energy characteristic and is still better than other nozzles. This type of rainfall simulator provides about 80% of the required kinetic energy per volume of natural rain [5, 12, 13]. This nonzero pressurised nozzle has the following advantages over the hanging yarn simulator [10] as presented by **Figure 2**:

i. They can be used in the field and their intensities can be varied more than the drop forming type of simulator.

ii. Since the nozzle simulator has an initial velocity greater zero, it requires shorter height to reproduce the terminal velocity obtained from natural rain.

iii. According to Home, (2017), this simulator is often portable compared to drop former.

Hybrid type simulator: uses the principles of pressurised and drip former techniques of simulation incorporated together. It was first developed by [15] to reduce the kinetic energy impact of the rainfall, but the research indicated that the technique reduced the kinetic energy at the detriment of the rain uniformity [3]. Wildhaber et al. used a similar method by placing mesh 0.5 m of aperture 2 mm × 1.7 mm under a spraying nozzle. The obtained result was not far from the non-pressurised simulator type. Carvalho et al. also designed a pressurised nozzle simulator with mesh placed 2.35 m below the nozzle to change rainfall characteristics (see **Figure 3**), and varying the nozzles and mesh types. The results varied based on the aperture of the meshes employed. Conclusively, the hybrid simulator was noted as suitable tool to assessing erodibility of different types of soil.

According to its transportability, rainfall simulators are classified as indoor and outdoor [7].

Indoor rainfall simulator: this rainfall simulator is used for modelling precipitation in a controlled environment. It is also known as Laboratory scale model. This simulator reduces lot of disadvantages incurred by the transportable type of rainfall simulator [7]. For example, Darboux et al. designed an indoor rainfall simulator system that simulated infiltration, run-off and erosion (see **Figure 4**), and the output was effective but the system was constrained with lack of non-recycle of the water system as well as not portable.

Outdoor rainfall simulator: could be portable or large depending on the projected purpose. Many of these types of simulator have been used to relate soil surface characteristics and controlling to runoff, infiltration and erosion as influenced by different parameters [18–22].

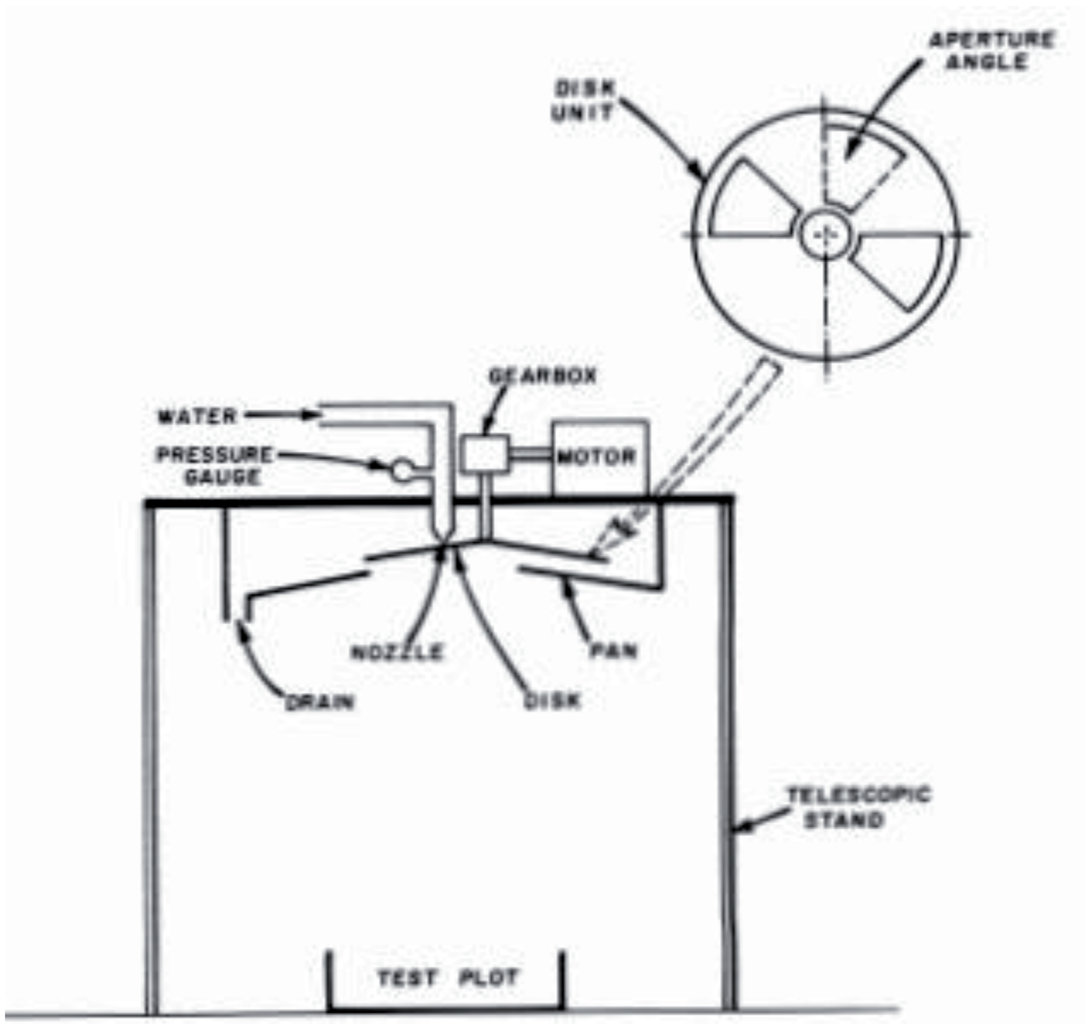

Figure 2.
Pressurised nozzle simulator [14].

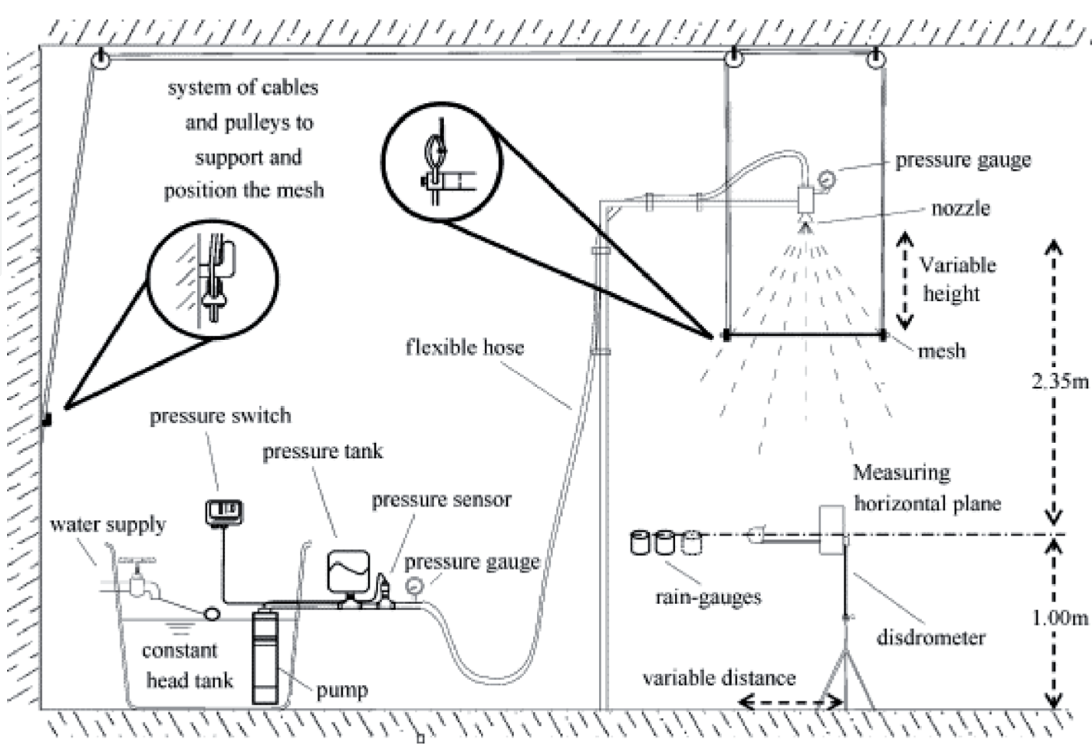

Figure 3.
Hybrid simulator [16].

A research carried out at Duke University Durham, using large transportable rainfall simulator of area 15.12 m^2 (**Figure 5**). The system was tested with common pressure washing nozzles which produced rainfall intensity of 62.43 mm/h and 32 mm h^{-1} with a corresponding uniformity coefficient (C.U) of 76.65 and 62% [13]. [23] developed a portable field simulator for use in hillside and obtained a consistent raindrop size of 2.58 mm with an intensities of 20 to 90 mm h^{-1} and C.U of 91.7% at an intensity of 60 mmh^{-1}. In a similar event Abudi et al. [24] also designed and constructed a portable rainfall simulator for field investigation of runoff, the drop size obtained was 1.5 mm with a ground hitting velocity near that of natural rainfall and energy flux 76% of the natural rainfall. All the simulators offered good

Figure 4.
Rainfall simulation building [17].

Figure 5.
Outdoor rainfall simulator [13].

performance. The merit of these simulators is that it can be used to study field parameters required for hydrologic modelling on any surface including the ones covered with vegetation. But they were limited by problem of natural rainfall which resulted to dismantling the setup when experiment schedule was not over and water was not recycled.

From the numerous studies carried out on the simulation of rainfall both in field and laboratory experiment, two merits of rainfall simulator in a research carried out in 2010 using laboratory simulator [25] were pointed out as:

i. It is faster in data collection without waiting for the natural rain.

ii. With rainfall simulator, you can work with controlled rain, thereby, eliminating the erratic and unpredictable changeability of natural rainfall.

4. Requirements and considerations for rainfall simulator

The characteristics of raindrop is also important for storm-water management purpose particularly in relation to understanding runoff process [26, 27]. Rainfall simulation should exemplify the following fundamental characteristic of the natural rain [7, 28].

i. Drop size distribution

ii. Terminal velocity

iii. Distribution uniformity

iv. The rainfall intensity and

v. Kinetic energy

4.1 Drop size distribution

One of the basic natural rainfall characteristics that are considered is it drop size which ranges between 0.5 and 5 mm [3]. The measurement of rain droplets sizes has been studied using various approaches [28], but there is no established standard for obtaining raindrop diameter size [3]. Basically, there are two methods used for determining drop size; manual and automatic raindrop measurement [26].

The manual measurement techniques of drop size distribution includes; stain, flour pellet, oil immersion and photographic methods while automated raindrop measurement techniques include; impact disdrometers (acoustic and displacement); optical disdrometer (optical image and optical scattering). **Figure 6** presents a tree of the drop size distribution classification. Drop size can be determined using Eq. (1):

$$D_r = \sqrt[3]{\frac{6}{\pi}W} \quad (1)$$

where *W* is the weight of the formed.

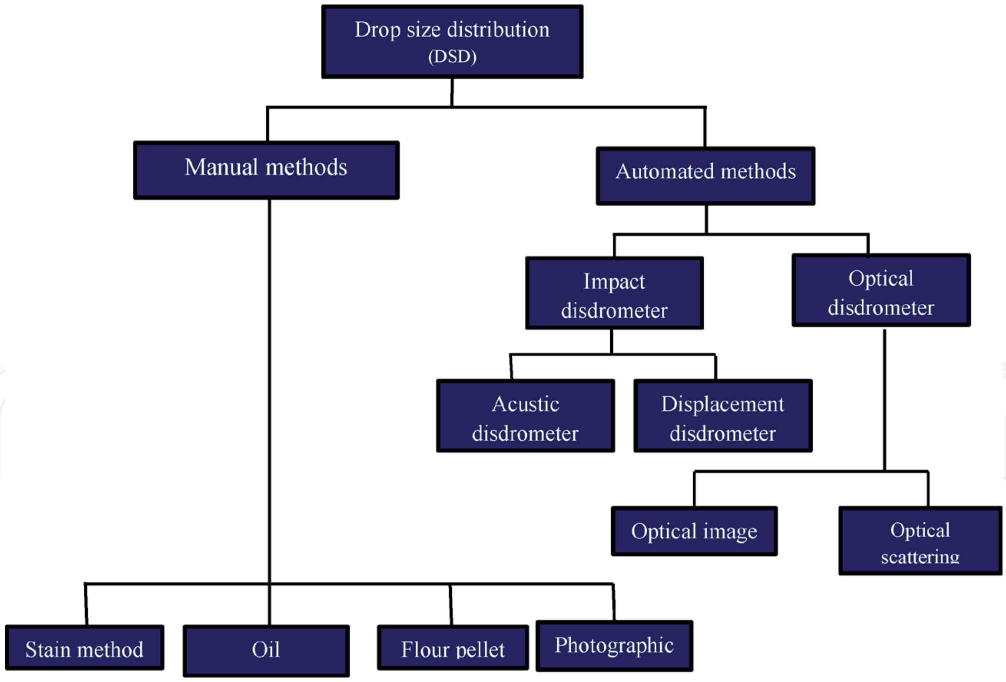

Figure 6.
Classification of drop size distribution methods.

4.2 Terminal velocity

A natural raindrop from greater height tends to reach terminal velocity before impact. This impact produces several effects on soil disintegration and infiltration. This is important particularly for studying soil erosion challenges where drops should reach their terminal velocity before impact [28]. This rainfall characteristic highly depends on the height of the simulator [3]. When the downward gravitational forces acting on the rainfall are cancelled out by the drag acting on the drop, the terminal velocity is achieved. Terminal velocity have been measured by many researchers using electronic devices to estimate the time for drops to pass consecutive point via photograph during fall [1, 7, 22, 28, 29] by stopwatch, timing the individual fall from a known height or simple computation [28, 30]. Computation of velocity of drop reaching the ground at an angle in natural precipitation (storm) with wind conditions 3. Simulated rainfall if well done can attain up to 94% of the terminal velocity of the natural rainfall [3, 31].

4.3 Rain intensity

One of the major ways to assess rainfall simulators is by the simulated rain intensity which the means by which other rainfall characteristics are defined, especially the rain impact kinetic energy [3]. Another characteristic that correlated with intensity is the drop size distribution [11]. The method to control rain intensity varies in rainfall simulator. But it is quite a difficult task most especially using drop forming simulator because it involved the manual movement of the frame [3, 11, 32]. In the case of pressurised nozzle simulators, intensity and drop diameter are control the varying the pressure [3] or by introducing a body in a swinging or rotating motion under the nozzle [6, 14].

4.4 Kinetic energy

Kinetic energy of rainfall is the degree by which the energy of the rain is measured. It is the major factor in soil detachment process. The energy of the rain is relational to its "erosivity" [1], and it is expressed in $Jm^{-2}\ mm^{-1}$. The technique of varying kinetic energy differs among rainfall simulators and the purpose for which a research is carried out [3]. Obtaining higher kinetic energy with drop forming simulator is an indication of the non-portability of the simulator because it requires higher height get such KE value. Aksoy et al. [33] in an investigation obtained kinetic energy of 21 $Jm^{-2}\ mm^{-1}$, using pressurised nozzle simulator at lower rainfall intensity of 45 mm/h and a height of 2.4 m. By varying the drop diameter from 2.7 to 5.1 mm and height of fall from 0.17 to 2.5 m, similar result was obtained [34].

The kinetic energy of rainfall is depending on two factors; terminal velocity at impact and the spraying nozzle which give intensity. Therefore when a simulator is designed for investigation of potential erosion by simulated rainfall, these aforementioned two factors should be taken note of [29]. This can however, be determined by using Eq. (2) [35].

$$KE = 0.119 + 0.0873 \log I \tag{2}$$

where KE is the kinetic energy of the rainfall in ($MJha^{-1}\ mm^{-1}$) and I is the rainfall intensity in (mm/h).

4.5 Rainfall distribution uniformity

In simulated rainfall on a plot, uniformity is one the most important measure of determining how spatially distributed the rainfall is on a plot to avoid ponding and over saturation on one side [3]. It therefore measures the equal catches of simulation of rainfall [28]. There are factors that sometimes affect uniformity: this includes; wind, slope and altitude [1]. The degree of uniformity is dependent of the rainfall type. It is estimated using the Christiansen uniformity coefficient (C_u) equation as presented in Eq. (3) [3]

$$C_u = 1 - \frac{SD}{I_m} \tag{3}$$

where C_u is the Christiansen uniformity coefficient; SD is the standard deviation of simulated rain over the plot; I_m is the mean simulated rain intensity.

Eq. (2) can further be expressed as in Eq. (4)

$$CU = 1 - \left[\frac{\sum / X_i - X_{m/}}{nX_m}\right] x100 \tag{4}$$

where X_i is the individual rain gauge, X_m is the mean gauge of the rainfall and n is total number of rain gauges.

Spray patterns of different types are obtained from different nozzles. In rainfall simulators, there are two different types of nozzles that are often used based on their mould. Namely; flat and cone spray nozzles. From each of these nozzles there tends to be decrease in uniformity from centre to outward of the sprayed plot [3, 24]. The challenge of rainfall uniformity reducing from centre to outward of the plot can be mitigated by using network of nozzles, taking into consideration the wetted perimeter of individual nozzles. The wetted perimeter depends on the distance of the simulator from the plot for nozzle that produces cone spray, operating pressure [36] in drop forming simulators (DFs) whereas in pressurised simulator (PN) C_u is increased based on increase in pressure and intensity [3]. Many researches have been carried out to estimate uniform application of depths as was used by Christensen to investigate the factors affecting water distribution from group of sprinklers [28, 29, 37–39], but this has been recently criticised based on the fact that is less significant and that size of rain gauge for uniformity and intensity affects the results [14], yet it often used as guide in rainfall simulation. Uniformity of can be more than 90% [31] contrary to sprinkler uniformity standard bench mark of 85% [10].

The methods employed to measure coefficient of uniformity plays a significant role in achieving correct simulated rainfall data [3]. It is therefore difficult to compare the uniformity results of simulated rainfall from different report [31]. In a review, [5] pointed out that drop forming simulators produces higher rainfall uniformity than pressurised nozzle simulator at lower rain intensity. Generally speaking without considering rainfall simulator type, investigator achieved average rain uniformity of 83% within the intensity range of 10 mm/h and 182 mm/h [1, 3, 31].

5. Design requirements of rainfall simulator

To successfully achieve afore listed natural rainfall characteristics, a designer of a rainfall simulator should take into considerations the following phonotypical features; pump pressure, simulators height, plot size and nozzle spacing. Each these physical features have impact on the purpose for which the rainfall simulator is designed.

5.1 Pressure

In pressurised nozzle simulator the choice of pressure is a determining factor to mimic the natural rainfall to the nearest possible outcome [40]. The basis for selecting pressure should be such that balance is stroked among rain intensity, uniformity, rain drop size and kinetic energy, but different researchers are embedded with different approach toward pressure [3]. For example, in an investigation carried out by Cerda et al. indicated that uniformity was obtained at pressure 152 kPa using HARDI-1553-10 single nozzle and anything above this settings resulted to higher rain concentration at the plot boarder and below resulted to concentration of rain at the centre of the plot. The researcher therefore noted that increase in pressure has a maximum limit when targeting at rain uniformity above which decreases the uniformity [3]. In similar research by Sousa-Junior & Siqueira [31], similar trend of results were observed. Simulator under rainfall intensity of 3.1 mm/min, produced uniformity coefficient of 85% at 40 kPa [36]. Comparing the result of [35] with [41] investigation of rainfall intensity at 20 kPa and achieving 1.42–1.58 mm/min with an average rain uniformity of 60%, therefore, the effect of pressure cannot be over emphasised.

In Aksoy et al. [33] investigation, the orifice size was appreciated on examining the effects of pressure on 4-Veejet 8030, 4-Veejet 8050, 5-Veejet 8060 and 5-Veejet 8070 nozzles of different orifices, except for 5-Veejet 8060 nozzle which gave rain uniformity of 83.6% at 33 kPa pressure otherwise the others mimicked uniformity of 82.1, 86, and 88.8% at 40, 42 and 48 kPa respectively. Larger orifice resulted to increase in uniformity though with increase in pressure. According to [14], study on development and calibration of pressurised nozzle simulator observed that uniformity and intensity of modelled rainfall are affected by nozzle pressure disc angular velocity and angle of aperture.

5.2 Nozzle spacing

Nozzle spacing in rainfall simulation is a very vital parameter to be considered in the study of the rain uniformity. Where there is overlapping during spray from two or more nozzles results to higher intensity and uniformity. But report discussion on this has always been mute in literatures [3]. An average CU of 80% was obtained with the use of 4 fixed Veejet nozzles spaced between 2 and 4 m, but when the spacing was reduced to 1, 2 m greater uniformity >86% was achieved [42]. Gabric et al. [34] design Veejet 80,100 nozzle and spaced 100 cm apart to assess intensity and uniformity of simulated rainfall, he achieved a uniformity of 86% at pressures of 40 kPa. Aksoy et al. [32] also studied rain uniformity using a similar nozzle Veejet 8030 and varied nozzle space between 1.45 and 1.25 m at 40 kPa and they achieved CU of 82.1%. A similar trend of results was obtained by [31] using 2-FullJet1/2 SSHH40 nozzle with 1.06 m spacing and varied pressure between 50 and 170 kPa. This shows that the smaller the nozzle spacing, the less pressure required and the larger the spacing the more will be required to mimic good rain uniformity.

5.3 Plot size

The size of a plot is very crucial in the simulation of rainfall most especially in the determination of uniformity. The plot is therefore the predefined seclusion upon which parameter are examined for the purpose of research using simulated rain. It determines the size of the rainfall simulator [3]. Previous research showed that plot area varied from 0.24 [38] to 99 m^2 [43]. Many investigators' results showed that the smaller the plot size for rainfall simulation the higher the uniformity [3]. An example is the result obtained by Sanguesa et al. as cited by [3] with one nozzle used on 1 m × 1 m and 2 m × 2 m plot size they achieved a CU of 91 and 86% respectively. The results gotten when four nozzles arranged in strength line on a plot size of approximately 4.0625 m^2 was 90% [3]. To explicate more on the effect of plot size on uniformity, 4flood jet nozzle was used on two different plot sizes of 3.56 m^2 [10] and 8.84 m^2 [33] and they obtained a corresponding uniformity coefficient of >90% and an average of 85.1%. The aforementioned result confirms that the plot size of a rainfall simulator affects the rain uniformity thus; increase in rainfall simulator plot size will decrease the uniformity. Sometimes the size of plot for rainfall simulation depends on the purpose for which the simulator is designed for. For example [38] selected plot size larger than the simulator top while [5] in a review pointed out some researchers makes use of smaller to obtain good uniformity. In nutshell, the factor determines selection of plot size in rainfall simulator is size of the simulator and the parameter under investigation [23].

Based on the simulator type, drop forming simulators are generally small in area (0.98 ± 68 m^2) which can cover plot size of area 1.07 ± 0.12 m^2 while in the case of pressurised nozzle type of simulator except for those using single; it can be as large as 5.12 ± 1.58 m^2 [3]. Larger plot size in pressurised nozzle requires high pressure at higher height to attain good rain uniformity on the plot. For example, with plot size of 2.8 m^2, rainfall intensity of 1.43–1.58 mm/h and rain uniformity of only 60% was achieved with operating pressure of 20 kPa [41]. These results were not encouraging at all but when pressure of 41 kPa was used on similar plot size of 2 m × 1.5 m (3 m^2) a rainfall uniformity of 95% was achieved as cited by [5].

5.4 Simulator height and kinetic energy

Kinetic energy of simulated rain is being influenced by two major factors; height of simulator and surface of plot, most especially in drop former (DF) simulators

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Type/class of rainfall simulator	Drop size (mm)	Area (m^2)	Terminal velocity (m/s)	Uniformity coefficient (%)	Rainfall intensity (mm/h)	Height (m)	Ref.
Drip former RS	4.5	1	0.08	75	0.25–160 (Avg = 80.13)	14	Regmi and Thomson [47]
Drip former RS	3–6 (Avg = 4.5)	0.36	0.023	50–70 (Avg = 60)	78	10–13 (Avg. = 11.5)	Law [11]
Average	**4.5**		**0.05**	**67.5**	**79.06**	**12.75**	
Pressurised RS	0.9–2	0.95	0.63–0.86 (Avg = 0.75)	81.2–88.5 (Avg = 84.85)	55–88 (Avg = 71.5)	1.5–2.5 (Avg = 2)	Ngasoh [48]
Pressurised	2.35–2.55	1.2	1.01	85.7–87.5 (Avg = 86.6)	50.8–152.4 (Avg = 101.6)	4.27	Rick et al. [49]
Average	**2.45**		**0.88**	**85.72**	**86.55**	**3.14**	
Hybrid RS	2.2–8 (Avg = 5.1)	1	0.35	96.5–98.7 (Avg = 97.6)	65–70 (Avg. = 67.2)	2.35	Carvalho et al. [16]
Hybrid RS	2.3	2.5–8	0.123	93	15–120 (Avg. = 67.5)	3.4	Bowyer-Bower and Bur [4]
Average	**3.7**		**0.23**	**95.3**	**67.35**	**2.88**	
Natural rain	0.125–1 (Avg = 0.56)		0.85–5	≥85	15–160 (Avg = 87.5)		Liu et al., [50]

Table 1.
Results of test from different rainfall simulator compared to natural rainfall.

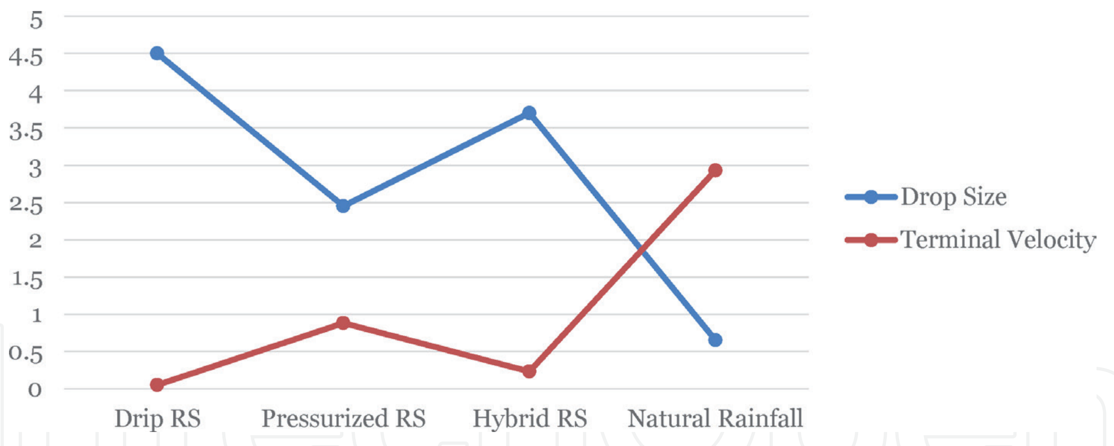

Figure 7.
Representation of rainfall drop size and terminal velocity of different rainfall simulator compared to natural rainfall.

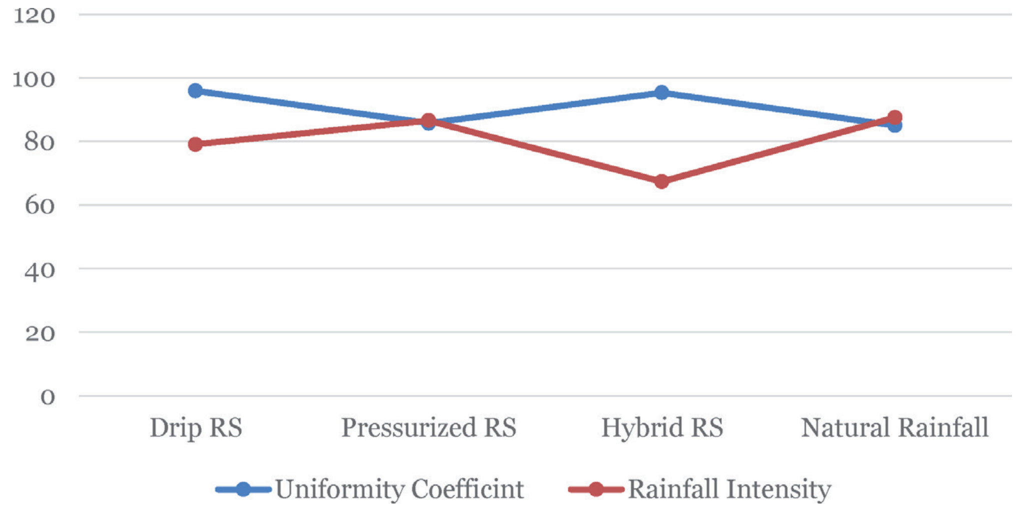

Figure 8.
Representation of rainfall intensity and uniformity coefficient of different rainfall simulator compared to natural rainfall.

[3] requires huge range of height from 7 m [6] and 10 m [44] to reach the terminal velocity. In similar research [45] developed a laboratory rainfall DF simulator, they would achieve the desired kinetic, the dripper was placed at 14 m above the plot. Examining the above results shows that the height of a simulator has significant influence on terminal velocity and kinetic energy. For example low kinetic energy of 5.8 Jm^{-2} mm^{-1} was achieved in a research due to low height of 2 m was used for their simulator [46]. This was also confirmed by when [34] used portable rainfall simulator to control rainfall, some of the rainfall parameters like KE was mimicked at 5 m above the plot to achieve the KE similar to natural rain.

One of the underlined differences between drop former (DF) simulator and pressurised nozzle (PN) is height of the simulator. The pressurised due to the pressure achieves kinetic energy (25 Jm^{-2} mm^{-1}) and D_{50} of 2.19 mm at the height of as low as 2.4 m above the plot as indicated by [24, 33]. According to [5] comparing the results of drop former simulator and pressurised nozzle both positioned at downward spray, pressurised nozzles overestimated the kinetic energy while drip former underestimated the kinetic energy.

After close analysis of the relationships of rainfall simulator components interdependently, [5] further observed that increased in pressure increases the intensity, rain uniformity and kinetic energy. Differences in plot size do not relate any other parameter apart from uniformity. Nozzle spray angle of aperture impacts the nozzle spacing. The research further recommended that any rain simulator designer should take into consideration intensity, kinetic energy and uniformity when designing a rain simulator. **Table 1** showed the results gotten by different researchers using different types of the rainfall simulators.

The average results from the various test indicated that Drop former produces higher rainfall drop sizes followed by hybrid while with pressurised rainfall simulator, an average of 2.5 mm rainfall drop size is produced. That is, among the different types of rainfall simulators, the pressurised rainfall simulator produces small varieties of drop sizes close to that of the natural rain. However, on the terminal velocity, the natural rainfall attains it before reaching it is fall from an infinity distance compared to the on obtainable from simulated rainfall (see **Figure** 7).

Figure 8 compares the uniformity and rainfall intensity of different types of rainfall simulators to the one obtainable from natural rainfall. The findings indicate that Drop former and hybrid rainfall simulator produces higher uniformity coefficient compared to what is obtainable from natural rainfall. While, intensity of a rainfall from pressurised rainfall simulator is similar to the ones obtainable from natural rainfall.

6. Rainfall simulation on non-erodible and erodible surface

For a rainfall simulator to be used to study either on erodible or non-erodible surface, it needs to achieve rainfall characteristics close to those of natural rainfall, it needs to be portable and easy to control [3].

Furthermost of the research on erodible surface have involved erosion, infiltration and tillage studies [24, 51]. In disparity, the process concerning urban wet weather studies involved non-erodible surface and were defined based on pollutant volume and the corresponding discharge volume [3, 52]. In run off and sediment yield studied by [53] from an erodible watershed and non-erodible watershed using 10 modelled precipitation event, they achieved a runoff volume and sediment load of 5.5 ± 2.7 and 5.5 ± 2.3 respectively, and the proportion of precipitation to runoff volume was on the average 14.5%. The simulated result was greater than when it was done on non-erodible soil surface. A conclusion was also made by [51, 54] that drop size and the fall velocity are given basic attention in the study of erosion and infiltration model involving erodible surfaces and [53] also noted that simulation on non-erodible surface increased runoff volumes linearly and peak flow rate exponentially and served as means of control of sediment load and flow rate by its spatial characteristics.

7. Conclusion

First of all, the method employed to accumulating runoff on non-erodible and erodible surface not the same. Simulating precipitation and collection of runoff on non-erodible surface is more challenging because non-erodible surface are mostly tiled surfaces where excavation is controlled. Recovering of the runoff from non-erodible surface is the priority of researchers but the task is difficult. To overcome the difficulties in regenerating the runoff from an urban non-erodible surface.

Secondly, take note of the length and slope of the study area in the study of erosion and infiltration as they are important requirement in simulation.

Thirdly, pressurised nozzle simulator will be suitable for simulating reasonable intensity, runoff and rain depth most especially for nonpoint source study on non-erodible surfaces because the controlling intensity will be limited using drop former simulator.

Fourthly, in the simulation of drop size and distribution, water quality should be taken note of. Though it may not be significant in the simulation of infiltration and soil erosion, but in urban water quality simulation which deals with measurement of pollutant level it is a very important factor to consider. In an investigation carried out in Malaysia [55], water quality presented a challenge in simulating intensity drop size, drop size distribution and uniformity using drop former simulator. As water is stored and kept for long period of time algae and other micro-organism may develop in it or around the dripper. This challenge is predominant in drop forming simulators and less in pressurised nozzle simulator because the pressure applied at the nozzle orifice reduces the risk of clogging. To minimise the challenge of clogging of dripper and nozzle orifices, screen should be provided at suction point or water source.

Duration of experiment on non-erodible surface using rain simulator is an important requirement. To overcome the delay in runoff generation on studying runoff on non-erodible surface which is predominant in drop former simulator, pressurised nozzles are preferable because it offers reasonable amount of runoff with short time. In contrast, on erodible surface, drop former simulators are preferred especially in the study of infiltration.

Rainfall uniformity is achieved higher in drop forming and hybrid simulators which is a good requirement for erodible surface that include infiltration studies where the interest is on measuring downward filtered water on the plot. Simulating on erodible surface, saturation of the plot surface is slower than simulation on non-erodible surface. On the non-erodible surface the study interest is runoff collection. The researcher further recommended that mounting and dismounting of rainfall simulator should be flexible.

Finally, to achieve a good rainfall distribution uniformity using rainfall simulator, the plot must be smaller than the wetted perimeter of the simulator most especially for outdoor simulator. In the case of indoor rainfall simulator, the plot can be larger than the wetted perimeter but consideration can only be given to collectors around the wetted perimeter.

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