MAUSAM, **75**, 4 (October 2024), 1133-1140

MAUSAM

Homepage: https://mausamjournal.imd.gov.in/index.php/MAUSAM

**L E T T E R S**

UDC No. 551.577.1(540)
DOI : https://doi.org/10.54302/mausam.v75i4.6570

## DECODING THE RAIN MICROPHYSICS FOR TWO TROPICAL STATIONS USING DISDROMETER DATA

1. The exploration of the distribution of drop sizes in rainfall, known as rainfall drop size distribution (DSD), holds immense significance across a diverse range of scientific fields. These encompass radar meteorology, microwave communication, satellite remote sensing, soil erosion and cloud physics. These domains have witnessed a surge in attention for multiple reasons, notably driven by climate alterations and the resulting rise in occurrences of intense rainfall events. Precise assessments of drop size distributions play a pivotal role in numerous meteorological applications. These applications span from deducing rainfall estimates through radar reflectivity measurements to investigating cloud radiative transfer processes, as well as initializing and validating cloud models (Baltas *et al*., 2016).

Scientific advancements have resulted in the creation of two main types of ground-based instruments for directly assessing rainfall drop size distributions (DSDs): impact and optical Disdrometer. A more recent innovation is the acoustic Disdrometer, which infers rainfall properties from the sound generated upon raindrop impact on water surfaces. Despite its potential, the adoption of acoustic Disdrometer remains limited in current applications (Winder *et al*., 2011). Optical Disdrometer employ a light source, usually a laser, and a light detector like a photodiode to capture signals generated as precipitation particles traverse the measurement area. Diverse designs of optical Disdrometer are available, including the two-dimensional video Disdrometer (2DVD), enabling real-time measurements of precipitation and drop size distribution (Kruger and Krajewski, 2002, Schonhuber *et al*., 2008), On the contrary, impact disdrometer utilize the mechanical force of rainfall drops hitting a solid surface to produce electrical signals. The pioneering automatic impact disdrometer, known as the Joss-Waldvogel disdrometer (JWD), was introduced by Joss and Waldvogel (Joss and Waldvogel, 1967), standing as a standard for DSD measurements.

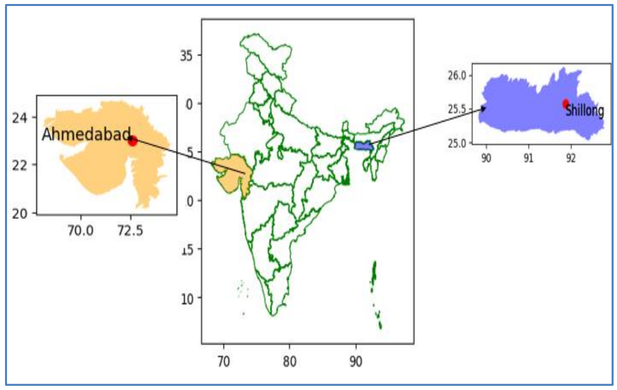



**Fig. 1**. Study area location on India map

In this study, we conducted an analysis utilizing RD-80 Disdrometer data obtained from two distinct meteorological stations, namely Ahmedabad and Shillong. The period of focus encompassed the monsoon months spanning from June to September as the Indian Summer Monsoon (ISM) is responsible for a substantial 75-80% of India's total annual rainfall (Maharana *et al*., 2019; Turner and Annamalai, 2012). Also, The ISM, a prominent weather phenomenon impacting the Indian subcontinent, stands out due to its distinct pattern of seasonal wind reversal, accompanied by shifts in rainfall patterns. Numerous comprehensive analyses have delved into the intricacies of the monsoon, encompassing its primary features, predictability, and forecasting (Webster *et al*., 1998; Goswami, 2004). The evolving climate introduces uncertainty into the equation, as climate models present varying perspectives on the monsoon's response to these changes (Dobler and Ahrens, 2011). This spatial and temporal distribution significantly shapes the socio-economic conditions of more than a billion lives within the subcontinent. Its effects ripple through crucial aspects like agricultural productivity and food security.

### 2. Study area

Ahmedabad and Shillong were chosen in part due to the geographic variety they represent shown in Fig. 1 below. Ahmedabad, located in the arid region of Gujarat, stands in stark contrast to Shillong, situated in the northeastern part of India. Due to the geographic diversity, it is possible to thoroughly analyze the patterns of rainfall throughout several climatic zones, which aids in understanding the variables affecting precipitation. Ahmedabad is characterized by a semi-arid climate, characterized by hot and dry summers. On the other hand, Shillong enjoys a subtropical highland climate with a substantial amount of rainfall, particularly during the monsoon season. This stark difference in climatic conditions provides a unique opportunity to investigate the impact of varying environments on local rainfall trends and variations.

2.1. *Ahmedabad*

Ahmedabad city is positioned in the semi-arid expanse of Gujarat State in western India, with coordinates 23.03° N latitude and 72.54° E longitude. Situated at an elevation of 55 meters, the city experiences four distinct seasons: summer (March-May), monsoon (June-September), autumn (October) and winter (November-February). The temperature ranges during summer spans 25 to 40 °C, while winter temperatures typically fluctuate between 15 and 35 °C. Over the long term, the meteorological station in Ahmedabad has registered an average annual rainfall of around 80 cm (http://www.imdahm.gov.in/). The vast majority of Ahmedabad's annual rainfall accumulates within approximately 30 days of rain during the four-month period of the Southwest Indian Summer Monsoon (ISM). This monsoon holds significance as a vital element of the broader Asian Summer Monsoon (Attri and Tyagi, 2010; Das, 1968; Menon, 2005).

2.2. *Shillong*

Shillong is located at 25.5760° N latitude and 91.8825° E longitude, the city's elevation of around 1,525 meters within the eastern Himalayas is a defining factor. Shillong's subtropical highland climate delineates distinct seasons: a mild summer spanning 15 °C to 24 °C, a monsoon season characterized by substantial rainfall (June-September), a transition to autumn characterized by clearer skies and a brisk yet temperate winter (December-February) averaging 4 °C to 15 °C. Shillong's geographical attributes play a significant role in shaping its rainfall patterns. This urban center holds importance due to its proximity to the globe's most intense rainfall location, Mawsynram/Cherrapunjee. However, Shillong experiences notably reduced rainfall due to the influence of orography. Following Köppen's classification, the city showcases a subtropical highland climate (Cwb). The summertime seasons are characterized by warmth and abundant rainfall, while the winters bring cool and arid conditions (Tanti *et al*., 2017).

2.3. *Data used*

We relied on the RD-80 disdrometer data corresponding to the years listed in Table 1. Our primary attention was directed towards the stations located in Ahmedabad and Shillong, particularly during the pivotal monsoon period spanning from June to September. These months hold significant importance as they largely dictate the annual rainfall patterns across India.

**TABLE 1**

**Available Data from Rd-80 Disdrometer**

| Station | Year and Months |
|---|---|
| Ahmedabad | 2005 (June-October), 2006 (June-August), 2007 (June-September), 2008 (June-September) |
| Shillong | 2005(June-October), 2006(June-August) |

The RD-80 is composed of three primary units: the transducer that encounters the rainfall, the processor and the analog-to-digital converter, referred to as the Analyzer ADA 90-an instrument designed to continuously and autonomously measure raindrop size distributions (Joss and Waldvogel, 1967). According to its operational principle, it gauges the size distribution of raindrops as they fall onto the sensitive surface of the transducer. The real distribution of drop sizes in a volume of air can be easily derived from these measurements. The instrument's capability covers drop diameters ranging from 0.300 mm to 5.373 mm; drops smaller than 0.300 mm cannot be measured due to practical limitations associated with the measurement principle and they usually have minimal significance for the intended applications of the instrument. Drops larger than 5.373 mm are exceptionally rare due to the instability and fragmentation of larger drops. Another drawback of the instrument is its tendency to underestimate the count of small drops during heavy rainfall due to the disdrometer's inherent "dead time" (Tokay *et al*., 2003).

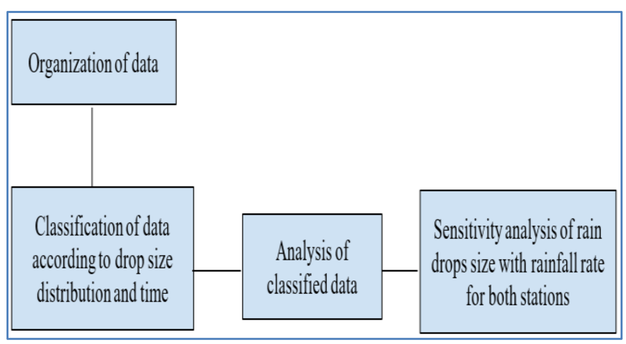



**Fig. 2**. Flow chart of the RD-80 Disdrometer data analysis for Ahmedabad and Shillong.

## 3. Methodology

Fig. 2 shows the flow chart of the analysis carried out in this study. We compiled the data by extracting information from periods during which both stations encountered rainfall and filter out the non-rainfall data, as

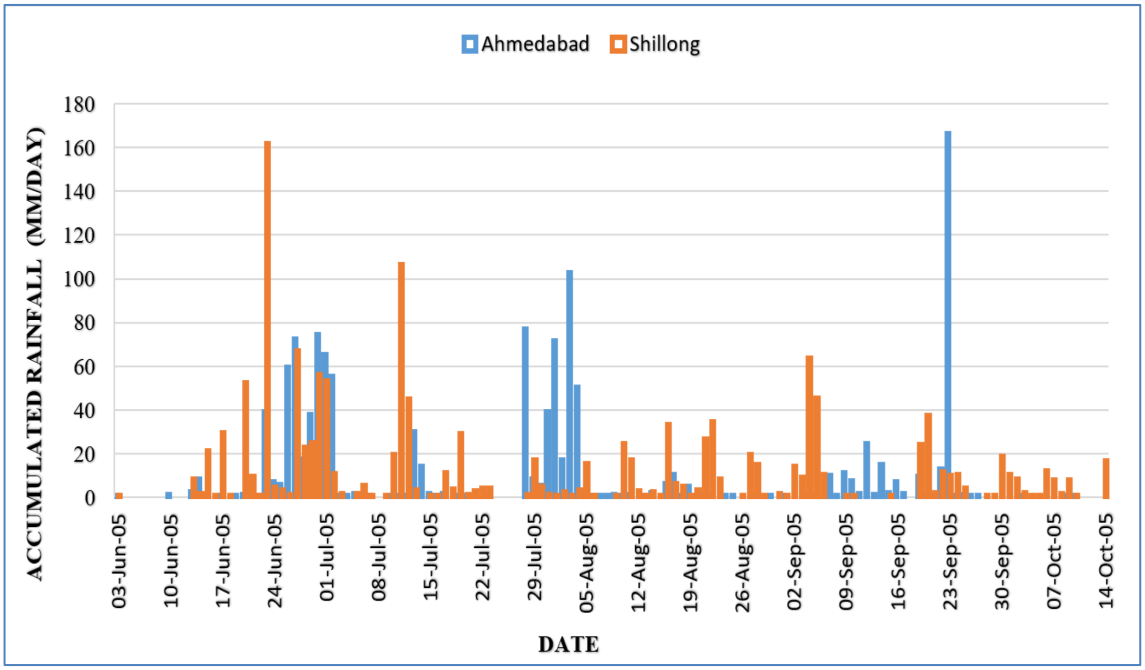



**Fig. 3**. Comparative Daily Accumulated Rainfall (aggregating data recorded at a temporal resolution of 30-second intervals over a full day) in the 2005 Monsoon Season between Ahmedabad and Shillong for the available data (3 June to 14 October).

it narrows down the dataset to instances where direct comparisons are feasible for both stations. Then to understand the variation of RDSD and to assess the impact of raindrop sizes on each station and the alterations influenced by location differences we categorized the data into three different categories: Small Raindrops, Medium Raindrops and Big Raindrops as shown in Table 2.

**TABLE 2**

**Classification of rain drop size**

| | |
|---|---|
| Small Raindrops | 0.15650-0.4995 mm |
| Medium Raindrops | 0.4995-1.2050 mm |
| Big Raindrops | 1.2050-2.80025 mm |

In order to have a deeper comprehension of how day shifts affect RDSD, we additionally divided the data into four time zones: morning, afternoon, evening and night. By categorizing raindrop sizes as per our defined classes, the disdrometer provides numerical density data for each category. This prepared data allows us to discern the evolving patterns in raindrop sizes throughout the monsoon season for both locations. This approach also assists in identifying the fluctuations in raindrop sizes influenced by the distinctive attributes of each station, including its geographical and climatic disparities.

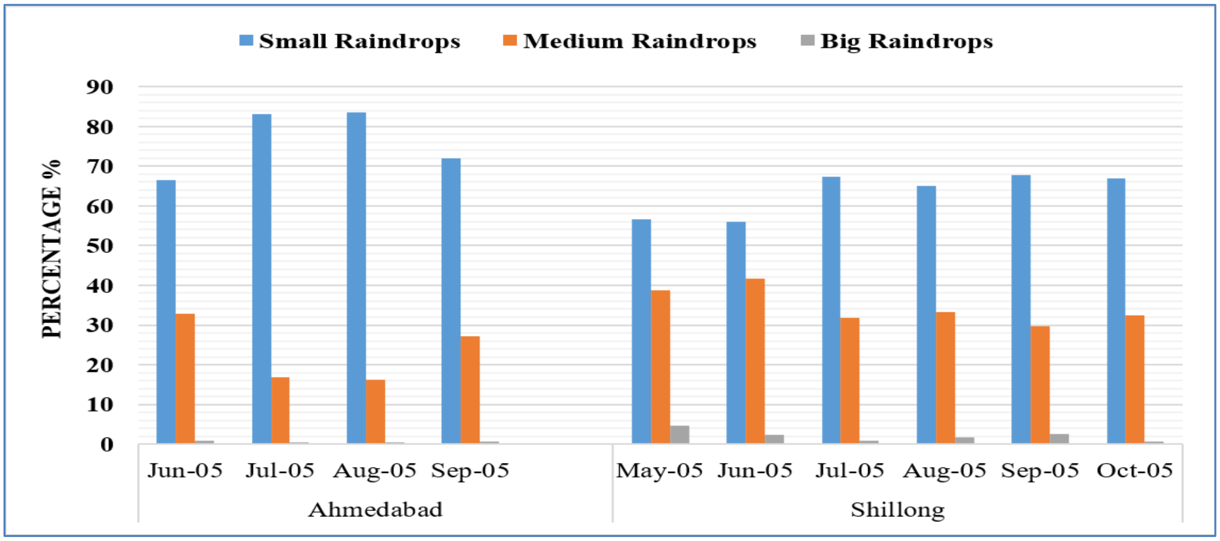
The purpose of our research was to investigate how the distribution of raindrop sizes fluctuates and how they react to variations in rainfall intensity. In order to do this, we assessed the disdrometer sensitivity to the rate of rainfall for each category of raindrop size.

## 4. Result and discussion

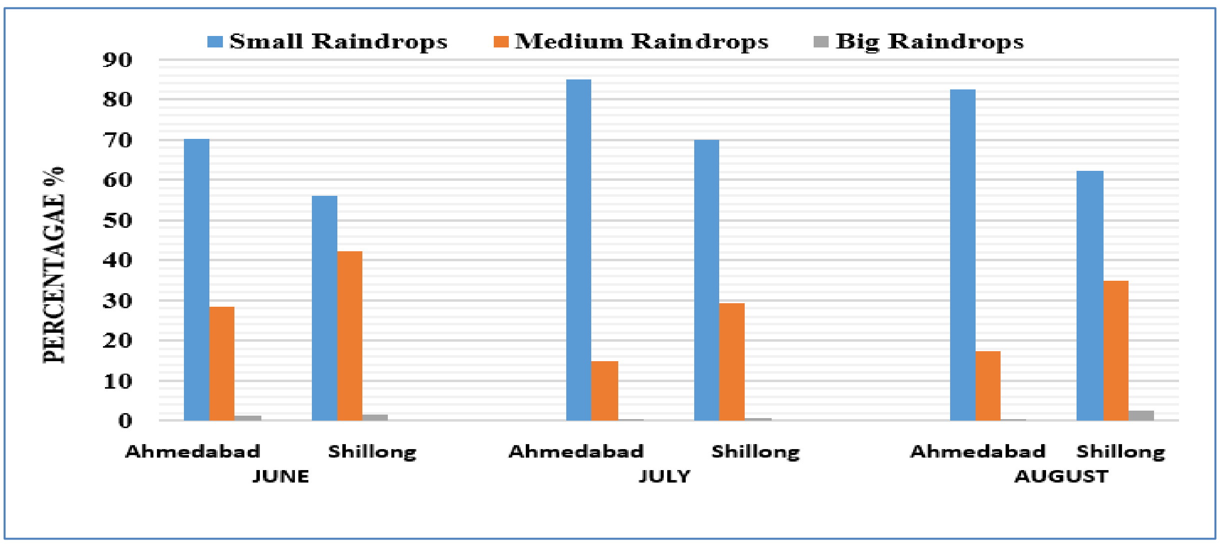
Fig. 3 illustrates the precipitation levels during instances of rainfall for the year 2005 at both stations. It draws attention to the heavy rainfall that occurs in Ahmedabad during the early monsoon months and the increased precipitation that occurs in Shillong during the mid-monsoon. Ahmedabad, which is usually described as a place with little precipitation, saw a substantial amount of precipitation in 2005. This divergence is correlated with the Findlater Jet's strengthening over the Arabian Sea, which is pushing more moisture toward western India. Simultaneously, changes in the circulation of heat and the direction of the northward wind have created an environment that is favorable to rain-producing mechanisms. Current trends of Moisture Static Energy (MSE) reinforce the ideal conditions for rainfall in western India.

As a result of the enhanced atmospheric moisture and favorable weather patterns, Gujarat and southern Rajasthan in India see increased rainfall (Mohanty, 2015; Maharana *et al.*, 2021).

The classified raindrop size distributions for both stations in the months of June, July, August, and




(a)




**(b)**

**Fig. 4**. **(a &b)**. a) Influence of Small, Medium, and Large Raindrops on Total Rainfall Recorded at Both Stations for year 2005 and b) for year 2006.

September are shown in Fig. 4a. It allows us to compare the stations and gain a better understanding of the differences in raindrop sizes over the monsoon months.

We observed a distinct variation in the behavior of the two stations with regard to the size of raindrops during the months of July and August. While it was 2% in Ahmedabad, the distribution of large raindrops in July was either nonexistent or accounted for less than 1% in Shillong. On the other hand, Ahmedabad saw only 1% of the larger raindrops seen in August, whereas Shillong recorded a higher presence of these droplets, accounting for 5% of the total. Moreover, the Shillong station shows a greater percentage rise in the presence of larger raindrops than Ahmedabad as the monsoon season draws to an end.

Fig. 4b illustrates the influence of small, medium, and large raindrops in 2006 for both Ahmedabad and Shillong. It is observed that Shillong has a larger average droplet size compared to Ahmedabad. The raindrop size distribution in Shillong shows a significant presence of medium and large droplets, indicating heavier rainfall. Conversely, Ahmedabad exhibits a dominance of smaller droplets, suggesting lighter rainfall conditions in comparison to Shillong. This difference in raindrop size distribution can be attributed to the varying climatic conditions, geographical features, and weather patterns between the two locations. Shillong, being in a hilly region with a more humid climate, likely promotes the formation of larger droplets, whereas Ahmedabad,

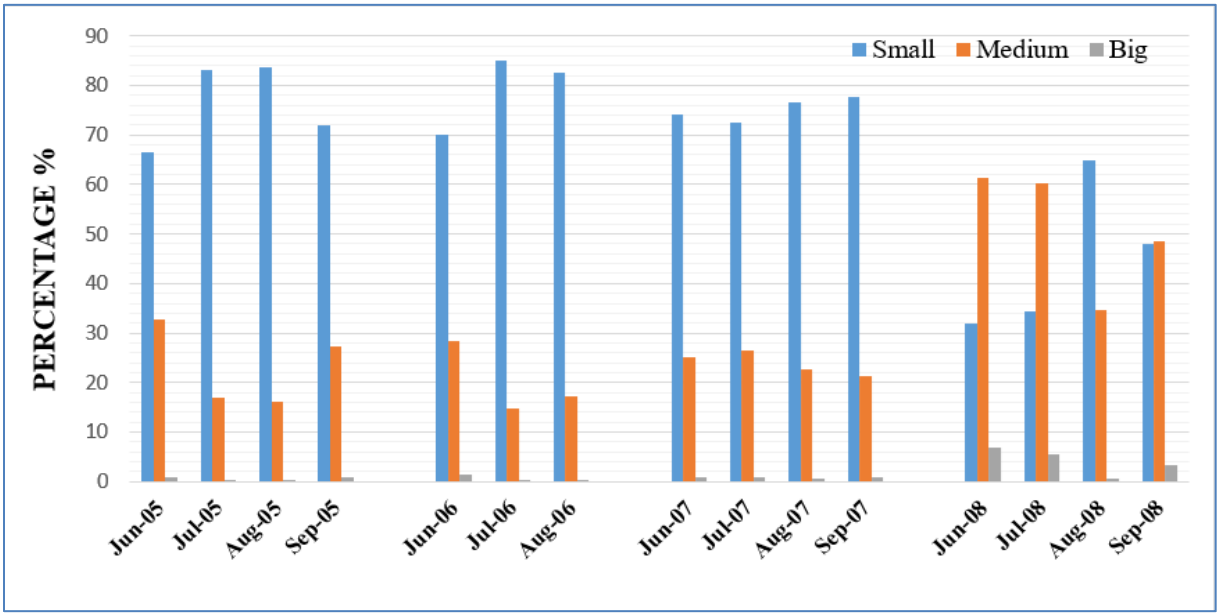



**Fig. 5**. Influence of Small, Medium and Large Raindrops on Total Rainfall Recorded at Ahmedabad in year 2005-2008.

situated in a more arid region, tends to have smaller droplets.

The yearly variation in droplet size is also depicted in Fig. 5. In 2005, there is a clear dominance of smaller droplets. However, as the year's progress, there is a gradual shift towards an increasing presence of medium and large droplets.

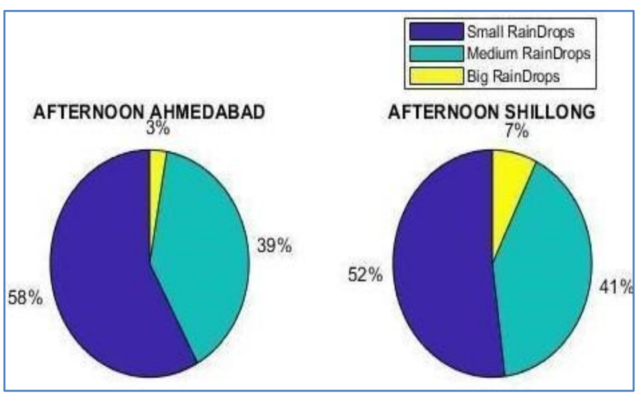



**Fig. 6**. Classification of Raindrop Size Distribution Variations during Afternoon Hours at Both Stations.

In Fig. 6, we found divergence in the occurrence of larger raindrops, particularly during the afternoon hours. Specifically, when compared to Ahmedabad, we saw that Shillong had a higher concentration of larger raindrops in the afternoon. This phenomenon is influenced by the topography & local weather patterns of Shillong. Shillong's high altitude combined with its closeness to moist air masses can cause a build-up of water vapor during the day. It is more likely that this accumulated moisture will condense into larger raindrops in the afternoon when the environment may be more favorable for condensation and aggregation. Furthermore, late-afternoon thunderstorm development is linked to nor 'wester occurrences during the summer. Despite having a small spatial extent (less than 50 km), these nor 'westers are quite important compared to the larger area that we studied. Strong convection processes are the source of these thunderstorms (Pradhan *et al.*, 2019; Tyagi *et al.*, 2012).

In comparison to medium- and large-sized raindrops, Fig. 7 demonstrates that the frequency and number density of smaller raindrops are extremely high for both locations. In addition, it is abundantly evident from the data visualizations that Ahmedabad experienced significantly more rainfall in 2005 than would be expected for that time of year. This conclusion is further supported by the Ahmedabad IMD report from the same year. (IMD, Monsoon 2005).

Fig. 8 shows the Disdrometer Size Distribution (DSD) and how it relates to the rate of rainfall in 2005's monsoon month (June-September). The main goal is to decipher the complex sensitivity that exists between the DSD patterns and the associated rates of precipitation at these various geographic locations. Because Ahmedabad and Shillong have very different geographical features and climates, comparing them is especially insightful. When the monsoon begins in June and ends in September in Ahmedabad, there is a noticeable increase in sensitivity during these times. This suggests that there are notable fluctuations in the corresponding rainfall rate during these

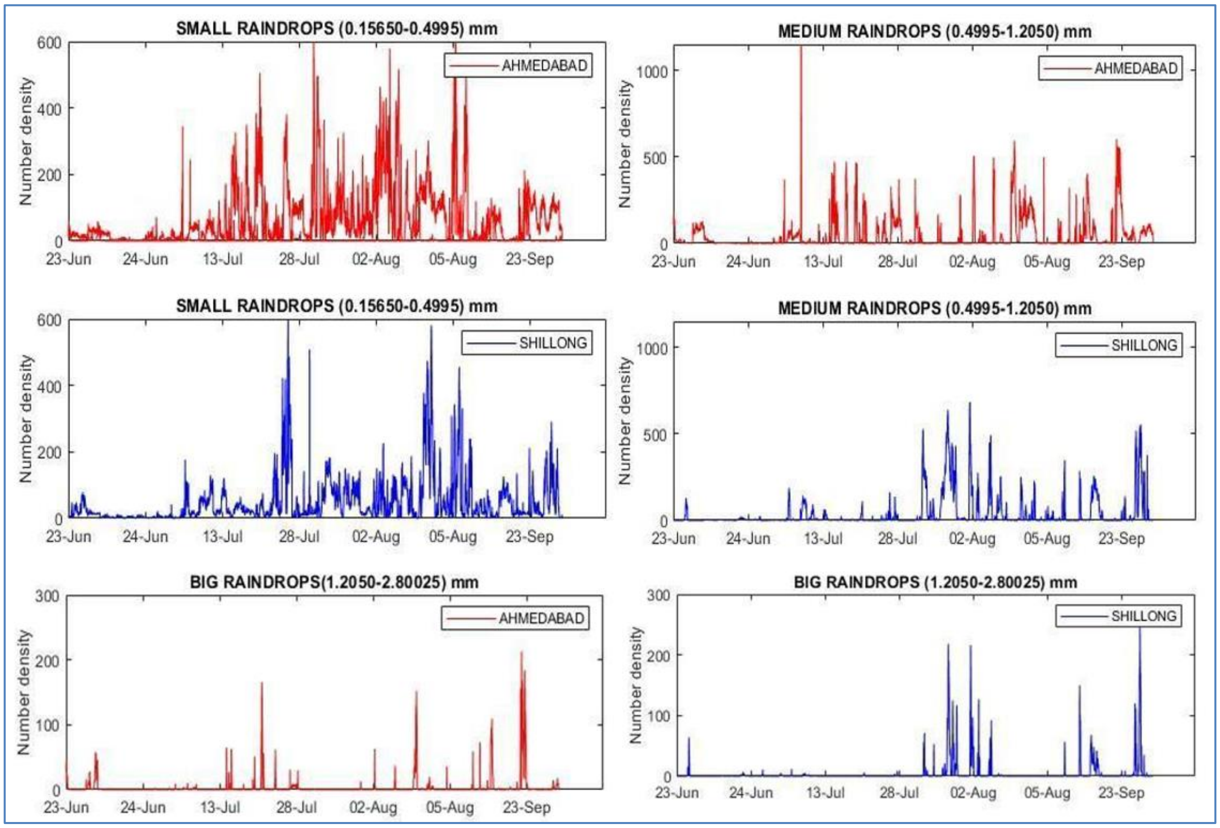



**Fig. 7**. Number density plots depicting the distribution of small, medium, and large raindrops throughout the monsoon months (June-September) at both the Ahmedabad and Shillong station.

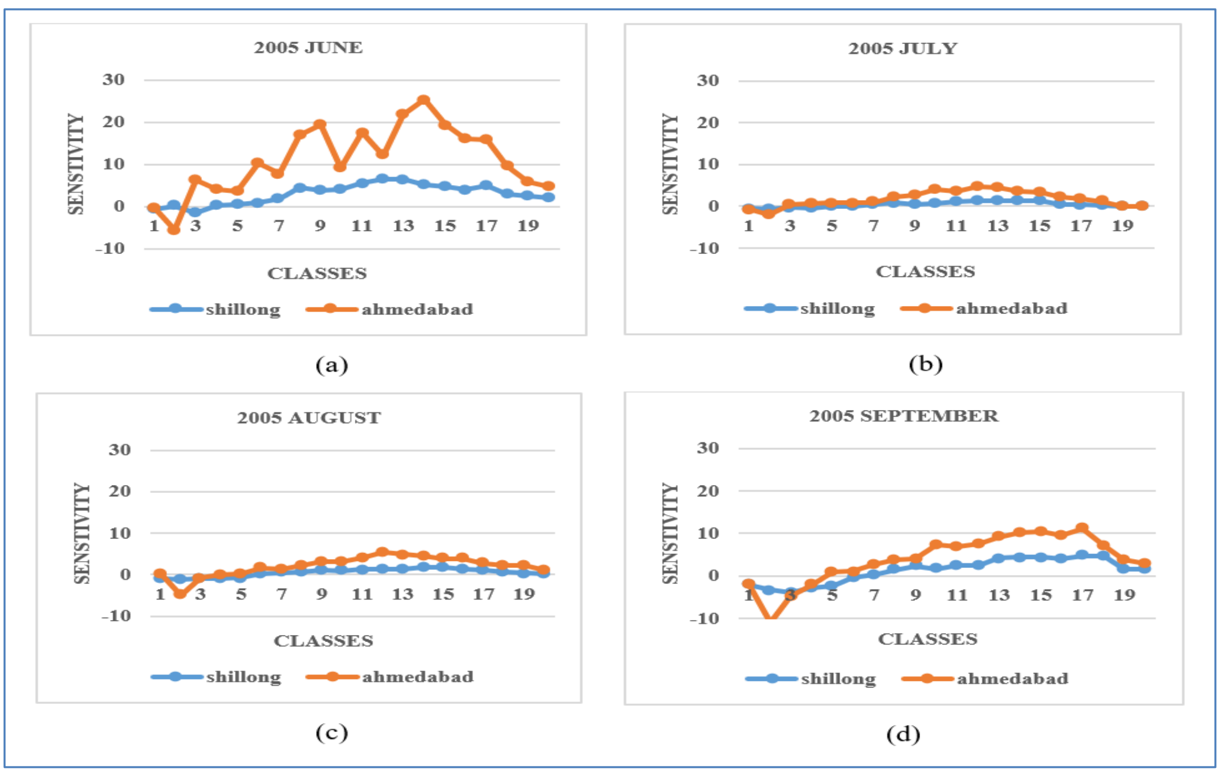



**Fig. 8**. Visualization of Sensitivity: Exploring the Relationship Between Pre-defined Disdrometer Drop Size Classes and Rainfall Rate.

months due to variations in the DSD. Conversely, Shillong displays a more consistent sensitivity pattern over the course of the monsoon. Significant differences exist between Ahmedabad and Shillong when comparing their sensitivity levels. In particular, Shillong exhibits consistently lower sensitivity in all drop size bins, indicating that variations in the DSD influence the rainfall rate with comparatively less severity. Ahmedabad, on the other hand, has a higher sensitivity for different drop size bins, suggesting that slight changes in the DSD have a more noticeable effect on the rate of rainfall.

The differences in sensitivity that exist can be ascribed to the weather that existed in these areas in 2005. Notably, Ahmedabad had above-average rainfall for the year, which may have added to the increased sensitivity brought on by the DSD's larger variations. It's possible that Shillong's unique climatic and geographical characteristics, which moderate the relationship between DSD and rainfall rate, are the cause of its more consistent sensitivity behavior. (IMD, Monsoon 2005).

## 4. Conclusions

In this study we conclude that, while Shillong experiences more precipitation in the middle of the monsoon season, Ahmedabad experiences significant rainfall in the early monsoon months. The results show that the data from 2005 deviates from the historical description of Ahmedabad as a region with moderate rainfall, challenging conventional notions about the area. Additionally, we noticed that in both stations, the frequency of smaller raindrops was noticeably higher than that of medium and large ones. Also by classifying raindrops into distinct size groups, our research revealed the heterogeneous character of precipitation patterns. The finding that Shillong has a higher frequency of larger raindrops in the afternoon was especially noteworthy. This diurnal variation emphasizes how important local atmospheric factors are in determining the size of raindrops. In the sensitivity analysis of RDSD with rainfall rate we find that in Shillong, the degree of sensitivity is consistently lower for all drop size categories, suggesting that variations in the Drop Size Distribution (DSD) have a less significant effect on the rate of rainfall. On the other hand, Ahmedabad shows greater sensitivity in all drop size categories, indicating that even small changes in the DSD have a more noticeable impact on the rate of precipitation. Furthermore, when there are plenty of larger raindrops, a lot more water falls rapidly. Flooding can result from significant rainfall overloading drainage systems, particularly in places where the infrastructure isn't prepared to handle the volume of water. This also occurred in Ahmedabad in 2005. Floods are frequently caused by rapid, heavy rains. Knowing these trends makes it easier to forecast and control the dangers associated with high precipitation, particularly in areas that are prone to flooding.

## 5. Statements and declarations

*Competing Interest :*

The authors declare that they have no competing interests.

*Acknowledgment:*

The authors express sincere gratitude to the Director of Space Applications Center (SAC), ISRO Ahmedabad, for his guidance and support. A part of the research was carried out under the ISRO-SMART Research Initiative Program.

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(*Received 19 Febuary 2024, Accepted 17 July 2024*)

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