Mausam, (1987), **38**, 1, 93-96

551.577.21 : 551.57

Rainfall in the upper Yamuna catchment in relation to moisture transport over Delhi

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(*Received 17 April 1985*)

सार — ऊपरी यमुना जलग्रहण क्षेत्र में वर्षा की औसत गहराई के साथ, दिल्ली में आर्द्रता वहन के परस्पर संबंध को प्रस्तुत किया गया है। दिल्ली में आर्द्रता वहन में वृद्धि और उसी के अनुरूप वर्षा की औसत गहराई में वृद्धि के मध्य अनुकूलता देखी गई है। 5 सें. मी. या इससे अधिक की वर्षा की औसत गहराई के लिए यह संबंध 80 प्रतिशत से अधिक मामलों में सही पाया गया है।

ABSTRACT. An interrelation between the moisture transport over Delhi with the average depth of rainfall over the upper Yamuna catchment is presented. A correspondence is seen to exist between the increase in moisture transport over Delhi and the corresponding increase in the average depth of rainfall. For an average depth of rainfall of 5 cm or more the relation is found to be true in more than 80 per cent cases.

1. Introduction

It is common experience of forecasters that increase in moisture content generally leads to increase in rainfall provided vertical velocity is favourable. The factors responsible for generation of vertical velocity can be grouped into static component due to orography or the transient component due to passage of dynamical systems like low pressure area or upper air circulations/ troughs etc. In the present study the authors consider the orography of uper Yamuna catchment comprising hills of west Uttar Pradesh and Himachal Pradesh as a static factor of generation of vertical velocity; the contribution to vertical velocity on account of passage of dynamical systems is not taken into consideration. With the above constraint and the assumption that moisture transport is an essential factor to cause rainfall, an attempt is made by the authors to correlate quantitatively the rainfall over upper Yamuna catchment pertaining to flood dates of Delhi and the moisture transport over Delhi. The Yamuna catchment area upto Delhi is broadly divided into two main parts, *viz.*, the Himalayan reach from source to Kalanaur known as the upper catchment and the plains from Kalanaur to Delhi known as the lower catchment. The rainfall in the upper Yamuna catchment area is only taken into consideration and assumed responsible for causing floods in the Yamuna because Dhar (1962) has shown that the upper catchment areas are the first to receive heavy rainfall resulting in floods in the *Yamuna* at Delhi. These heavy rains have been associated by Dhar (1962) with the flood producing meteorological situations like monsoon depressions, waves in the westerlies and the orography of the catchment area which provide a constant lifting mechanism for condensation and precipitation processes. Ghosh *et al*. (1982) also in their comparative hydrometeorological study of the historical floods in the *Yamuna* river have concluded that floods occur due to heavy rainfall in the catchment, the amount of rainfall for storm duration being greater in the upper catchment as compared to lower catchment.

2. Data used and methodology

For calculating the moisture transport over Delhi tephigrams of 0000 GMT of New Delhi for the period 1970 to 1983 are utilised. It is well known (*e.g.*, Ghosh *et al.* 1978).

$$T_M \text{ (Water vapour transport)} = \frac{1}{g}\int_p\int_s V(p,s)\,q(p,s)\,dp\,ds$$

where the symbols have their usual meanings.

Keeping in view the experience of forecasters that the major transport of moisture takes place in the lower layer of the atmosphere an attempt is made to evaluate the wind and moisture components at Delhi for different flood dates for the layer between the surface and 850 mb level. To evaluate the moisture transport over Delhi between the surface and 850 mb the winds at the surface and 850 mb along with the humidity mixing ratio values are picked up at the two levels. The winds at surface and 850 mb level are broken into zonal (towards east) and meridional (towards north) components.

The average zonal and meridional moisture transport components between surface and 850 mb level per unit length per unit thickness are given as :

$$U, V = \frac{1}{2}\sum_{i=1}^{2} u_i\, q_i,\; \frac{1}{2}\sum_{i=1}^{2} v_i\, q_i$$

where,

u_i = Westerly component of wind (mps) at surface and 850 mb

v_i = Southerly component of wind (mps) at surface and 850 mb

q_i = Humidity mixing ratio (gm/kg) at surface and 850 mb

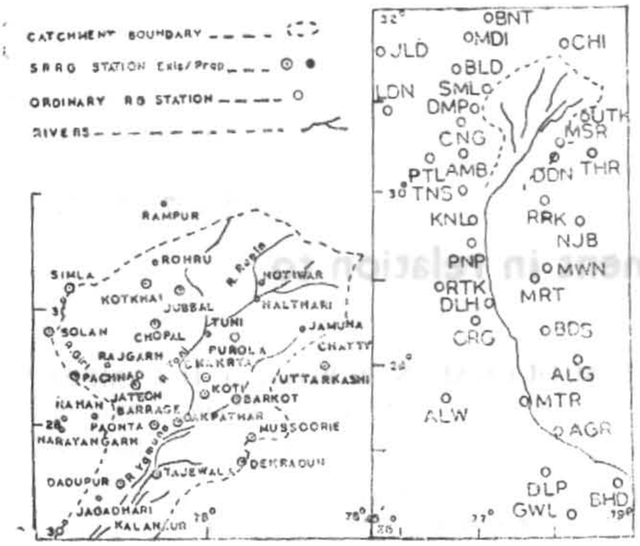

Fig. 1. The upper Yamuna river catchment with observatories

The magnitude of the resultant average moisture transport (R) per unit length per unit thickness is $\sqrt{(U^2+V^2)}$. For the purpose of calculation the unit of length (ds) is taken as a degree of Lat./Long. at Delhi (110 km at 28.5°N, 77°E) and the unit of thickness (dp) is taken as 150 mb (between surface and 850 mb level). Accordingly the magnitude of moisture transport can be represented for the above defined units from the water transport equation by :

$$T_M = \frac{R\, ds\, dp}{g}$$

$$= R \times 0.014547 \times 10^9 \text{ metric tons/day.}$$

For calculating the average depth of rainfall over the upper Yamuna catchment area, isohyetal method for working out the weighted average of rainfall over the area is used. The average depth of rainfall by this method is given by :

$$\Sigma\, A_i\, x_i \;/\; \Sigma\, A_i$$

where, A_i is the area in between two consecutive isohyets and x_i mean rainfall between the corresponding isohyets.

3. Analysis

The upper Yamuna catchment with rainguage observatories is shown in Fig. 1. In order to correlate the moisture transport over Delhi with the rainfall in the upper catchment, the data for flood dates for Delhi are picked up from the records maintained by the Central Water Commission. As is the practice a flood date is taken as the day on which the level of the river *Yamuna* under the Delhi Railway Bridge reaches or exceeds the danger mark of 204.83 m. The data of a few days before and after the flood dates are also analysed. Average isohyetal depth of rainfall is calculated for each date corresponding to the above period. Further, an attempt is made to interrelate this mean isohyetal depth of rainfall recorded at 0300 GMT of the day with the magnitude of the resultant average moisture transport.

TABLE 1

Cases of success (%)

Rainfall amount (mm)	Total No. of obs.	Total No. of cases of success	Percentage success (%)
All values	137	72	53
Upto 25 mm	56	24	43
>25 mm and upto 50 mm	97	55	57
>50 mm	23	19	83

TABLE 2

Prediction equations and *t*-statistics

S. No.	Rainfall amount ranges	*t*-value	Correlation coefficient	Prediction equation
1	Upto 25 mm	−0.72	0.07	$Y = -0.01\,X+12.2$
2	25 mm to 40 mm	2.44	0.39	$Y = 0.06\,X+25.4$
3	≥40 mm	1.97	0.39	$Y = 0.11\,X+43.3$

T_M over Delhi average between surface and 850 mb level is computed with 0000 GMT radiosonde/rawin observation of the previous day. The above data are graphically represented in Fig. 2. The figure shows a good qualitative correspondence between increase (decrease) in average moisture transport over Delhi and the corresonding increase (decrease) in rainfall over the upper Yamuna catchment.

4. Interpretation of results

Percentage number of cases of success have been calculated for different amounts of rainfall and are given in Table 1.

A case of success is reckoned when corresponding to increase in the moisture transport over Delhi there is a corresponding increase of average depth of rainfall in the catchment area and *vice versa*. It is seen from the table that overall success is more than 50%. Further for low amounts of rainfall (<25 mm) though the percentage success is low, it gradually increases with higher amount of rainfall and is more than 80% for rainfall of 50 mm or more. This shows that there is a satisfactory increase in corresondence between the variables with increase in rainfall even when only the orography is assumed to provide vertical lifting of air and moisture transport is evaluated based on a single station observation.

Now since floods are caused due to heavy rainfall mainly in the upper catchment (Dhar 1962) and the increase in rainfall has very good correspondence with the increase in moisture transport over the region it is possible to predict average rainfall in the upper catchment resulting in subsequent floods at Delhi by quantitatively estimating the rainfall through moisture transport evaluation over the region. With the above in view the authors attempt to estimate rainfall by developing suitable regression equations for different amounts of rainfall for the upper Yamuna catchment.

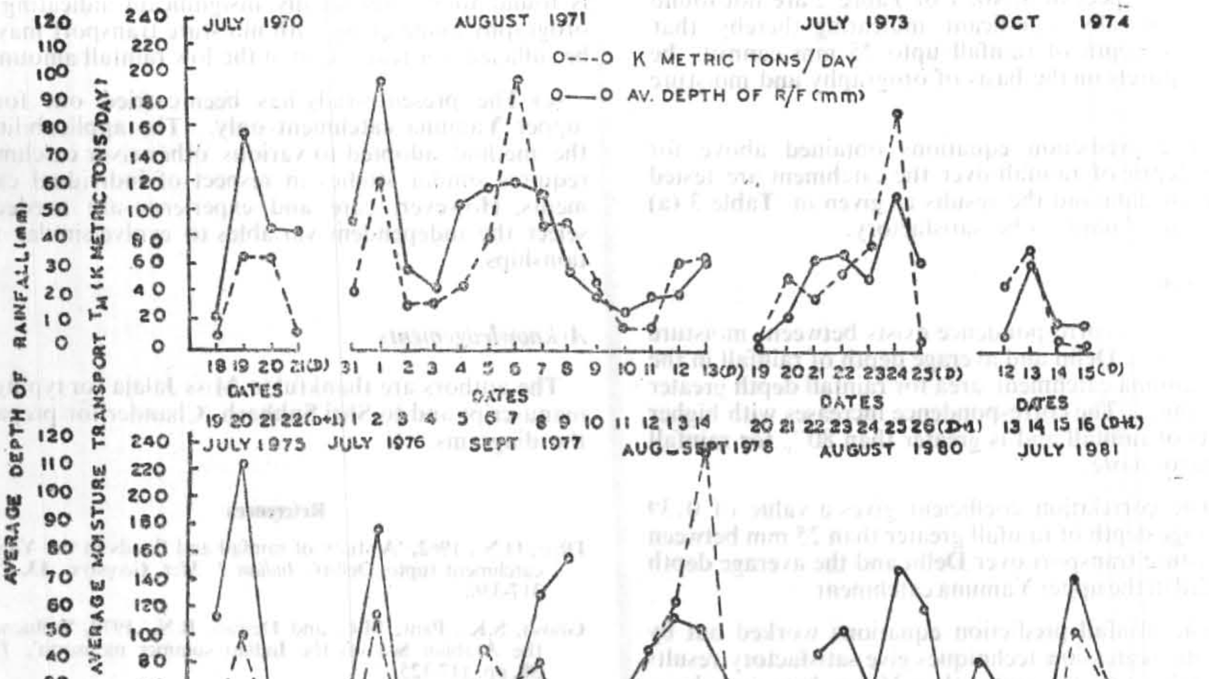

Fig. 2. Graphical correspondence of moisture transport over Delhi and areal rainfall depth over upper Yamuna catchment on the following day

TABLE 3

Observed and estimated rainfall depths (mm)

S. No.	Obs. R/F (mm)	Resultant average moisture transport (K^{-1} metric tons/day)	Estimated R/F (mm)	Residual
(a) Rainfall 25 mm upto 40 mm				
1	28.0	26.3	27.1	0.9
2	33.0	103.5	32.1	0.9
3	31.0	80.7	30.6	0.4
4	30.0	58.9	29.2	0.8
5	27.0	37.7	27.8	−0.8
6	34.0	35.1	27.7	6.3
(b) Rainfall > 40 mm				
1	45.0	23.7	46.0	−1.0
2	61.0	146.2	59.7	1.3
3	47.0	23.3	45.9	1.1
4	53.0	55.5	49.6	3.4
5	46.0	45.5	48.4	−2.4
6	63.0	113.9	56.1	6.9

$K = 0.014547 \times 10^9$

4.1. The stepwise multiple regression technique was employed to find out prediction equation for quantitative prediction of rainfall in various ranges. The correlation coefficient and the prediction equations obtained are given in Table 2.

t-value is the value of significance of sampling distribution of statistics for small samples and is known as the student's t-test. The t-score or t-test for a normal population is given (Spiegel 1961) as :

$$t = (r\sqrt{N-2}) / \sqrt{1-r^2}$$

where, r is the correlation coefficient and
N is the number of observations.

Y is the estimated average depth of rainfall (mm) over the upper Yamuna catchment and X, the corresponding magnitude of the resultant average moisture transport R (per unit length per unit thickness) over Delhi between surface and 850 mb level. The magnitude of the moisture transport T_M in metric tons/day is obtained by multiplying X by a constant factor 0.014547×10^9. The order of magnitude of the moisture transport over a degree of Lat./Long. and 150 mb thickness agrees with the order of magnitude worked out by Ghosh *et al.* (1978) in their study on the Indian summer monsoon. The t-value is found to be statistically signficant at 95% level of confidence. The above equations in respect of S. Nos. 2 and 3 of the Table 2 may be used for prediction of rainfall for different ranges as stated. The results obtained in respect of S.No. 1 of Table 2 are not found to be statistically significant indicating thereby that the average depth of rainfall upto 25 mm cannot be explained purely on the basis of orography and moisture transport.

4.2. The prediction equations obtained above for average depth of rainfall over the catchment are tested on a set of data and the results as given in Table 3 (a) and (b) are found to be satisfactory.

5. Conclusions

(a) A good correspondence exists between moisture transport over Delhi and average depth of rainfall in the upper Yamuna catchment area for rainfall depth greater than 25 mm. The correspondence increases with higher amounts of rainfall and is greater than 80% for rainfall of 50 mm or more.

(b) The correlation coefficient gives a value of 0.39 for average depth of rainfall greater than 25 mm between the moisture transport over Delhi and the average depth of rainfall in the upper Yamuna catchment.

(c) The rainfall prediction equations worked out by employing regression techniques give satisfactory results for rainfall amounts greater than 25 mm between observed and estimated rainfall values and can be used for prediction of average depth of rainfall.

(d) The correlation between moisture transport and low amounts of average depth of rainfall upto 25 mm is found to be statistically insignificant indicating that orography alone along with moisture transport may not be sufficient for realisation of the low rainfall amounts.

(e) The present study has been carried out for the upper Yamuna catchment only. The applicability of the method adopted to various other river catchments requires similar studies in respect of individual catchments. However, care and experience are needed to select the independent variables to evolve similar relationships.

Acknowledgements

The authors are thankful to Miss Jalaja for typing the manuscript and to Shri Subhash Chander for preparing the diagrams.

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