Variation of Total Ozone Concentration and Rainfall over Different Stations of India.

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ABSTRACT

This paper presents the significant relationship between total ozone concentration and rainfall over some important stations of India. Analysis shows that low temperature of troposphere, presence of sufficient water vapor, and CCN (Cloud Condensation Nuclei) are not the sufficient conditions of rainfall. Critical analysis is done and the following important results are obtained:

(i) Depletion of ozone concentration effects rainfall. For all stations we have considered rainfall increases and ozone decreases with the increase of time.

(ii) Rain occurs only when ozone concentration lies in a certain concentration level.

(iii) Using analysis of variance we can conclude that effects of different classes of ozone concentration are same on rainfall variation. For Delhi, we can conclude that there is a significant difference between the average monsoon rainfall due to classes 265.80 – 273.80, 281.80 – 289.80 and no significant differences among the others. Rainfall is more affected by 265.80 – 273.80 class of ozone concentration.

(iv) Possible explanations based on physical considerations and chemical kinetics of O_3 formation and destruction mechanisms are also presented.

(Keywords: ozone depletion, stratosphere, Cloud Condensation Nuclei, precipitation).

INTRODUCTION

Ozone is a minor constituent of the atmosphere. It is mainly distributed in the stratosphere. Ozone is mainly found in two regions of the Earth's atmosphere. Most ozone (about 90%) resides in a layer between approximately 10 and 50 km above the Earth's surface, in the region of the atmosphere called the stratosphere. The remaining ozone is in the lower region of the atmosphere, the troposphere.

The total column ozone indicates both the tropospheric as well as stratospheric ozone over a specified region. It absorbs dangerous solar UV rays and plays an important role to control the chemical kinetics of lower and upper atmospheric constituents. WMO Bulletin (1992) confirms that O_3 is depleted everywhere with smaller amounts but dramatic decreases of O_3 concentration takes place only over Antarctica during spring time.

It is well established that stratospheric ozone controls different environmental parameters and a definite correlation exists between weather conditions in the troposphere and ozone content in the stratosphere. Dobson et al. [2] reported that a fall in ozone content in the stratosphere takes place over England before the arrival of warm fronts at the ground surface. They also reported that the rise in ozone content in the stratosphere takes place when cold fronts reach near the ground level.

Mitra [3] reported the close relationship between barometric height, tropospheric weather, and ionospheric parameters of the upper atmosphere. It was observed that minimum height of F region and average E ionization tend to follow the variation of barometric height. Mitra [3] also mentioned that correlation was observed between lowest virtual height of E region and ground temperature at Stanford, California, USA.

Midya et al. [4] have shown that relative humidity and ozone concentration over Calcutta is well correlated. In another literature publication, Midya et al. [5] also showed that surface temperature is directly related with ozone concentration over Calcutta. Rain is an important parameter of our environment. The purpose of this paper is to investigate the correlation between ozone concentration and rainfall over different stations of India.

OBSERVATIONS AND RESULTS

Rainfall data and corresponding ozone data for different stations are taken from the following web sites:

http://grads.iges.org/India/Partha.subdiv.html and http://jwocky.gsfc.nasa.gov.

Rainfall data used here is average of June, July, August, and September of every year (monsoon period). Corresponding mean ozone data of same stations or of the very nearest station for the same period is taken into consideration. Figures 1(a) – 6(a) show the variation of ozone concentration; Figures 1(b) - 6(b) show the variation of monsoon rainfall; and Figures 1(c) - 6(c) show the variation of monsoon rainfall with corresponding ozone concentration for different stations over India for the period (1979-1998).

It is clear from these figures that ozone concentration decreases, monsoon rainfall increases with time and monsoon rainfall occurs only when ozone concentration reaches to a certain concentration level along with other parameters of precipitation. This level slightly differs from station to station and it confirms latitudinal variations of ozone concentration for which rainfall takes place.

Figure 3a shows the variation of ozone concentration for long period since 1979 to 1998 over New Delhi. The meteorological parameter, monsoon rainfall is included synoptic scale of measurement which covers hundreds to thousands of kilometers.

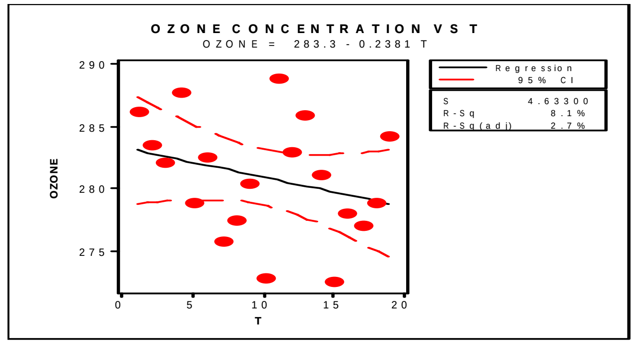

Figure 1a: Variation of Ozone Concentration.

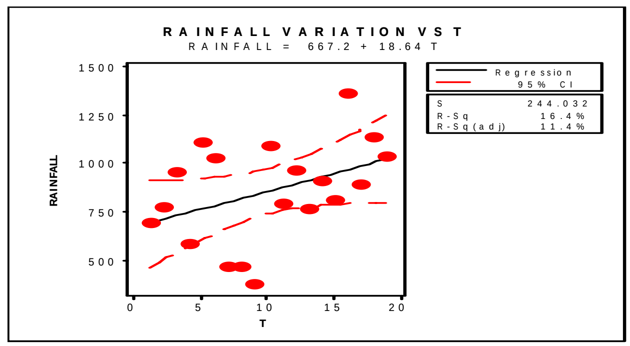

Figure 1b: Variation of Corresponding Rainfall.

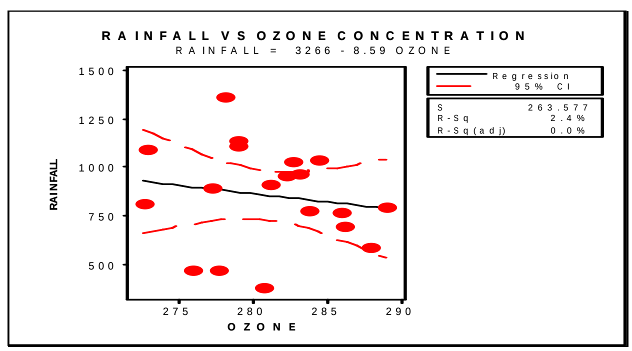

Figure 1c: Variation of Rainfall with the Variation of O_3 Concentration over Ahmedabad during the period 1979 to 1998.

Figure 1: Station- Ahmadabad.

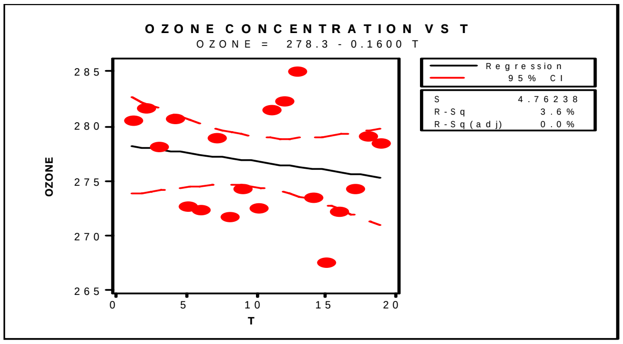

Figure 2a: Variation of Ozone Concentration.

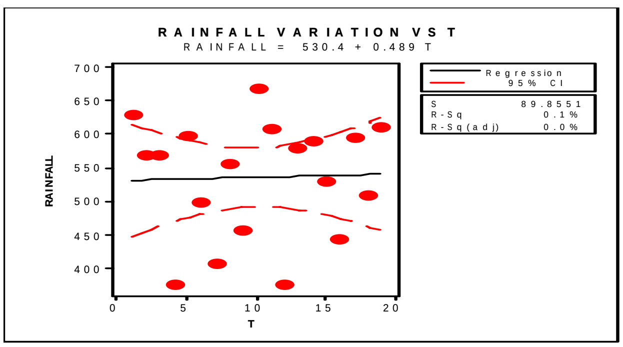

Figure 2b: Variation of Corresponding Rainfall.

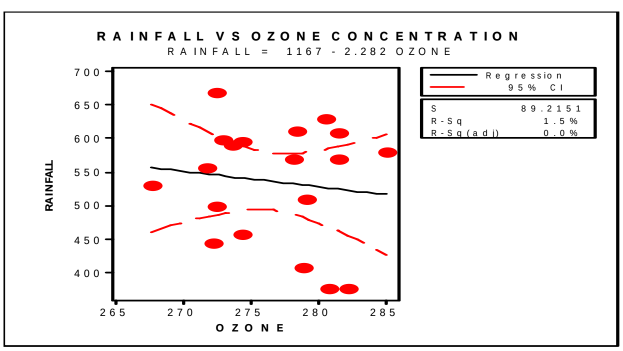

Figure 2c: Variation of Rainfall with the Variation of O_3 Concentration over Bangalore during the period 1979 to 1998.

Figure 2: Station- Bangalore.

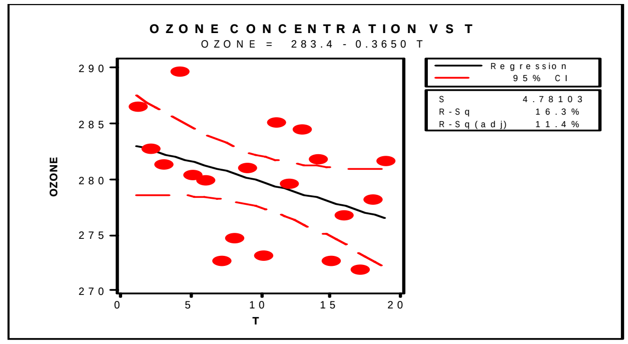

Figure 3a: Variation of Ozone Concentration.

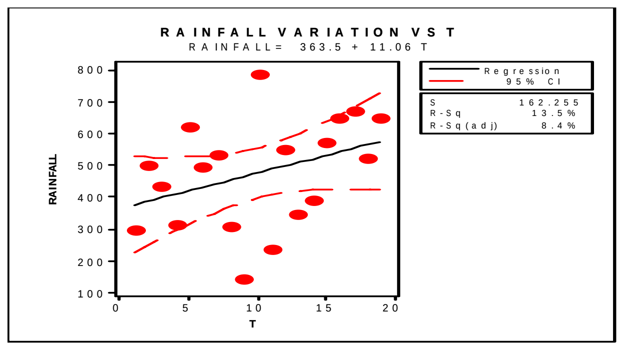

Figure 3b: Variation of Corresponding Rainfall.

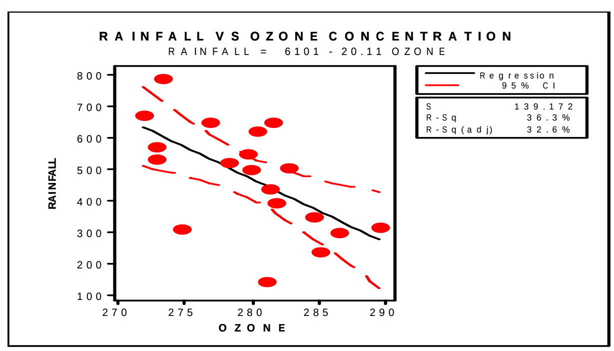

Figure 3c: Variation of Rainfall with the Variation of O_3 Concentration over Delhi during the period 1979 to 1998.

Figure 3: Station- Delhi.

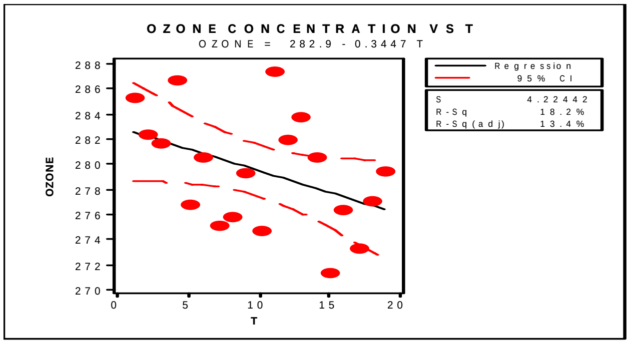

Figure 4a: Variation of Ozone Concentration.

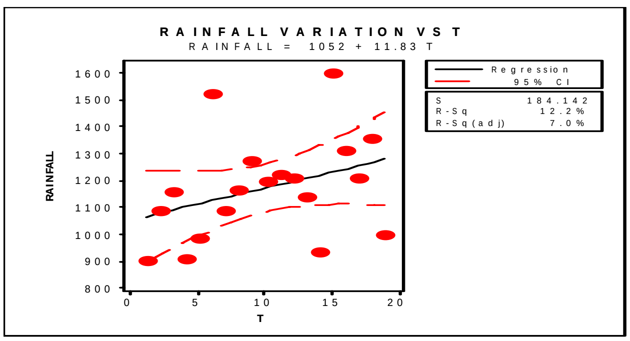

Figure 4b: Variation of Corresponding Rainfall.

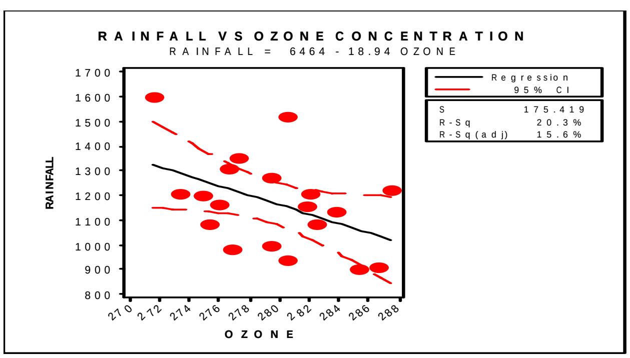

Figure 4c: Variation of Rainfall with the Variation of O_3 Concentration over Dumdum during the period 1979 to 1998.

Figure 4: Station- Dumdum.

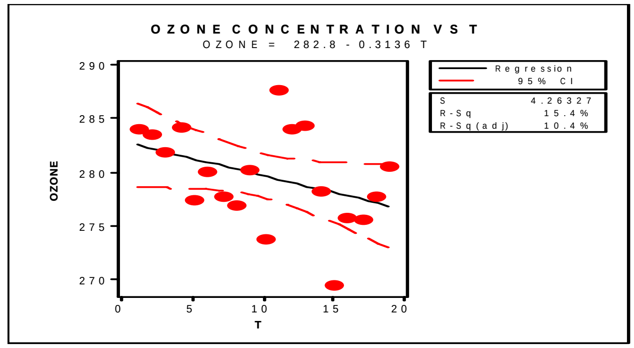

Figure 5a: Variation of Ozone Concentration.

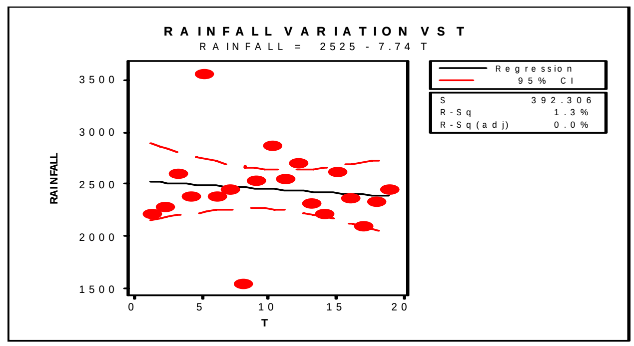

Figure 5b: Variation of Corresponding Rainfall.

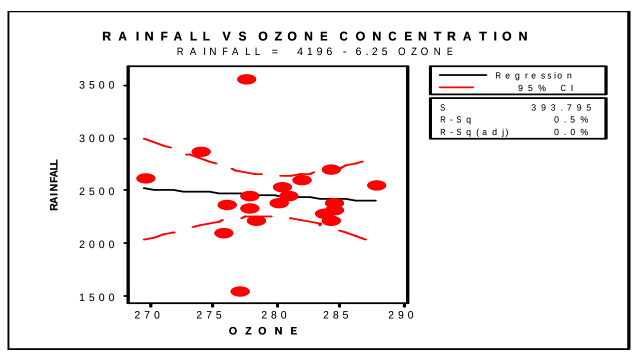

Figure 5c: Variation of Rainfall with the Variation of O_3 Concentration over Poona during the period 1979 to 1998.

Figure 5: Station- Poona.

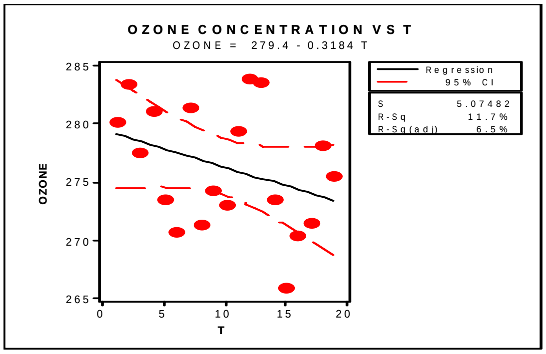

Figure 6a : Variation of Ozone Concentration.

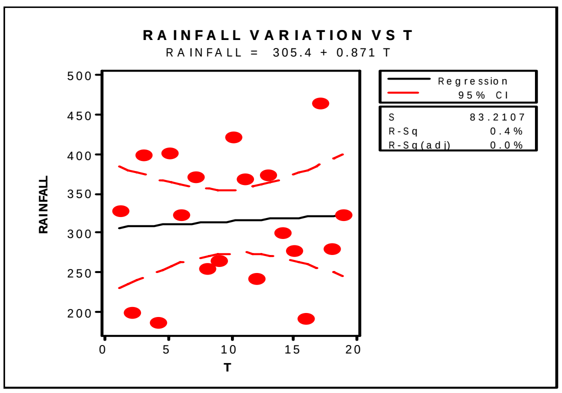

Figure 6b: Variation of Corresponding Rainfall.

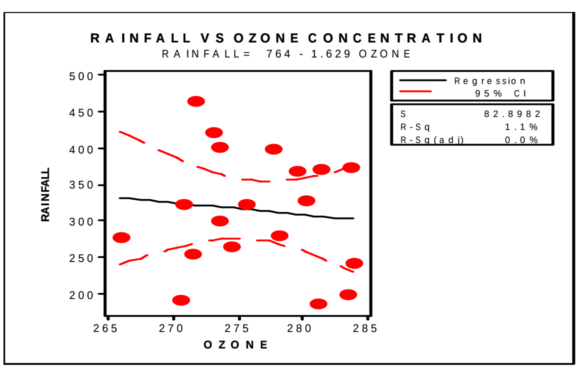

Figure 6c: Variation of Rainfall with the Variation of O_3 Concentration over Tamilnadu during the period 1979 to 1998.

Figure 6: Station- Tamilnadu.

So in absence of rainfall data over New Delhi, rainfall data of Haryana is used because these two stations are very near to each other. Figure 3b shows the variation of rainfall over Haryana and it is clear that monsoon rainfall also increases with time just like other stations.

The stations at Mumbai and Trivandrum lie on the seashore and monsoon rainfall may be affected due to the special meteorological conditions of those two stations. So we exclude those two stations from our analysis.

Statistical analysis of the variation of ozone concentration and monsoon rainfall over different stations throughout India for the period 1979 – 1998 is given in Tables 1, 2, and 3. Ranges of ozone concentration for which rainfall takes place for different stations are shown in Table 4.

Maximum and minimum variations of ozone concentration and rainfall variation during the period 1979-1998 for different stations are shown in Figures 7 and 8. It clearly shows that the nature of variation of two parameters follows the same trend for different stations. In the case of Dumdum, station daily rainfall data throughout year for the period 1996-1999 is collected from Alipore Meteorological station, because these two stations are very near to each other (Figure 9).

The results also confirm that rainfall takes place for a particular range of ozone concentration just like monsoon rainfall of other stations. So it may be concluded that the rainfall takes place when ozone concentration attains a particular range for a particular station and this is valid not only for monsoon period but also for other days of a year (Dumdum data is considered for all days throughout year for the period 1996-1999).

DISCUSSIONS

Results of these observations can be explained from three considerations. They are as follows:

A. From Statistical Analysis

At first we grouped all observations (rainfall) with respect to ozone concentration into four classes i.e. 265.80 – 273.80, 273.80 – 277.80, 277.80 – 281.80, 281.80 – 289.80 for different stations of India.

Table 1: ANOVA Table.

Stations →	Ahmedabad	Delhi	Poona	Tamil Nadu	Bangalore	Dumdum
S.S.O	280833.8	206985.1	208895.7	8295.304	9946.404	162327.5
S.S .E	929489.4	310235	2441628	109844.9	127447	493900.4
D.F.O	3	3	3	3	3	3
D.F.E	15	15	15	15	15	15
M.S.O	93611.26	68995.04	69631.9	2765.101	3315.468	54109.15
M.S.E	61965.96	20682.33	162775.2	7322.994	8496.465	32926.69
F	1.510689	3.335941	0.42778	0.377592	0.390217	1.643322
$F_{.05\,;\;3,15}$	3.287382	3.287382	3.287382	3.287382	3.287382	3.287382

S.S.O: - Sum of squares due to different class of ozone concentration
S.S.E: - Sum of squares due to error
M.S.O.:- Mean square due to different class of ozone concentration
M.S.E:- Mean square due to error
D.F.O.:- Degrees of freedom for S.S.O
D.F.E.:- Degrees of freedom for S.S.E
F = M.S.O. / M.S.

Table 2: Analysis of Rainfall Variation and Ozone Concentration for Different Stations over India.

Number of stations considered	Rainfall (Min)	Rainfall (Max)	Ozone (Min)	Ozone (Max)
6 (considering all stations of Table 1)	Average Rainfall X = 588	Average Rainfall X = 1407	Average Ozone concentration X = 269.79	Average Ozone concentration X = 287.15
	σ = 544	σ = 1138	σ = 2.63	σ = 2.24
	(σ / X) *100 =CV = 92.48%	(σ / X) *100 =CV = 80.88%	(σ / X) *100 =CV = .97%	(σ / X) *100 =CV = .78%

Table 3: Statistical Analysis of the Variations of Ozone Concentrations and Monsoon Rainfall over Different Stations throughout India for the Period 1979 to 1998.

Name of stations	Empirical relations between rainfall and O_3 concentration R.F. = stands for rainfall	Correlation coefficient
1. Ahmedabad	R.F. = -8.59 O_3 + 3265.63	R = - 0.16
2. Bangalore	R.F. = -2.28 O_3 + 1166.9	R = - 0.12
3. Dumdum	R.F. = -18.94 O_3 + 6463.6	R = - 0.45
4. Poona	R.F. = -6.25 O_3 + 4195.9	R = - 0.07
5. Tamilnadu	R.F. = -1.63 O_3 + 764.02	R = - 0.11
6. Delhi	R.F. = -20.12 O_3 + 6100.7	R = - 0.6

Table 4: Ranges of Ozone Concentration for which Rainfall takes place for Different Stations.

Name of Stations	Rainfall (Min)	Rainfall (Max)	Ozone (Min)	Ozone (Max)
Ahmedabad	371.9	1361.9	272.53	288.9
Bangalore	374.6	669.6	267.62	285.13
New Delhi	142.4	785.7	271.88	289.78
Tamilnadu	185.2	465.9	265.89	283.91
Dum Dum	903.6	1601.2	271.42	287.45
Poona	1550.2	3555.5	269.42	287.74

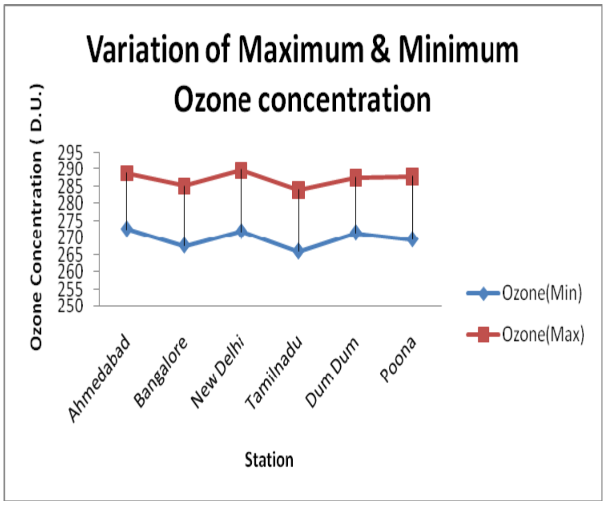

Figure 7: Variation of Maximum and Minimum of O_3 Concentration for Different Stations over India during the period 1979-1998.

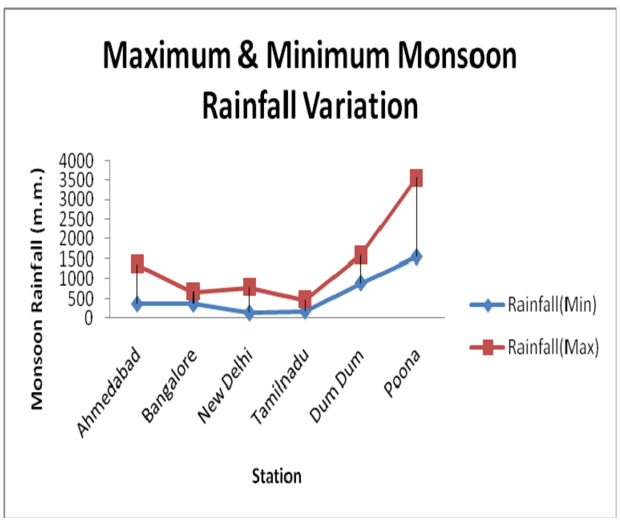

Figure 8: Maximum and Minimum Monsoon Rainfall Variation of Different Indian Stations for the period 1979-1998.

Now we want to find out which class of ozone concentration is most responsible for rainfall by ANOVA (one way classified data with fixed effects model).

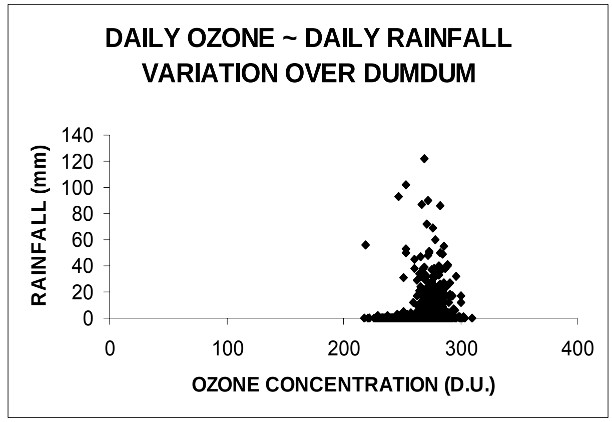

Figure 9: Daily Rainfall Variation with Corresponding Ozone Concentration over Dumdum during the period 1996 – 1999.

Model

Here we use the model $y_{ij} = \mu + \alpha_i + e_{ij}$, i = 1, 2, 3, 4;

j= 1, 2,……. n_i, n_i is the no. of observations in the i-th class.

$\sum_{i=1}^{4} n_i = n$ = total no. of observations = 19(for each station)

y_{ij} is the j-th observation due to i-th class of ozone concentration.

$\mu =$ General effect.

α_i = additional effect due to i-th class of ozone concentration.

e_{ij} is the random error follows i.i.d N ($0, \sigma^2{}_e$).

Also we assume that $\sum_{i=1}^{4} \sum_{j=1}^{n_i} \alpha_i = 0$.

Hypothesis

Here we want to test the hypothesis

$$H_0 : \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = 0$$

against the alternative hypothesis

$$H_1 : all\ \alpha_i 's\ are\ not\ same.$$

Conclusion from Statistical Analysis

Since for Ahmedabad calculated F (= 1.510689); for Poona calculated F(= 0 .42778); for Tamil Nadu calculated F(= 0.377592); for Bangalore calculated F(= 0.390217); for Dumdum calculated F(= 1.643322) .

All are < tabulated $F_{.05;3,15}$ (= 3.287382) ,so we accept the null hypothesis (i.e., the effect due to different classes of ozone concentration on rainfall are same).

Since for Delhi calculated F (= 3.335941) > tabulated $F_{.05;3,15}$ (= 3.287382).

So we reject the null hypothesis (i.e., the effect due to different classes of ozone concentration are not same).

Now we want to find out which class is more effective. Here, our null hypothesis is $H_{01} : \alpha_i = \alpha_{i'}$, $\forall i \neq i'$ against $H_{11} : \alpha_i \neq \alpha_{i'}$.

y_{i0} is the average rainfall for the i-th class of ozone concentration.

y_{10} = 638.85,

y_{20} = 476.55,

y_{30} = 488.24,

y_{40} = 46.95.

Since,

$$y_{10} - y_{30} = 150.61 < t_{.025,15} * \sqrt{\left(\frac{1}{4} + \frac{1}{7}\right) * MSE}\ (= 192.088)$$

$$y_{10} - y_{20} = 162.3 < t_{.025,15} * \sqrt{\left(\frac{1}{4} + \frac{1}{2}\right) * MSE}\ (= 265.532)$$

$$y_{10} - y_{40} = 291.6 > t_{.025,15} * \sqrt{\left(\frac{1}{4} + \frac{1}{6}\right) * MSE}\ (= 197.82)$$

$$y_{30} - y_{20} = 116.9 < t_{.025,15} * \sqrt{\left(\frac{1}{2} + \frac{1}{7}\right) * MSE}\ (= 245.72)$$

$$y_{30} - y_{40} = 141.29 < t_{.025,15} * \sqrt{\left(\frac{1}{7} + \frac{1}{6}\right) * MSE}\ (= 170.50)$$

$$y_{20} - y_{40} = 129.6 < t_{.025,15} * \sqrt{\left(\frac{1}{2} + \frac{1}{6}\right) * MSE}\ (= 250.23)$$

So, we can conclude that there is a significant difference between the average rainfall due to classes 265.80 – 273.80 and 281.80 – 289.80 and no significant differences among the others. Rainfall is more affected by the 265.80 – 273.80 class of ozone concentration for Delhi.

B. From Physical Consideration

Mechanism of Rainfall

1. Enough solar radiation is essential to evaporate sufficient amount of water-vapor to form a large cloud for heavy rainfall. Updraft of the air containing the water-vapor is required. The ascent should be such that no hot dry air can mix up with this air. The core of this air must not be very large in size and should have intense updraft tendency. Common atmospheric particles (such as common salt crystals) are essential to form cloud. These particles are called Cloud Condensation Nuclei (CCN).

2. To have heavy rainfall from this cloud, the cloud must contain ice crystals (i.e., the top of the cloud must be at a temperature less than the freezing point of water).

3. In the absence of CCN, heavy rain cannot occur even when the temperature of the top is as below as -30^{0}C. Generally, rain occurs when this temperature is about -5 to -10 ^{0}C. To have such a

temperature, the cloud must be a large one or it must enter the stratosphere.

4. The relationship between monsoon rainfall and El Nino (rise of sea surface temperature of the Pacific Ocean) is now well established. It is reported that if El Nino takes place in central Pacific Ocean, it leads to severe drought in India and if it takes place in the eastern Pacific, its impact on Indian monsoon is less severe.

Dependence of Rainfall on O_3 Concentration

O_3 concentration is maximum at a height of about 25 km above sea level [6]. UV rays contain high energy photons which decompose ozone into oxygen. Ozone of the stratosphere absorbs maximum of the incoming UV photons resulting a warm ozonosphere. But, it resists the photons to fall directly on the clouds of the troposphere whose maximum height is about 18 km above from the sea level. Hence it resists the unwanted warming of cloud by UV rays and the high concentration of ozone in the stratosphere helps heavy rainfall.

The net reaction for the formation of ozone in the stratosphere is given below:

$$O_2 + O_2 \rightarrow O_3 + O$$
$$O + O_2 + M \rightarrow O_3 + M$$
$$\overline{\qquad\qquad\qquad\qquad}$$
$$3\,O_2 \rightarrow 2\,O_3$$

It is shown by Midya et al. [7] that if we consider that the reaction is endothermic, this helps us to explain the dramatic decrease of ozone concentration over Antarctica during spring time. So the higher temperature of the stratosphere will favor the higher equilibrium concentration of ozone. Thus when the temperature of the stratosphere increases by absorbing solar radiation, this will try to attain higher ozone concentration of stratosphere. This also helps to attain low temperature of troposphere and heavy rainfall. When stratospheric ozone is depleted, solar UV ray falls directly on troposphere. As a result temperature of stratosphere decreases and that of troposphere increases. This helps to attain an unfavorable condition of rainfall.

This mechanism will be applicable only when the first 3 steps of rain mechanism occur properly. As such, we can get high concentration of ozone for any station but a very poor rain fall (sometimes not at all) due to the absence of the first 3 steps properly. Although this is the main mechanism of rain fall, less intense rain (showers) can occur even when the cloud does not contain ice crystals at all. But, the presence of CCN is essential for heavy rainfall. From our analysis, it is confirmed that stratospheric ozone concentration must be at a certain concentration level in order to obtain sufficient rainfall.

C. From Chemical Kinetics

O_3 is created in the atmosphere due to the decomposition of water molecules in the atmosphere. Special ozone destruction chemical reactions are responsible for the decrease of O_3 concentrations. Different formation and destruction processes of ozone are given bellow:

Reactions	Rate Constants
1. $O_3 + h\nu \xrightarrow{I_{abs}} O_3^*$	I_{abs}
2. $O_3^* \xrightarrow{K_1} O_2 + O$	K_1
3. $O + O_3 \xrightarrow{K_2} 2O_2$	K_2
4. $O + O^*_3 \xrightarrow{K3} 2O_2$	K_3
5. $O + O \xrightarrow{K_4} O_2$	K_4
6. $O + O_2 \xrightarrow{K_5} O_3$	K_5

Midya et al. [8] established an empirical equation of O_3 concentration with the concentrations of other atmospheric constituents:

$$[O_3] = \{K_5[O_2]/K_2\} - \{I_{abs}/K_2[O]\} - \{1/K_2[O]\}\exp[-K_2[O](K_{10}+t)]$$

$[O_3]$, $[O_2]$, and $[O]$ are the concentrations of ozone, molecular oxygen, and atomic oxygen, respectively. I_{abs} and all K values are the rate constants of different reactions.

From analysis, all of the rate constants are calculated by Midya et al. [8]. From the equation it is clear that O_3 concentration depends on concentrations of atomic and molecular oxygen.

Midya et al. [9] showed that the minor constituent N_2O plays important role in the depletion of ozone in the stratosphere. In another report, Midya et al. [10] have also showed that CH_3CN plays an important role in the formation of ozone in the troposphere. It may be concluded that due to the increase of N_2O and other ozone depleting substances in the atmosphere, stratospheric ozone concentrations over Indian stations slightly decrease with time. As a result, atomic and molecular oxygen are produced due to the decomposition of H_2O molecules in the troposphere. This is done by unabsorbed solar UV ray by Ghosh and Midya [11] as given below:

$$H_2O \rightarrow H + OH$$
$$OH \rightarrow O + H$$
$$O + O + M \rightarrow O_2 + M$$

Decrease of rainfall due to the decomposition of water molecules is quite expected. Again, atomic oxygen, molecular oxygen and CH_3CN help to increase tropospheric ozone concentration and it acts as greenhouse gas. As a result, the temperature of the troposphere increases and this also decreases the probability of rain.

Monsoon rainfall is a very complex process. It not only depends on ozone concentration but also on CCN, humidity, temperature, El-Nino, etc. Table 3 provides the statistical analysis of which gives the empirical relations between monsoon rainfall and stratospheric ozone concentrations for different stations. Poor correlation coefficients confirm that monsoon rainfall depends on different factors mentioned earlier. In this study, we conclude that monsoon rainfall starts when ozone concentration reaches to a certain concentration level and monsoon rainfall decreases with the increase of ozone concentration.

Our result fairly agrees with WMO bulletin (1992) which confirms that O_3 is depleted everywhere with smaller amount but dramatic decrease of O_3 concentration takes place over Antarctica during spring time. The dramatic decrease of ozone concentration over Antarctica is due to its some special meteorological condition. Midya et al [9] showed in a previous study that N_2O plays important role in the depletion of stratospheric O_3. Decrease of O_3 concentrations over India may be due to the increase of N_2O over India. As a result solar UV ray passes through the stratosphere and transfer the greenhouse gas N_2O of troposphere to NO as follows:

$$N_2O + hv \longrightarrow N_2 + O(^1D)$$

$$N_2O + O(^1D) \longrightarrow 2NO$$

These NO molecules initiate the depletion process of O_3. The major portion of solar UV ray is utilized to decompose N_2O. Thus the probability of decomposition of water molecules of troposphere by solar UV rays which passes through the stratosphere during monsoon period is restricted and it increases the probability of monsoon rainfall.

Unabsorbed high energetic solar UV rays fall on the surface of the earth and increases the evaporation rate. This increases the probability of rainfall. Ozone is mainly distributed in the stratosphere. So the depletion of total ozone concentration may be considered mainly due to the depletion of stratospheric ozone. Thus decrease of monsoon rainfall with the increase of ozone concentration is quite expected and it is clear from our Figures 1c - 6c.

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SUGGESTED CITATION

Midya, S.K., U. Saha, P. Panda, A. Kundu, A. Chaudhuri, and H. Sarkar. 2011. "Variation of Total Ozone Concentration and Rainfall over Different Stations of India". *Pacific Journal of Science and Technology*. 12(1): 580-590.

Pacific Journal of Science and Technology