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# MOISTURE INFLOW OVER INDIA AND ITS CONTRIBUTION TO RAINFALL DURING NORMAL, GOOD AND BAD MONSOON YEARS

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Conventional methods to derive a reasonable water budget for any region are normally based on the observations of various hydrological parameters viz. precipitation, evapotranspiration, run-off, subsurface storage etc. However, because of limited observing stations and other difficulties in taking the observations of some of these parameters, specially evapotranspiration and changes in storage etc., a different dynamical technique, as suggested by Benton and Nyberg using "Hydrological Balance Equation", is used to compute the following, using the data of 10 years comprising of normal, good and bad monsoon years :

i) total monthwise inflow of moisture into the country during these years (for monsoon period).

ii) the contribution of this inflow moisture to the monsoon rainfall i.e. its percentage efficiency.

iii) total monthwise evapotranspiration in the country during these years (for monsoon period).

The monthly averaged aerological data (Radiosonde) from surface to 500 hpa (millibar) level have been used for this work.

## 1. Introduction

Conventional methods for calculating the water budget necessitate the calculation of a large number of hydrological parameters viz. precipitation, evapotranspiration, run off, subsurface storage etc. most of which are difficult to estimate let alone calculate. Following a different approach, Benton et. al (1950) and Nyberg (1965), using the 'Hydrological Balance Equation', tried to estimate the evapotranspiration using the aerological data and precipitation. Benton and Estoque (1954) had determined the total water vapour transfer over north American continent. Palmen (1967) and Peixto (1973) have also given details of the evaluation of atmospheric moisture transport and computation of atmospheric vapour flux.

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Using a similar approach, Datta and Dewan (1975) calculated the net moisture inflow into the country during 2 contrasting monsoon years and compared these with the normal monsoon. The two years chosen were 1965 - a year of below normal monsoon rainfall and 1967 - a year of above normal monsoon rainfall. They also estimated the evapotranspiration over the country for these contrasting years. Encouraged by the results achieved, Dewan & Datta (1976), in order to make the results more purposeful for water planning and proper budgeting, attempted to calculate the same parameters for individual meteorologically homogeneous subdivisions of the country. It was found that when the areas of calculation were made too small, the results were not very accurate, probably due to the difficulty in estimating the winds accurately at the boundaries of these areas where a small variation could vitiate the results.

In the present study, therefore, a major part of the country has been considered as a single unit. Further, data of 10 years has been utilised for this study - 3 years of above normal monsoon rainfall (i.e. 1975, 1978 & 1983), 3 years of near normal (1976, 1977 & 1984) and 4 years of below normal monsoon rainfall (i.e. 1972, 1974, 1979 & 1982), so as to get realistic average values of the net inflow of moisture and evapotranspiration during monsoon season.

## 2. Methodology :

The following 'Hydrological Balance Equation' has been used in this study :

$$E = P + K - I$$

where E is the evapotranspiration, P the total precipitation, K the difference in the depth of precipitable water in the atmosphere between the end and the beginning of the period and I is the net moisture inflow over the area of study.

The total precipitation P in a month has been computed as a weighted mean in the normal way, the weights being the areas of respective subdivisions.

It had been found from the calculations done in the earlier study by Datta & Dewan (1975) that the value of K was very small compared with P or I. In fact it was about 1 % of either of these values. It has, therefore, been ignored without affecting the results in any way.

The net influx of moisture into the country I has been calculated using the monthly mean upper air humidity and wind data from Radiosonde (RS) stations enveloping the area of study.

The actual area considered for this study and the various Radiosonde stations used are shown in Fig. 1. A total of 27 meteorological subdivisions covering an area of approx. $2.66 \times 10^6$ sq. Km have been considered for this study. Northeastern parts of the country as well as J & K, Himachal Pradesh and hills of West U.P. have been left out of the computations. For obvious reasons, it was also assumed that there was no inflow or outflow of moisture across the Himalayas.

The mean monthly aerological data from surface to 500 hpa (about 6 Km above msl) at intervals of every 50 hpa has been utilised for this study. Since the moisture content in the atmosphere drops very sharply at higher levels, it can easily be ignored beyond 500 hpa.

The net moisture flux I has been calculated for the area of study shown in Fig. 1 using the following equation :

$$I = \frac{t}{g} \int_{\text{Surface}}^{500\ \text{hpa}} (\Sigma L u x)\, \Delta p$$

where L is the length of the each element, u is the wind component normal to each element inwards to the region, x is the mean humidity mixing ratio along each element, $\Sigma$ being the summation over the boundary of the region and $\Delta p$ has been taken as 50 hpa. Also, t is the time for which the net inflow has been calculated (i.e. 1 month) and g the acceleration due to gravity.

## 3. Discussions of Results :

In the Tables I, II, III and IV, we present the monthwise (June to Sept) figures calculated for P (total ppt.) and I (net inflow) for the whole area of study shown in the Fig 1. These figures are presented for all the 10 years individually. Since K is negligible, the total evapotranspiration E has been calculated from the formula :

$$E = P - I$$

and shown in the above Tables. The rainfall which should have occurred as a result of net inflow of moisture (I) in the country has also been computed by dividing net inflow by the area under study. It is termed as computed rainfall and shown in these Tables.

Table V shows the consolidated picture of the complete monsoon season for all these 10 years wherein the figures for all the individual months (June to Sept) have been added up. In individual months also, one can generally see that

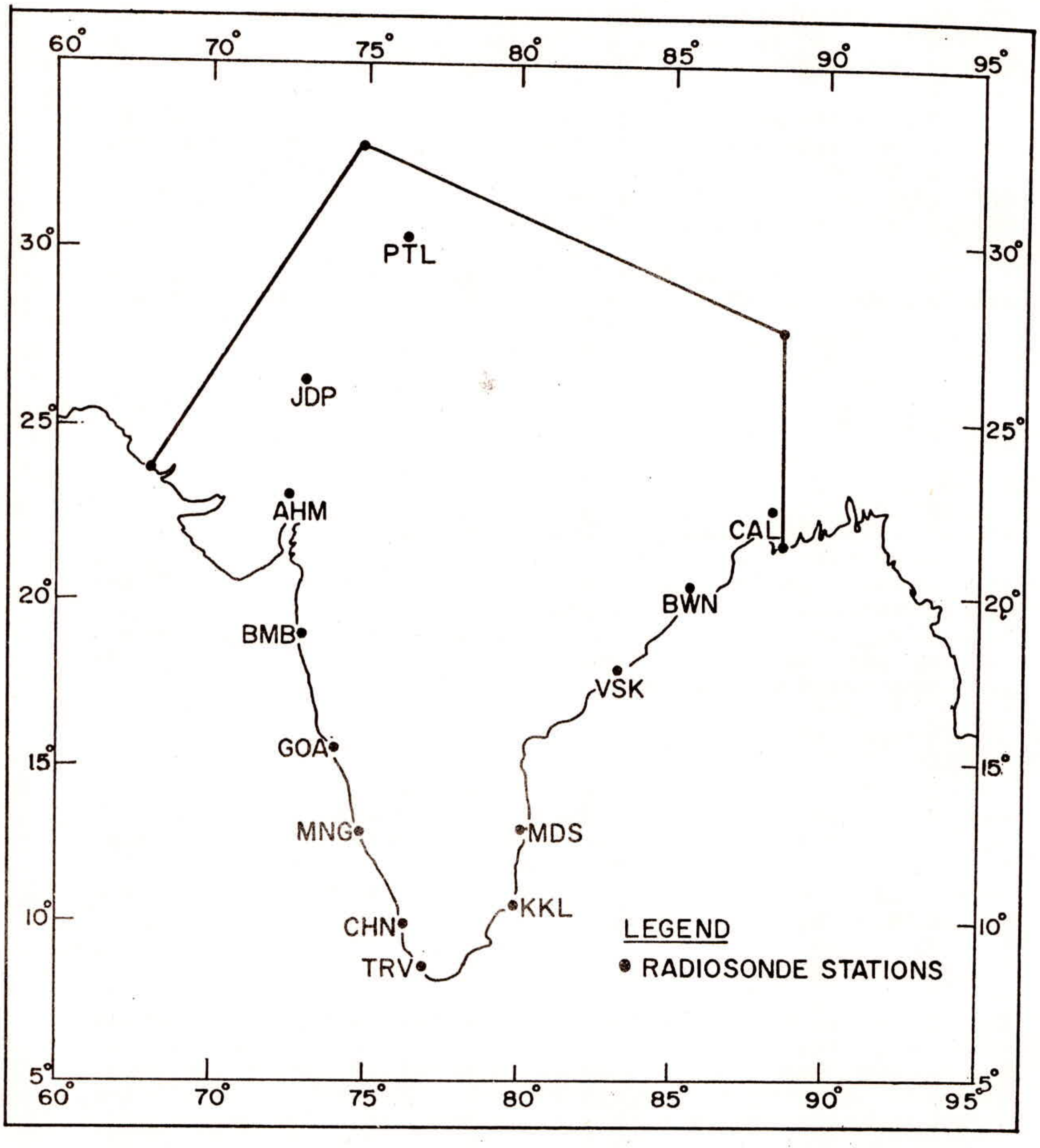


FIG. 1: AREA CONSIDERED FOR CALCULATING NET INFLUX

Table I

JUNE

| Year | Normal RF (cm) | Actual RF (cm) | Actual RF-'P' (metric tonnes x $10^{12}$) | Net Inflow-'I' (metric tonnes x $10^{12}$) | Computed RF (cm) | Evap-'E' (metric tonnes x $10^{12}$) | Evap (cm) |
|---|---|---|---|---|---|---|---|
| 1975 | 13.6 | 16.5 | 0.44 | 0.55 | 20.6 | -0.11 | -4.1 |
| 1978 | 13.6 | 18.1 | 0.48 | 0.51 | 19.2 | -0.03 | -1.1 |
| 1983 | 13.6 | 13.0 | 0.35 | 0.22 | 8.1 | 0.13 | 4.9 |
| Mean | 13.6 | 15.9 | | | 16.0 | | -0.1 |
| 1976 | 13.6 | 11.9 | 0.32 | -0.05 | -2.0 | 0.37 | 13.9 |
| 1977 | 13.6 | 17.3 | 0.46 | 0.37 | 13.9 | 0.09 | 3.4 |
| 1984 | 13.6 | 15.7 | 0.42 | 0.16 | 6:0 | 0.26 | 9.7 |
| Mean | 13.6 | 15.0 | | | 6.0 | | 9.0 |
| 1972 | 13.6 | 9.9 | 0.26 | 0.06 | 2.4 | 0.20 | 7.5 |
| 1974 | 13.6 | 8.5 | 0.23 | 0.07 | 2.5 | 0.16 | 6.0 |
| 1979 | 13.6 | 13.1 | 0.35 | 0.05 | 1.9 | 0.30 | 11.2 |
| 1982 | 13.6 | 11.8 | 0.31 | 0.01 | 0.5 | 0.30 | 11.3 |
| Mean | 13.6 | 10.8 | | | 1.8 | | 9.0 |

Table II

JULY

| Year | Normal RF (cm) | Actual RF (cm) | Actual RF-'P' (metric tonnes x $10^{12}$) | Net Inflow-'I' (metric tonnes x $10^{12}$) | Computed RF (cm) | Evap-'E' (metric tonnes x $10^{12}$) | Evap (cm) |
|---|---|---|---|---|---|---|---|
| 1975 | 26.6 | 28.7 | 0.76 | 0.64 | 24.1 | 0.12 | 4.6 |
| 1978 | 26.6 | 28.0 | 0.74 | 0.46 | 17.3 | 0.28 | 10.7 |
| 1983 | 26.6 | 26.3 | 0.70 | 0.40 | 15.0 | 0.30 | 11.3 |
| Mean | 26.6 | 27.7 | | | 18.8 | | 8.9 |
| 1976 | 26.6 | 27.9 | 0.74 | 0.67 | 25.2 | 0.07 | 2.7 |
| 1977 | 26.6 | 30.4 | 0.81 | 0.69 | 25.8 | 0.12 | 4.6 |
| 1984 | 26.6 | 23.9 | 0.64 | 0.36 | 13.4 | 0.28 | 10.5 |
| Mean | 26.6 | 27.4 | | | 21.5 | | 5.9 |
| 1972 | 26.6 | 17.5 | 0.47 | 0.23 | 8.5 | 0.24 | 9.0 |
| 1974 | 26.6 | 24.8 | 0.66 | 0.10 | 3.7 | 0.56 | 21.1 |
| 1979 | 26.6 | 20.5 | 0.55 | 0.25 | 9.3 | 0.30 | 11.2 |
| 1982 | 26.6 | 20.4 | 0.54 | 0.10 | 3.7 | 0.44 | 16.7 |
| Mean | 26.6 | 20.8 | | | 6.3 | | 14.5 |

Table III

AUG

| Year | Normal RF (cm) | Actual RF (cm) | Actual RF-'P' (metric tonnes x $10^{12}$) | Net Inflow-'I' (metric tonnes x $10^{12}$) | Computed RF (cm) | Evap-'E' (metric tonnes x $10^{12}$) | Evap (cm) |
|---|---|---|---|---|---|---|---|
| 1975 | 23.3 | 28.7 | 0.76 | 0.41 | 15.4 | 0.35 | 13.3 |
| 1978 | 23.3 | 27.6 | 0.73 | 0.84 | 31.6 | -0.11 | -4.0 |
| 1983 | 23.3 | 30.8 | 0.82 | 0.45 | 16.1 | 0.37 | 14.7 |
| Mean | 23.3 | 29.0 | | | 21.0 | | 8.0 |
| 1976 | 23.3 | 29.0 | 0.77 | 0.65 | 24.4 | 0.12 | 4.6 |
| 1977 | 23.3 | 22.8 | 0.61 | 0.41 | 15.3 | 0.20 | 7.5 |
| 1984 | 23.3 | 25.9 | 0.69 | 0.13 | 4.9 | 0.56 | 21.0 |
| Mean | 23.3 | 25.9 | | | 14.9 | | 11.0 |
| 1972 | 23.3 | 21.9 | 0.58 | 0.27 | 10.1 | 0.31 | 11.8 |
| 1974 | 23.3 | 21.4 | 0.57 | 0.30 | 11.3 | 0.27 | 10.1 |
| 1979 | 23.3 | 20.2 | 0.54 | 0.11 | 4.1 | 0.43 | 16.1 |
| 1982 | 23.3 | 27.4 | 0.73 | 0.21 | 7.9 | 0.52 | 19.5 |
| Mean | 23.3 | 22.7 | | | 8.3 | | 14.4 |

Table IV

SEPT

| Year | Normal RF (cm) | Actual RF (cm) | Actual RF-'P' (metric tonnes x $10^{12}$) | Net Inflow-'I' (metric tonnes x $10^{12}$) | Computed RF (cm) | Evap-'E' (metric tonnes x $10^{12}$) | Evap (cm) |
|---|---|---|---|---|---|---|---|
| 1975 | 16.9 | 22.6 | 0.60 | 0.49 | 18.4 | 0.11 | 4.2 |
| 1978 | 16.9 | 15.9 | 0.42 | 0.14 | 5.3 | 0.28 | 10.6 |
| 1983 | 16.9 | 24.1 | 0.64 | 0.61 | 23.0 | 0.03 | 1.1 |
| Mean | 16.9 | 20.9 | | | 15.6 | | 5.3 |
| 1976 | 16.9 | 14.1 | 0.38 | -0.05 | -2.0 | 0.43 | 16.1 |
| 1977 | 16.9 | 14.0 | 0.37 | 0.27 | 10.2 | 0.10 | 3.8 |
| 1984 | 16.9 | 13.1 | 0.35 | 0.11 | 4.1 | 0.24 | 9.0 |
| Mean | 16.9 | 13.7 | | | 4.1 | | 9.6 |
| 1972 | 16.9 | 13.0 | 0.35 | 0.15 | 5.5 | 0.20 | 7.5 |
| 1974 | 16.9 | 12.5 | 0.33 | 0 | 0 | 0.33 | 12.5 |
| 1979 | 16.9 | 11.4 | 0.30 | -0.04 | -1.5 | 0.34 | 12.9 |
| 1982 | 16.9 | 10.8 | 0.29 | 0.09 | 3.3 | 0.20 | 7.5 |
| Mean | 16.9 | 11.9 | | | 1.8 | | 10.1 |

Table V

For Monsoon Season (June-Sept)

| Year | Normal RF (cm) | Actual RF (cm) | Actual RF-'P' (metric tonnes x $10^{12}$) | Net Inflow-'I' (metric tonnes x $10^{12}$) | Computed RF (cm) | Evap-'E' (metric tonnes x $10^{12}$) | Evap (cm) |
|---|---|---|---|---|---|---|---|
| 1975 | 80.4 | 96.5 | 2.56 | 2.09 | 78.5 | 0.47 | 18.0 |
| 1978 | 80.4 | 89.6 | 2.37 | 1.95 | 73.4 | 0.42 | 16.2 |
| 1983 | 80.4 | 94.2 | 2.51 | 1.68 | 62.2 | 0.83 | 32.0 |
| Mean | 80.4 | 93.4 | | | 71.3 | | 22.1 |
| 1976 | 80.4 | 82.9 | 2.21 | 1.22 | 45.6 | 0.99 | 37.3 |
| 1977 | 80.4 | 84.5 | 2.25 | 1.74 | 65.2 | 0.51 | 19.3 |
| 1984 | 80.4 | 78.6 | 2.10 | 0.76 | 28.4 | 1.34 | 50.2 |
| Mean | 80.4 | 82.0 | | | 46.4 | | 35.6 |
| 1972 | 80.4 | 62.3 | 1.66 | 0.72 | 26.5 | 0.95 | 35.8 |
| 1974 | 80.4 | 67.2 | 1.79 | 0.47 | 17.5 | 1.32 | 49.7 |
| 1979 | 80.4 | 65.2 | 1.74 | 0.37 | 13.8 | 1.37 | 51.4 |
| 1982 | 80.4 | 70.4 | 1.87 | 0.41 | 15.4 | 1.46 | 55.0 |
| Mean | 80.4 | 66.3 | | | 18.3 | | 48.0 |

the moisture inflow in the country during monsoon months varies considerably during good, normal and bad monsoon years. It is found to be higher than normal during good and lower than normal during bad monsoon years. The evapotranspiration also shows a similar variation but in a reverse order.

3.1 Net Inflow of Moisture :

The picture becomes very clear when we consider the annual figures in Table V. In the monsoon season while the normal precipitation in the whole country is 85.3 cm (Mooley and Parthasarthy (1984)), the normal precipitation found in the area of our study is 80.4 cm only. However, for the 3 years of near normal rainfall considered for study (i.e. 1976, 1977 & 1984), the average rainfall was found to be 82.0 cm. In these 3 years, the total average moisture inflow was 46.4 cm i.e. about 57 % of the total rainfall. It can be noticed that the actual amount of this inflow sharply increases to 71.3 cm in good monsoon years (1975, 1978 & 1983) accounting for about 76 % of the total rainfall and falls to 18.3 cm in bad monsoon years (1972, 1974, 1979 & 1982) i.e. about 28 % of the total rainfall in these years.

3.2 Evapotranspiration .

Considering the evapotranspiration values in these 3 types of situations, the results are reverse. It is seen that for normal years, evapotranspiration is 35.6 cm and falls considerably to 22.1 cm in good monsoon years and increases to 48.0 cm in bad monsoon years. This should normally be expected also due to the fact that a bad monsoon season brings more sunshine, clear skies and insufficient moisture in the atmosphere thus favouring rapid evapotranspiration. Since the rate of moisture inflow falls sharply during bad monsoon years, it is obvious that the evapotranspiration plays a major role in the total rainfall that falls during these years and accounts for 72 % of it while in normal years, it is about for 43 % and in good monsoon years, only 24 %. Therefore, it is obvious that considerable recycling of moisture is going on in the atmosphere during normal and bad monsoon years.

Further, the average evapotranspiration for good, normal and bad monsoon seasons (Table V) works out to 22.1 cm (1.8 mm per day), 35.6 cm (3 mm per day) and 48.0 cm (4 mm per day) respectively. Earlier Rao et. al (1971) and Saha and Bavadekar (1973) using conventional methods for large water surfaces had obtained evaporation values as 6 mm/day and 4 mm/day respectively. Comparing these with our values, we feel that those obtained by us for three different monsoon situations appear very realistic and accurate enough to be easily used for water planning, budgeting and other similar purposes.

3.3 Outflow vs Inflow :

Using IIOE data, Pisharoty (1965) had calculated that $5.9 \times 10^{10}$ metric tonnes/day of moisture was crossing the western boundary of India into the country during monsoon. Similar calculations done by Saha (1970) had shown that this moisture flux across $75^{\circ}$E was $5.5 \times 10^{10}$ metric tonnes/day while Ghosh et. al (1978), using ISMEX data, had computed this value to be $9 \times 10^{10}$ metric tonnes/day. However, considering that these calculations are from $0^{\circ}$N while the borders of the country start much higher at $8^{\circ}$N, one has to reduce these estimates accordingly. A realistic value of 5 or $6 \times 10^{10}$ metric tonnes/day can, therefore, be assumed for the purpose. Taking an average of the net influx values of moisture from Table V, it appears that total retention of moisture in the country in monsoon season works out to be approx. $1.1 \times 10^{10}$ metric tonnes/day. Anjaneyulu (1969) had also calculated the net influx of moisture over an elliptic area (between $18^{\circ}$N to $27^{\circ}$N and $68^{\circ}$E to $91^{\circ}$E) for the months of July and August. He found this figure to be $2.8 \times 10^{10}$ metric tonnes/day. Since this study was done over a smaller area and that too for only 2 months of July and August, when the rainfall is very heavy, it can not be compared with our values. It would, therefore, appear that out of the total moisture coming into the country, only 20 to 25 % is retained for producing rain.

4. Conclusions

The computations done on the rainfall and aerological data of monsoon seasons of 10 years (3 good, 4 bad and 3 normal monsoon seasons) show the following results :

i) The net inflow of the moisture into the country in the monsoon season considerably influences the total monsoon rainfall in that season. In a normal monsoon season, it accounts for approx. 55 % of the total rainfall while in the good monsoon season, this percentage increases to about 75 % and falls to about 30 % in a bad monsoon year. This shows that in normal and bad monsoon seasons, evapotranspiration plays a major role in producing rainfall through the recycling process, as it is able to contribute about 45 % and 70 % of total rainfall resp.

ii) The evapotranspiration in the normal monsoon season has been found to be 3 mm/day approx. It is higher in a bad monsoon season (4 mm/day) and lower in a good monsoon season (1.8 mm/day).

iii) Out of the total moisture transported into the country, only about 20 to 25 % is being retained as monsoon rainfall.

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