ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 8, Issue 11 , November 2021

Annual Total Rainfall in India: Confidence Interval and Significance of Change

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ABSTRACT: A study has been made on probabilistic forecasting of rainfall in India with reference to (i) the determination of confidence interval of annual total rainfall and (ii) the significance of change of rainfall in India. The study has been done on the basis of data from 1969 onwards. This paper is based on the findings of the study.

KEYWORDS: Gaussian distribution, area property, annual total rainfall, confidence interval

I. INTRODUCTION

Temperature and rainfall are two of the prime/major factors that determine the weather and the climate of a location. The ecological system also depends upon these two factors. The growth, production and preservation of the resources for survivability of human beings primarily depend upon these two. Again, these two factors changes continuously over time. The change in these two factors may yield adverse impact upon weather, climate, ecological system and on the production of the resources. Thus, there is necessity of continuous study on the changes in these two factors over time. Maximum temperature, minimum temperature, average temperature (daily); Mean Maximum temperature, highest maximum temperature, mean minimum temperature, lowest minimum temperature, average temperature (monthly/seasonally); Mean Maximum temperature, highest maximum temperature, mean minimum temperature, lowest minimum temperature, average temperature (yearly) are the characteristics/parameters of temperature which together can give a picture of temperature at a location. Similarly, total rainfall (daily), total rainfall (monthly), total rainfall (seasonally), total rainfall (annually), heaviest 24 hours rainfall (monthly), heaviest 24 hours rainfall (Seasonally), heaviest 24 hours rainfall (yearly), number of rainy days (monthly), number of rainy days (seasonally), number of rainy days (yearly) are the characteristics/parameters of rainfall which together can give a picture of rainfall at a location.

There have already been several studies on the theoretical aspect of the above characteristics/parameters of temperature as well as on its application aspect in the context of Assam and India. Some of them are (1) determination of natural value of extremum and natural interval of monthly extremum of temperature in the context of Assam [16 , 18]. In some other studies, some methods have been developed for determining the value of parameter from a set of observations composed of the parameter itself and chance errors [17, 21 , 24 , 25]. The methods developed have already been applied in several studies on determining the central tendency of annual maximum and annual minimum of ambient air temperature in the context of Assam [22 , 23 , 41 , 43 , 45 , 46 , 47 , 49 , 51 , 53]. The methods developed have also been applied in several studies on determining the confidence interval of each of annual maximum and annual minimum of ambient air temperature in the context of Assam [27 , 50 , 52 , 54]. However, the above characteristics/parameters of rainfall are yet to studied. Of course a single study has been made on the determination of the natural limits of annual total rainfall in the context of India [20]. In the present attempt, study has been made on the theoretical aspect of the determination of annual total rainfall as well as on its application aspects in the context of Assam and India.

Rainfall at a location / region changes over time. The change occurs basically due to two broad causes namely (1) Assignable or controllable cause (or causes) and (2) Chance cause. The change can be interpreted as significant (or equivalently as effective or equivalently as countable) if and only if it occurs due to both the causes and as insignificant (or equivalently as ineffective or equivalently as negligible) if and only if it occurs due to chance cause only. There is necessity of determining whether the change occurs due to both the causes or due to the chance cause only because, the task of controlling the change arises only when the change occurs due to assignable cause (or causes). The study, presented here, is based on this necessity. This paper is based on a study made to search for some method of determining the natural limits of annual total rainfall at a location by the application of the area property of normal probability distribution. The method has been applied in determining the natural limits of total rainfall in the context of India. Once the values of the natural limits of annual total rainfall at a location are known, it would be possible to know if the rainfall

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
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of the location is influenced by some unnatural factor/factors by analyzing the past and present scenario in respect of the rainfall at the location.
Analysis of variance *[33 , 35 , 39 , 41 , 55]* discovered by Ronald A. Fisher [45 , 33] is a statistical tool that can be applied in knowing whether there exists any significant assignable cause in a region which compels the rainfall in the region to be changed. It is possible to apply this tool in determining forecasted interval value with desired degree of confidence.

II. GAUSSIAN DISTRIBUTION AND ITS AREA PROPERTY

In the year 1809, a famous German mathematician *Carl Friedrich Gauss* [36] discovered the most significant probability distribution in statistics which is popularly known as normal probability distribution as well as Gaussian distribution [1 , 34 , 36 , 38 , 39 , 40 , 42 , 56 , 59 , 60] that plays the key role in the theory of statistics as well as in the application of statistics. However, some authors accord the credit for this discovery to a French mathematician *Abraham De Moivre* [31 , 33 , 58] due to the reason that he published a paper in 1738 on the normal distribution as an approximation to the binomial distribution discovered by *James Bernoulli* in 1713 [2 , 3 , 6 , 7 , 8 , 9 , 10 , 11 , 12 , 13 , 14 , 15 , 31 , 32 , 33 , 44].
The normal probability distribution [1 , 34 , 36 , 38 , 39 , 40 , 56 , 59] is described by the probability density function

$$f(x : \mu , \sigma) = \{\sigma (2\pi)^{½}\}^{-1} \, exp\, [- ½ \, \{(x - \mu)/\sigma\}^2] , \quad -\infty < x < \infty , \; -\infty < \mu < \infty , \; 0 < \sigma < \infty \qquad (2.1)$$

where (i) X is the associated normal variable,
(ii) μ & σ are the two parameters of the distribution
and (iii) Mean of $X = \mu$ & Standard Deviation of $X = \sigma$.

Note: If $\mu = 0$ & $\sigma = 1$,
the density is standardized and X then becomes a standard normal variable. A standard normal variable is usually denoted by Z .
Thus, the probability density function of the standard normal variable Z is described by the probability density function

$$f(z) = (2\pi)^{-½} \; exp\, [- ½ \, z^2] , \quad -\infty < z < \infty \qquad (2.2)$$

Area Property of Normal Distribution

If X follows normal probability distribution with mean μ and standard deviation σ then

(i) $P(\mu - 1.96\, \sigma < X < \mu + 1.96\, \sigma) = 0.95,$ (2.3)
(ii) $P(\mu - 2.58\, \sigma < X < \mu + 2.58\, \sigma) = 0.99$ (2.4)
& (iii) $P(\mu - 3\, \sigma < X < \mu + 3\, \sigma) = 0.9973$. (2.5)

If Z is the standard normal variable then

(i) $P(-1.96 < Z < 1.96) = 0.95,$ (2.6)
(ii) $P(- 2.58 < Z < 2.58) = 0.99$ (2.7)
& (iii) $P(- 3 < Z < 3) = 0.9973$. (2.8)

Area property of normal distribution plays a significant role in the theory of statistics both in the development of statistical methods of analyzing data as well as in the application of statistical methods in data analysis. This property of normal distribution can be applied in determining confidence interval [30].

III. CONFIDENCE INTERVAL OF ANNUAL TOTAL RAINFALL

Let Y be the annual total rainfall at a location and Y_i be the observations on Y for the year i (i = 1 , 2 , 3 , …………..).
The true/actual value of Y is unique, say $\mu(Y)$. But the observed values are different which should be equal to $\mu(Y)$.
The variation in the observed values occur due to two types of causes/errors namely

1. Assignable Cause(s) that is (are) avoidable / controllable
& 2. Chance Cause/Error that is unavoidable / uncontrollable.

The values of Y_i should be constant if there exists no cause of variation in Y_i over years. However, chance cause (random cause) of variation exists always. Thus if no assignable cause of variation exists in Y_i over year, we have

$$Y_i = \mu(Y) + \varepsilon_i \qquad (3.1)$$

where $\mu(Y)$ = the true value of Y_i at the location in the year i
& ε_i = the amount of chance error associated to Y_i
(i = 1 , 2 , 3 , …………..).

The variable Y, in this case, satisfies the mathematical model

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International Journal of Advanced Research in Science, Engineering and Technology
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$$Y = \mu(Y) + \varepsilon \qquad (3.2)$$

where $\mu(Y)$ = the true value of Y
& ε = the variable representing the chance error associated to Y

It is to be noted that

(1) $Y_1, Y_2, \ldots\ldots\ldots\ldots, Y_n$ are known,
(2) $\mu, \varepsilon_1, \varepsilon_2, \ldots\ldots\ldots\ldots, \varepsilon_n$ are unknown,
(3) $\varepsilon_1, \varepsilon_2, \ldots\ldots\ldots, \varepsilon_n$ are values of the chance error variable ε associated to $Y_1, Y_2, \ldots\ldots, Y_n$ respectively which are unknown
& (4) the number of linear equations in (3.1) is n with $n + 1$ unknowns implying that the equations are not solvable mathematically.

Reasonable facts /Assumptions regarding ε_i

There are reasonable grounds to accept the following assumptions regarding the random errors [5 , 16 , 17 , 19 , 21 , 23 , 24 , 25 , 26 , 28 , 29].

(1) $\varepsilon_1, \varepsilon_2, \ldots\ldots\ldots, \varepsilon_n$ are unknown values of the variables ε.
(2) The values $\varepsilon_1, \varepsilon_2, \ldots\ldots\ldots\ldots, \varepsilon_n$ are very small relative to the respective values $Y_1, Y_2, \ldots\ldots\ldots\ldots, Y_n$.
(3) The variable ε assumes both positive and negative values.
(4) $P(-a - da < \varepsilon < -a) = P(a < \varepsilon < a + da)$ for every real a.
(5) $P(a < \varepsilon < a + da) > P(b < \varepsilon < b + db)$
& $P(-a - da < \varepsilon < -a) < P(-b - db < \varepsilon < -b)$
for every real positive $a < b$.
(6) The facts (3), (4) & (5) together imply that ε obeys the normal probability law.
(7) Sum of all possible values of each ε is 0 (zero) which together with the fact (6) implies that $E(\varepsilon) = 0$.
(8) Standard deviation of ε is unknown and small, say σ_ε.
(9) The facts (6), (7) & (8) together imply that ε obeys the normal probability law with mean 0 &standard deviation σ_ε.
Thus, $\varepsilon \sim N(0, \sigma_\varepsilon)$.

Confidence Interval

It is possible to obtain confidence interval [27 , 37 , 43 , 45 , 50] of Y.
Now, under the assumption number (9),

$$Y - \mu \sim N(0, \sigma_\varepsilon) \quad \text{or equivalently} \quad Y \sim N(\mu, \sigma_\varepsilon).$$

Also by the area property mentioned above,

(i) $P(\mu - 1.96\,\sigma_\varepsilon < Y < \mu + 1.96\,\sigma_\varepsilon) = 0.95$, (3.3)
(ii) $P(\mu - 2.58\,\sigma_\varepsilon < Y < \mu + 2.58\,\sigma_\varepsilon) = 0.99$ (3.4)
& (iii) $P(\mu - 3.00\,\sigma_\varepsilon < Y < \mu + 3.00\,\sigma_\varepsilon) = 0.9973$. (3.5)

These three properties carry the following implications:

(1) Equation (3.3) means that out of 100 observations, maximum 5 observations fall outside the interval

$$(\mu - 1.96\,\sigma_\varepsilon \;,\; \mu + 1.96\,\sigma_\varepsilon) \qquad (3.6)$$

(2) Equation (3.4) means that out of 100 observations, maximum 1 observation falls outside the interval

$$(\mu - 2.58\,\sigma_\varepsilon \;,\; \mu + 2.58\,\sigma_\varepsilon) \qquad (3.7)$$

(3) Equation (3.5) means that out of 10000 observations, maximum 27 observations fall outside the interval

$$(\mu - 3.00\,\sigma_\varepsilon \;,\; \mu + 3.00\,\sigma_\varepsilon) \qquad (3.8)$$

These three implications can be applied to determine whether the change in Y over year is significant.
These three properties also yield that the three intervals given by (3.6), (3.7) and (3.8) are respectively the 95% confidence interval, the 99% confidence interval and the 99.73% confidence interval of Y.
Again, the property given by the equation (3.5) implies that a random value of Y goes outside the interval given by (3.8) is 0.0027 which is very small. In other words, it is near certain that Y falls inside the interval that is it is natural that Y falls inside the interval. For this reason, this interval is termed as the natural interval of Y [4 , 18 , 20 , 35 , 48 , 57].

Note

The set of observations

$$Y_1, Y_2, \ldots\ldots\ldots, Y_i, \ldots\ldots\ldots, Y_n$$

constitute the population for the period from the year '1' to the year 'n'.
Thus, μ = Arithmetic Mean of $(Y_1, Y_2, \ldots\ldots\ldots, Y_i, \ldots\ldots\ldots, Y_n)$ (3.9)

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International Journal of Advanced Research in Science, Engineering and Technology
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and σ_ε^2 = Variance of (Y_1 , Y_2 , ……, Y_i, ….. , Y_n) (3.10)

Thus in order to determine the natural limits (more specifically natural upper limit and natural lower limit) of Y, it is required to determine μ and σ_ε which can be obtained by applying the relation (3.9) and (3.10) respectively.

IV. RAINFALL IN INDIA: INTERVAL ESTIMATE

The confidence interval (also the natural interval) of annual total rainfall has been estimated from the data, for the years 1960 onwards, on annual total rainfall at 41 stations in India. It has also been examined whether the observed values annual total rainfall for each of the 41 stations lie within the corresponding interval obtained.

Findings obtained in this study have been presented below:

(A) 99 % Confidence Interval

Table – 1
(99 % Confidence Limits of Annual Total Rainfall)

Name of Station	Lower Limit (in mm)	Upper limit (in mm)	Name of Station	Lower limit (in mm)	Upper limit (in mm)
Agartala	7017.3438	34652.564	Lucknow	0	22907.8895
Ahmedabad	0	16976.24	Mumbai	8587.428	36317.92
Allahbad	136.2284	18104.090	Nagpur	1883.6833	19143.8687
Amritsar	13.52486	14221.121	New Delhi	447.4668	14543.4432
Bangalore	3537.56	16010.332	Palam (A)	0	16341.986
Bhopal	1127.568	21642.543	Panjim	12596.4244	43135.8786
Bhubaneswar	7248.288	22793.996	Patiala	0	19292.9898
Bhunter (A)	0	19124.783	Patna (A)	0	22679.664
Chandigar	0	23963.888	Pondicherry	729.4848	25869.4242
Chandigarh(A)	0	21584.553	Port Blair	13986.043	44459.8989
Chennai	2514.5342	24204.7765	Pune	2680.0466	12110.002
Dehradun	3904.282	36303.2632	Shillong (A)	4504.664	40767.334
Dhubri	0	43983.119	Shillong/C.S.O.	7101.542	35949.4543
Dibrugarh	15748.9468	36759.4343	Silchar	4950.0664	52928.8766
Guwahati	9377.0484	25153.3327	Simla	0	33147.9943
Hissar	0	12591.004	Srinagar (A)	569.6648	12735.224
Hyderbad (A)	1688.2256	15066.59	Tezpur	0	37266.0808
Imphal	2918.5546	24994.0808	Trivandrum	7922.4432	26770.5654
Jaipur	0	14178.6869	Udaipur	0	12496..066
Jammu (A)	1141.2469	21151.775	Varanasi	0	19702.423
Kolkata	7685.459	27982.227			

(B) Significance of Change

It has been found that almost all the observed values of annual total rainfall for each of the 41 stations lie within the corresponding natural intervals presented in **Table – 2**. This implies that there is no any significant cause that influences upon the total rainfall in the context of India over years i.e. annual total rainfall in each of the 41 stations in India has not been changing (since 1969) over years significantly. The changes occurred in them are due to the chance causes only.

(C) Natural Interval

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Table – 2
(Natural Interval of Annual Total Rainfall)

Name of Station	Lower Limit (in mm)	Upper limit (in mm)	Name of Station	Lower limit (in mm)	Upper limit (in mm)
Agartala	7018.648	34653.19	Lucknow	0	22909.91
Ahmedabad	0	16977.78	Mumbai	8586.652	36318.04
Allahbad	135.0784	18105.55	Nagpur	1878.838	19146.96
Amritsar	13.71367	14222.95	New Delhi	446.284	14544.5
Bangalore	3535.12	16011.38	Palam (A)	0	16343.37
Bhopal	1126.521	21643.61	Panjim	12587.51	43137.42
Bhubaneswar	7246.744	22794.04	Patiala	0	19294.46
Bhunter (A)	0	19125.98	Patna (A)	0	22681.88
Chandigar	0	23964.28	Pondicherry	728.5158	25871.88
Chandigarh(A)	0	21585	Port Blair	13920.1	44461.9
Chennai	2502.218	24206.88	Pune	2675.6777	12111.53
Dehradun	3819.64	36304.28	Shillong (A)	4495.731	40768.27
Dhubri	0	43984.21	Shillong/C.S.O.	7092.879	35951.69
Dibrugarh	15647.75	36760.49	Silchar	4945.705	52930,18
Guwahati	9360.741	25154.43	Simla	0	33149.25
Hissar	0	12592.91	Srinagar (A)	568.026	12736.3
Hyderbad (A)	1629.815	15066.59	Tezpur	0	37268.66
Imphal	2905.96	24995.07	Trivandrum	7985.595	26771.07
Jaipur	0	14179.05	Udaipur	0	12498.39
Jammu (A)	1133.914	21152.814	Varanasi	0	19730.14
Kolkata	7683.686	27983.39			

V. SIGNIFICANCE OF CHANGE IN RAINFALL

Here, an attempt has been made on a study of the change in number of rainy days at a location. Analysis of variance *[33, 35, 39, 41 , 55], abbreviated as AOV*, discovered by Ronald A. Fisher [45 , 33] is a statistical tool that can be applied in knowing whether there exists any significant assignable cause in a region which compels the rainfall in the region to be changed. It is possible to apply this tool in determining forecasted interval value with desired degree of confidence.
Let X_{ij} be the number of rainy days observed at a location in the month " j " of the year " i " ($i = 1 , 2 . 3 , \ldots\ldots\ldots\ldots , 12$ & $j = 1 , 2 , 3 , \ldots\ldots\ldots\ldots\ldots , n$).
There are two sources of variation occurred in the data namely month and year.
The AOV technique can be applied to these data to test (1) whether the difference of among the numbers of rainy days in the months is significant and (2) whether the difference of among the numbers of rainy days over the years is significant. The data , in this case, can be classified in two way classification table with one observation per cell. Accordingly, the analysis of these data follows the AOV of two way classified data with single observation per cell *35 , 39 , 41]*.
Now, "the difference of among the numbers of rainy days over the years is insignificant" means/implies that there is no assignable cause of variation in the data due to the change of years. Thus, if the difference of among the numbers of rainy days over the years is found to be insignificant then one can conclude that there is no assignable cause of variation (in the data) that arises due to change of year and hence it can be accepted that the current picture of rainy days will prevail in future. If the said difference is found to be significant then there exist assignable cause(s) of variation (in the data) that occurs due to change in year and hence it can be accepted that the current picture of rainy days may not prevail in future. However, in this case, it is required to test the difference between the effects of each pair of years. This is necessary due to the reason that The AOV can show the difference among the effects of the years as significant due to the significance of the difference between the effects of a single pair of years even if the difference between the effects of each of the other pairs of years is insignificant.

ISSN: 2350-0328

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VI. RAINFALL IN INDIA: SIGNIFICANCE OF CHANGE

The significance of the change of number of rainfalls studied from the data, for the years 1960 onwards, on number of rainy days (monthly) at 41 stations in India.
Findings obtained in this study have been presented below:

Table – 3
Findings of AOV

Station	Significance of Change in			
	Heaviest 24 Hours Rainfall		Rainy Days (Monthly)	
	Over Year	Over Month	Over Year	Over Month
Agartala	Insignificant	Significant**	Significant**	Significant**
Ahmedabad	Significant**	Significant**	Significant**	Significant**
Allahbad	Significant**	Significant**	Significant**	Significant**
Amritsar	Insignificant	Significant**	Insignificant	Significant**
Bangalore	Significant**	Significant**	Insignificant	Significant**
Bhopal	Significant**	Significant**	Significant**	Significant**
Bhubaneswar	Insignificant	Significant**	Insignificant	Significant**
Bhunter (A)	Insignificant	Significant**	Significant**	Significant**
Chandigar	Significant**	Significant**	Insignificant	Significant**
Chandigarh(A)	Significant**	Significant**	Significant**	Significant**
Chennai	Insignificant	Significant**	Insignificant	Significant**
Dehradun	Insignificant	Significant**	Insignificant	Significant**
Dhubri	Significant**	Significant**	Significant**	Significant**
Dibrugarh	Insignificant	Significant**	Significant**	Significant**
Guwahati	Insignificant	Significant**	Significant**	Significant**
Hissar	Insignificant	Significant**	Significant**	Significant**
Hyderbad (A)	Insignificant	Significant**	Significant**	Significant**
Imphal	Significant**	Significant**	Significant**	Significant**
Jaipur	Insignificant	Significant**	Significant**	Significant**
Jammu (A)	Insignificant	Significant**	Insignificant	Significant**
Kolkata	Insignificant	Significant**	Significant**	Significant**
Lucknow	Significant**	Significant**	Significant**	Significant**
Mumbai	Insignificant	Significant**	Significant**	Significant**
Nagpur	Significant**	Significant**	Significant**	Significant**

Table – 3 Continued
Findings of AOV

Station	Significance of Change in			
	Heaviest 24 Hours Rainfall		Heaviest 24 Hours Rainfall	
	Over Year	Over Month	Over Year	Over Month
New Delhi	Significant**	Significant**	Significant**	Significant**
Palam (A)	Insignificant	Significant**	Significant**	Significant**
Panjim	Significant**	Significant**	Significant**	Significant**
Patiala	Insignificant	Significant**	Insignificant	Significant**
Patna (A)	Insignificant	Significant**	Significant**	Significant**
Pondicherry	Insignificant	Significant**	Significant**	Significant**

Port Blair	Significant**	Significant**	Significant**	Significant**
Pune	Insignificant	Significant**	Insignificant	Significant**
Shillong (A)	Insignificant	Significant**	Insignificant	Significant**
Shillong/C.S.O.	Significant**	Significant**	Significant**	Significant**
Silchar	Insignificant	Significant**	Significant**	Significant**
Simla	Insignificant	Significant**	Significant**	Significant**
Srinagar (A)	Insignificant	Significant**	Insignificant	Significant**
Tezpur	Significant**	Significant**	Significant**	Significant**
Trivandrum	Insignificant	Significant**	Insignificant	Significant**
Udaipur	Significant**	Significant**	Significant**	Significant**
Varanasi	Significant**	Significant**	Significant**	Significant**

Significant** means highly significant.

VII. CONCLUSION

The findings presented in Table – 1 means that the annual total rainfall at each station will fall within the corresponding interval, shown in Table – 1, in more than 99 years out of 100 years selected at random provided the rainfall is not affected by any assignable cause in future. Similarly, the findings presented in Table – 2 can be interpreted.
The current study is based on the following assumptions:
(1) The facts and figures on the annual total rainfall collected from the 41 stations are free from mechanical errors (i.e. errors due to the machine / tool having unknown defect / defects and due to wrong handling of machine / tool).
(2) The facts and figures observed have been recorded correctly.
(3) Data on the characteristics mentioned in (1) are free from inconsistency.
(4) Chance errors associated to the observations are independently and identically distributed with normal probability distribution having zero means and a common unknown variance.
Thus, the findings obtained in this study are reasonable / meaningful if these assumptions hold good. If any or all of the assumptions is (are) not true, the findings obtained in the study are bound to be questionable.
The following two results may be important to the meteorological and environmental scientists and for the society also:
(1) It is possible to apply the area property of normal distribution to know whether there exists any significant assignable cause in a region which forces the rainfall in the region to be changed and to determine forecasted interval value on this climatic component.
(2) There is no any significant cause that influence upon the changes in rainfall, in the 41 stations over years. The changes, occurred since 1969, are due to the chance causes only.
Finally, from the meaning of research [61 , 62 , 63 , 64], it can be concluded that the extraction of the information on the interval estimate and the significance of change in rainfall in India as described above, can be regarded as research findings carrying high significance in the meteorological data analysis.

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ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
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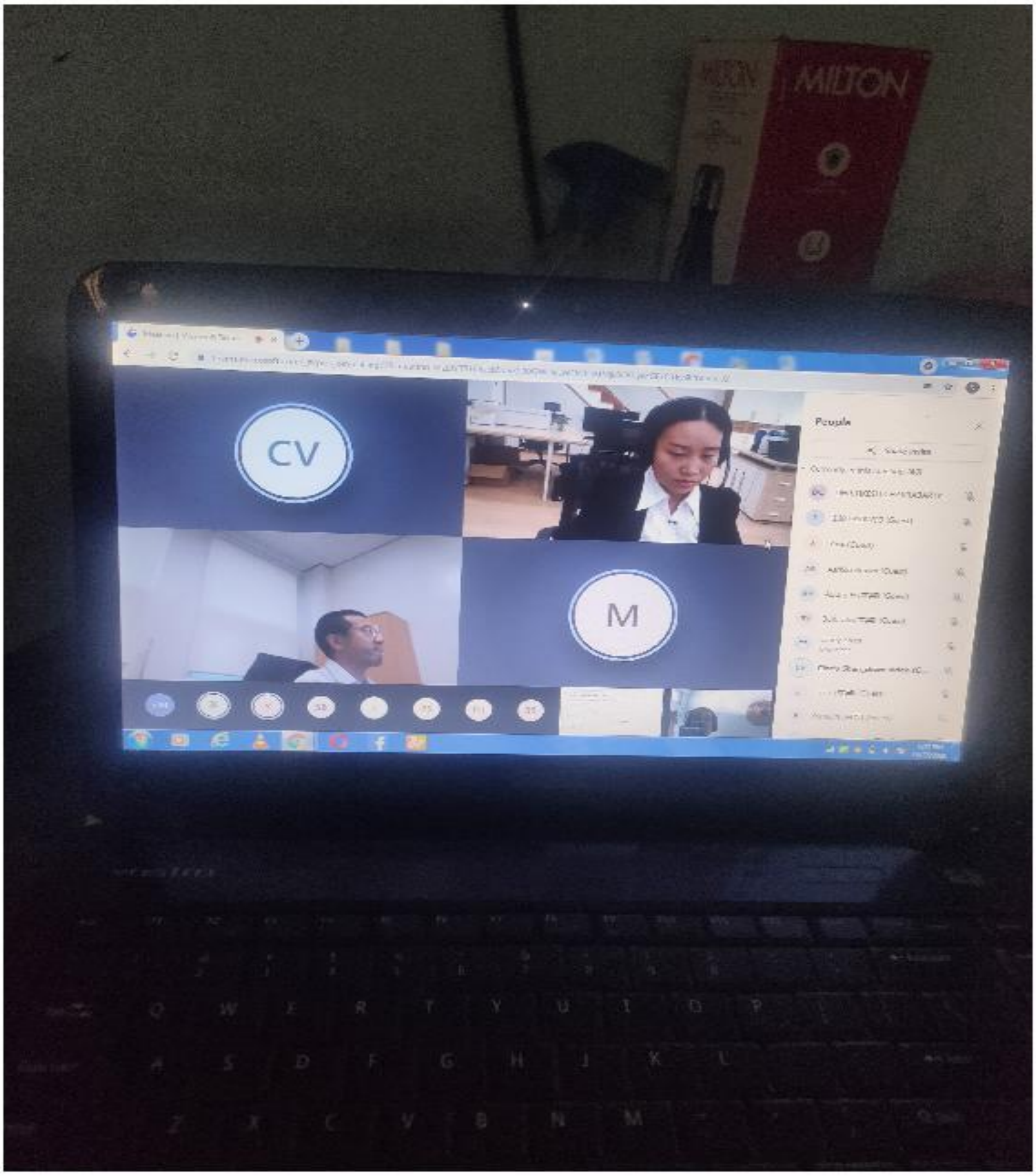

(Dr. Dhritikesh Chakrabarty (in the bottom) presenting an invited paper (*ONLINE via MS Teams*) in The 7th International Conference on Fuzzy Systems and Data Mining (FSDM 2021) held in Seoul, South Korea during *October 26 ─29, 2021*)

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ISSN: 2350-0328
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Dr. Dhritikesh Chakrabarty is also an awardee of the Post Doctoral Research Award by the University Grants Commission for the period 2002 – 05.

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