MAUSAM, 50, 4 (October 1999), 365-374

551.501.79 : 551.573

Determination of relative contribution of different meteorological elements on evaporation

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(*Received 2 February 1994, Modified 7 September 1999*)

सार — इस अध्ययन में कलकत्ता, पुणे और नई दिल्ली में विकिरण, अधिकतम तापमान, तेज धूप के घंटे, सापेक्ष आर्द्रता और वाष्पन पर सतह पवन के प्रभावों पर विचार किया गया है । इसके लिए वर्ष 1991से 94 तक के जनवरी, मई, जून, जुलाई अैंर अक्तूबर माह के दैनिक आँकड़ों का उपयोग किया गया है । "पथ विश्लेषण" के माध्यम से मौसम के घटकों के प्रत्यक्ष और अप्रत्यक्ष प्रभावों का निर्धारण किया गया है । आश्रित परिवर्ती के रूप में वाष्पन और स्वतंत्र परिवर्ती के रूप में उपरोक्त पाँच मौसम प्राचलों से बहुआयामी समाश्रयण समीकरणों का भी विकास किया गया है ।

परिणामों से पता चला है कि विकिरण और अधिकतम तापमान ही ऐसे दो अत्यधिक महत्वपूर्ण प्राचल हैं जिनसे वाष्पन में वृद्धि होती है । इनका प्रभाव अधिकांशतः सीधे ही पड़ता है हालाँकि कुछ मामलों में सापेक्ष अर्द्रता या पवन के साथ इनका पारस्परिक क्रिया भी वाष्पन में महत्वपूर्ण योगदान देती है । आर्द्रता और सतह पवन सामान्यतः वाष्पन में प्रत्यक्ष रूप से सार्थक योगदान नहीं देते हैं; इनका प्रभाव अधिकतम तापमान के साथ पारस्परिक क्रिया के माध्यम से अप्रत्यक्ष रूप से प्रकट होता है ।

ABSTRACT. The present study deals with influence of radiation, maximum temperature, hours of bright sunshine, relative humidity and surface wind on evaporation at Calcutta, Pune and New Delhi. Daily data from 1991-94 of January, May, June, July and October have been utilized. Direct and indirect influence of the weather factors have been determined through "path analysis" and discussed. Multiple regression equations have also been developed with evaporation as the dependent variable and the above five weather parameters as independent variables.

The results reveal that radiation and maximum temperature are the two most important parameters which enhance evaporation. Most of their effect is direct though in some cases their interaction with relative humidity or wind also contribute significantly to evaporation. Humidity and surface wind, generally, do not significantly contribute directly to evaporation; their effect is manifested through interaction with maximum temperature, indirectly.

Key words — Evaporation, Radiation, Relative humidity, Path analysis, Multiple regression.

1. Introduction

Evaporation is a process of conversion of water into aqueous vapour. In atmosphere, evaporation takes place from free liquid surfaces such as storage reservoirs, lakes and seas and from solids such as soil, vegetation *etc*. The problem of evaporation from the water bodies has received attention of research workers including hydrologists, plant physiologists, engineers, meteorologists *etc*. each of whom have a specific problem on evaporation. In meteorology, knowledge of moisture distribution in the atmosphere is important to forecast weather. In agricultural meteorology, amount of water lost by evaporation from soil and plants helps to evaluate crop water stress and hence scheduling of irrigation.

Theoretically, evaporation can be measured by solving diffusion equation. A second method called aerodynamic method uses Prandil's boundary layer theory, while a third approach relies mainly on direct measurement of water vapour momemtum transfer by eddy correlation technique. Energy balance is yet another approach which is based on estimating change of liquid to vapour phase. Besides, there are empirical formulae to measure evaporation loss. Directly, it is measured by US open pan evaporimeter.

Air temperature of the evaporating body, atmosphèric relative humidity or the vapour pressure deficit between evaporating surface and atmosphere, wind and solar radiation are some of the major factors which govern the loss of moisture from water. Among these factors radiation has a direct bearing on the evaporation process which also influences the process indirectly by regulating temperature of the evaporating body and the air. Atmospheric pressure also exert influence on evaporation but to a limited extent.

2. Purpose and scope of the study

Many hydrological and agricultural applications frequently require evaporation data. At most locations in India this data is generated from standard instrument *i.e.* US open pan evaporimeter. The network does not seem to be dense enough to facilitate interpolation. Naturally, recourse had to be taken to explore possibility of obtaining evaporation data for a location from readily available climatic information of homogeneous region.

Among the meteorological factors mentioned above which influence evaporation directly and substantially, it is not yet clear how much each contribute to the evaporation. It is also not clear whether these factors affect evaporation directly or indirectly through interaction with other factors. It is the aim of this study to identify such factors and the extent to which they directly or indirectly affect evaporation. It is also felt that it would be useful to determine contribution of various meteorological factors to the evaporation.. Venkataraman and Krishnamurthy (1965) observed that means of maximum and minimum temperatures and dew point could be used in estimating pan evaporation from meteorological factors in place of mean air temperature and dew point. Reference can also be made to the studies of Deo *et al.* (1963), Raghavan and Nagarkar (1965) in India. Rao *et al.* (1972) used correlation technique to assess the influence exerted by basic meteorological factors in controlling evaporative power of atmosphere. Gash *et al.* (1991) demonstrated that evaporation remains close to its potential value for 10 days after the last rainfall episode.

3. Material and method

For the purpose of this study Pune (18° 32′N, 73° 51′E), New Delhi (28° 35′N, 77° 12′E) and Calcutta (22° 32′ N, 88° 20′E) were chosen. Three months *i.e.* January representing winter, July, the monsoon and October, the post-monsoon season, were chosen. As May is hottest month in North India, it was selected for representing summer. June is a transition month between summer, with characteristically low humidity and July, with high humidity. As such June was also considered in the study.

Daily evaporation rates (mm), maximum temperature (°C), sunshine (hrs), surface wind (ms^{-1}) and relative humidity (%) (which has been assumed to represent vapour pressure deficit of the atmosphere) were the elements selected. As the range of variations in hours of bright sunshine or maximum temperature do not generally manifest the evaporation loss adequately, daily radiation (MJm^{-2}) as measured by pyranometer was used in the analysis. The study is based on data from 1991-94. Evaporation was measured by standard US open pan evaporimeter while the meteorological data pertains to the agromet observatory within which the evaporimeter is located.

In the presentation suffixes 1, 2,....,6 have been used. They represent the following elements.

Suffix	*Element*	*Symbol*
1	evaporation (mm)	x_1
2	radiation (MJ/m^2)	x_2
3	maximum temperature (°C)	x_3
4	sunshine (hrs)	x_4
5	relative humidity (%)	x_5
6	surface wind (m/s)	x_6

At the outset, the data was analysed based on a technique known as "path analysis". A path analysis is simply a standardised partial regression method. It measures the direct influence of one variable upon another and permits the separation of the correlation coefficient into components of 'direct' and 'indirect' effects (Dewey and Lu, 1959). If r_{23}, r_{24}, r_{25}, r_{34} are the partial correlation coefficients between radiation on one hand and each of the elements *i.e.* maximum temperature, sunshine hours, relative humidity and wind respectively and P_{12}, P_{13}, P_{14}, P_{15}, P_{16} are the path coefficients of evaporation with radiation, maximum temperature, sunshine hours, relative humidity and surface wind respectively, the path coefficients can be worked out from the following equations:

$$r_{12} = P_{12} + r_{23}P_{13} + r_{24}P_{14} + r_{25}P_{15} + r_{26}P_{16} \quad (1)$$

$$r_{13} = P_{13} + r_{23}P_{12} + r_{34}P_{14} + r_{35}P_{15} + r_{36}P_{16} \quad (2)$$

$$r_{14} = P_{14} + r_{24}P_{12} + r_{34}P_{13} + r_{45}P_{15} + r_{46}P_{16} \quad (3)$$

$$r_{15} = P_{15} + r_{25}P_{12} + r_{35}P_{13} + r_{45}P_{14} + r_{56}P_{16} \quad (4)$$

$$r_{16} = P_{16} + r_{26}P_{12} + r_{36}P_{13} + r_{46}P_{14} + r_{56}P_{15} \quad (5)$$

$$1 = P^2_{1x} + P^2_{12} + P^2_{13} + P^2_{14} + P^2_{15} + P^2_{16} + 2r_{23}P_{12}P_{13} + 2r_{24}P_{12}P_{14} + 2r_{25}P_{12}P_{15} + 2r_{26}P_{12}P_{16} + 2r_{34}P_{13}P_{14} + 2r_{35}P_{13}P_{15} + 2r_{36}P_{13}P_{16} + 2r_{45}P_{14}P_{15} + 2r_{46}P_{14}P_{16} + 2r_{56}P_{15}P_{16} \quad (6)$$

where x in equation (6) above represen residual factors.

In the above equations r_{12}, r_{13}, r_{14}, r_{15} and r_{16} are the linear correlation of evaporation with radiation, maximum temperature, sunshine hours, relative humidity and surface wind respectively. These equations can be solved through triangular reduction matrix method. In equation (1) the direct effect on evaporation is given by P_{12}. The indirect effect of radiation on evaporation *via* maximum temperature, sunshine, relative humidity and wind are respectively given by $r_{23}P_{13}$, $r_{24}P_{14}$, $r_{25}P_{15}$ and $r_{26}P_{16}$ respectively. Hence sum of the direct and indirect effects should be equal

TABLE 1

Correlation coefficients between evaporation and different parameters

Element/ Month	x_2	x_3	x_4	x_5	x_6	x_2	x_3	x_4	x_5	x_6	x_2	x_3	x_4	x_5	x_6
	New Delhi					**Calcutta**					**Pune**				
January	0.39 **	0.40 **	0.53 ***	-0.63 ***	0.22	0.40 **	0.54 ***	0.28	-0.32 *	0.40 **	0.37 **	0.29 *	0.31 *	-0.40 **	0.54 ***
May	0.76 ***	0.87 ***	0.67 ***	-0.06	0.66 ***	0.29 *	0.81 ***	0.23	-0.30 *	0.64 ***	0.85 ***	0.46 **	0.28 *	-0.22	0.42 *
June	0.80 ***	0.82 ***	0.50 **	-0.40 **	0.38 **	0.45 **	0.50 **	0.23	-0.38 **	0.31 *	0.54 ***	0.76 ***	0.45 **	-0.66 ***	0.64 ***
July	0.51 **	0.90 ***	0.39 **	-0.88 ***	0.67 ***	0.53 ***	0.48 **	0.20	0.01	0.30 *	0.51 ***	0.76 ***	0.56 ***	-0.40 **	0.54 ***
October	0.82 ***	0.54 **	0.36 *	-0.03	0.33	0.27 *	0.56 **	0.17	-0.33 *	0.33 *	0.39 *	0.48 **	0.24	-0.44 **	0.17

Note

* = significant at 5% level

** = significant at 1% level

*** = significant at 0.1% level

to r_{12} the correlation between evaporation and radiation. Similarly in equation (2) the direct effect of maximum temperature on evaporation is given by P_{13}, $r_{23}P_{12}$, $r_{34}P_{14}$, $r_{35}P_{15}$ and $r_{36}P_{16}$ indicate indirect effect of maximum temperature on evaporation *via* radiation, sunshine, humidity and wind respectively. Equations (3) to (5) can be similarly explained.

After evaluating contribution of the above parameters on evaporation rates, the data were subjected to multiple correlation analysis. Regression equations were developed connecting evaporation with the five independent variables mentioned above. In the formulation only those of the parameters were included for which the partial coefficients were significant at least at 5% level.

4. Results and discussion

4.1. *Linear correlations*

The linear correlations between evaporation (x_1) and the other parameters are given in Table 1. The importance of local energy in the form of radiation is clearly demonstrated by its correlation with evaporation. In nearly all cases, the correlations between the two were significant; in located cases even at 0.1% level. The high correlation seems more than a mere reflection of the basic dependence of evaporation on the available radiant energy. Results based as it is on widely distributed stations and different seasons, suggest that neither latitude nor season could differentiate between them (Hanna and Siam, 1981).

Evaporation though a continuous process, is measured at fixed hours. Maximum temperature which represents accumulation of insolation, too is observed at fixed hours in the afternoon. Apparently a good correlation should exist between the two. This is also demonstrated in Table 1. Evaporation rates during winter months are found low because of low ambient temperature. Nkemdirim (1991ab) observed that relationship between evaporation and maximum temperature could be best described by an exponential. Strikingly high correlation exists between evaporation and temperature during summer and early monsoon season. The high correlation in early monsoon season observed in Table 1 could be accounted by the heat storage in the air during summer with corresponding heat release in succeeding months, thereby increasing the energy availability. This effect is most pronounced in June and partially in July.

Another factor which represents insolation is hours of bright sunshine (SS). Its correlation with evaporation appears to be a function of latitude with New Delhi recording highest correlation. These correlations were, however, always lower than those for maximum temperature and radiation, perhaps due to the high inter-correlation already existing between maximum temperature and sunshine.

High humidity suppresses evaporation rates by decreasing the vapour pressure (as also temperature) gradient near the water surface. One must, in general, find humidity and evaporation to be negatively correlated. This is unambiguously brought out in Table 1. At all three locations, the highest (negative) correlation between evaporation and humidity can be seen during June and July.

Wind speed is one of the key factors in removing the evaporated water vapour from evaporating surface and altering the aerodynamic conditions and hence has bearing on the evaporation rate. Higher wind speed results in more evaporation. This is borne out in Table 1 where lowest

TABLE 2

Direct and indirect effects by various parameters during January

Element/Effect	x_2	x_3	x_4	x_5	x_6
			New Delhi		
Direct effect	0.31	0.22	0.35	-0.35	0.16
Indirect effects					
through x_2	-	0.02	0.00	-0.04	0.08
through x_3	0.01	-	0.02	-0.10	-0.07
through x_4	0.00	0.03	-	-0.13	0.07
through x_5	0.04	0.16	0.14	-	-0.04
through x_6	0.03	-0.03	0.02	-0.01	-
Corr. Coeff. with x_1	0.39	0.40	0.53	-0.63	0.22
			Calcutta		
Direct effect	0.23	0.48	0.06	-0.22	0.23
Indirect effects					
through x_2	-	0.01	0.05	-0.12	0.03
through x_3	0.01	—	0.11	0.04	0.12
through x_4	0.01	0.01	-	-0.01	0.01
through x_5	0.12	-0.02	0.03	-	0.01
through x_6	0.03	0.06	0.03	-0.01	-
Corr. Coeff. with x_1	0.40	0.54	0.28	-0.32	0.40
			Pune		
Direct effect	-0.06	0.45	0.17	-0.35	0.79
Indirect effects					
through x_2	-	-0.01	-0.03	0.01	-0.01
through x_3	0.09	-	0.01	-0.19	-0.17
through x_4	0.08	0.00	-	-0.05	0.01
through x_5	0.06	-0.12	0.11	-	-0.08
through x_6	0.19	-0.03	0.05	0.18	-
Corr. Coeff. with x_1	0.37	0.29	0.31	-0.40	0.54

correlations were observed in October, when the surface wind is either calm or light. On the other hand during May and June strong surface wind results in increased evaporation rates.

4.2. *Path analysis*

In the previous section we have discussed through linear correlation, how the weather parameters affect the evaporation. How much of this is due to direct influence, a parameter exerts on evaporation and the extent the parameter affects indirectly through interaction with the remaining parameters, is dealt in this section for the five months. The results have been achieved through application of path analysis and presented in Tables 2-6.

4.2.1. *January*

The solar elevation during January being low, radiation does not seem to contribute much to evaporation. The correlation between the two is nearly $r = 0.4$ at all the three locations (Table 2) and most of it at New Delhi and Calcutta is due to direct effect. Indirect effect of radiation through wind at Pune and through relative humidity at Calcutta are also, comparatively large. Results for maximum temperature are not much different from radiation. However, in this case, the indirect effect of maximum temperature through relative humidity at New Delhi and Pune cannot be ignored.

Sunshine effect is seen prominently at New Delhi and most of it is direct ($r = 0.35$) while at Calcutta the direct and indirect effects are nearly equal. Direct effect of sunshine is slightly more than the indirect effect through relative humidity though both are numerically not large.

New Delhi is affected more by Western Disturbances which bring in its wake, weather and high humidity during winter months. High humidity significantly contributes to reduce evaporation, directly at New Delhi and at Pune, each with $r = -0.35$.

At Calcutta also, the direct effect of humidity contribute nearly 70% of the correlation it bears with evaporation. Indirect effect on evaporation *via* radiation, maximum temperature or sunshine at the three locations is also quite large.

TABLE 3

Direct and indirect effects by various parameters during May

Element/Effect	x_2	x_3	x_4	x_5	x_6
			New Delhi		
Direct effect	0.23	0.58	0.00	0.01	0.22
Indirect effects					
through x_2	-	0.17	0.13	-0.01	0.11
through x_3	0.43	-	0.44	-0.06	0.33
through x_4	0.00	0.00	-	0.00	0.00
through x_5	0.00	-0.01	0.01	-	0.00
through x_6	0.10	0.13	0.09	0.00	-
Corr. Coeff. with x_1	0.76	0.87	0.67	-0.06	0.66
			Calcutta		
Direct effect	0.04	0.53	0.05	-0.24	0.50
Indirect effects					
through x_2	-	0.02	0.02	-0.01	0.02
through x_3	0.33	-	0.21	-0.15	0.18
through x_4	0.04	0.02	-	-0.01	-0.01
through x_5	0.08	0.07	0.08	-	-0.05
through x_6	-0.20	0.17	-0.13	-0.11	-
Corr. Coeff. with x_1	0.29	0.81	0.23	-0.30	0.64
			Pune		
Direct effect	0.70	0.24	-0.02	-0.05	0.26
Indirect effects					
through x_2	-	0.22	0.24	-0.15	0.20
through x_3	0.08	-	0.01	-0.13	-0.02
through x_4	-0.01	0.00	-	0.02	0.00
through x_5	0.01	0.03	0.01	-	-0.02
through x_6	0.07	-0.03	0.04	0.09	-
Corr. Coeff. with x_1	0.85	0.46	0.28	-0.22	0.42

January is also characterized by light surface winds which does not help to increase evaporation. Its direct effect is prominent at Pune ($r = 0.79$) but this gets neutralized to some extent through negative indirect effect of other parameters. Direct effect of wind is also marked at Calcutta.

4.2.2. *May*

During this month (Table 3), the direct effect of radiation contributes substantially (nearly 30%) of its total effect on evaporation at New Delhi; it is however predominant at Pune ($r = 0.70$). Surprisingly, radiation directly plays hardly any role in enhancing evaporation; most of its contribution is indirectly through maximum temperature. Similarly, indirect effect of radiation through maximum temperature is marked ($r = 0.43$) at New Delhi.

A large proportion of the effect of maximum temperature on evaporation is direct at New Delhi and Calcutta, with $r = 0.58$ and 0.53 respectively. Role of strong wind associated with "Andhi" at New Delhi and "Norwester" at Calcutta in indirectly contributing to increased evaporation through maximum temperature also cannot be overlooked at these two locations. At Pune nearly 50% of the effect of maximum temperature is direct whereas the remaining half contribution can be explained due to the indirect effect through radiation.

At all the three locations considered in the study, sunshine surprisingly hardly contributes directly to increase in evaporation during the month; most of its effect, albeit small, is indirect *via* radiation or maximum temperature.

TABLE 4

Direct and indirect effects by various parameters during June

Element/Effect	x_2	x_3	x_4	x_5	x_6
			New Delhi		
Direct effect	0.13	0.67	0.39	0.17	0.41
Indirect effects					
through x_2	-	0.09	0.06	-0.02	0.01
through x_3	0.48	-	0.21	-0.33	0.04
through x_4	0.19	0.13	-	-0.20	-0.08
through x_5	-0.03	-0.09	-0.09	-	0.00
through x_6	0.03	0.02	-0.07	-0.02	-
Corr. Coeff. with x_1	0.80	0.82	0.50	-0.40	0.38
			Calcutta		
Direct effect	0.39	0.38	-0.05	-0.12	0.33
Indirect effects					
through x_2	-	0.09	0.07	-0.04	-0.04
through x_3	0.09	-	0.14	-0.18	-0.01
through x_4	-0.01	-0.02	-	0.04	0.00
through x_5	0.01	0.06	0.08	-	0.03
through x_6	-0.03	-0.01	0.00	-0.08	-
Corr. Coeff. with x_1	0.45	0.50	0.23	-0.38	0.31
			Pune		
Direct effect	0.23	0.46	-0.19	-0.27	0.33
Indirect effects					
through x_2	-	0.11	0.05	-0.04	0.06
through x_3	0.21	-	0.26	-0.31	0.17
through x_4	-0.04	-0.11	-	0.15	-0.07
through x_5	0.05	0.18	0.20	-	0.15
through x_6	0.09	0.12	0.13	-0.19	-
Corr. Coeff. with x_1	0.54	0.76	0.45	-0.66	0.64

May is characterized by extreme dryness and low atmospheric humidity. Humidity as such, is found to have negative but weak influence on evaporation at Calcutta and Pune. At Calcutta its direct effect (r = - 0.24) and indirect effect through maximum temperature (r = - 0.15) are somewhat large. At Pune mostly, humidity affects evaporation indirectly through radiation and maximum temperature. Relative humidity at New Delhi, directly or indirectly does not seem to contribute anything to evaporation.

Surface wind helps considerably to increase evaporation in summer month. The direct effect overshadows the indirect effect at Calcutta with r = 0.50. Directly this element contributes to 1/3rd of its correlation with evaporation at New Delhi whereas it is about 60 % at Pune. Indirectly, wind, through radiation and/or maximum temperature helps to a great extent to enhance evaporation rates.

4.2.3. *June*

The monsoon sets over Pune and Calcutta during the second week of June and at New Delhi towards the end of this month. In its wake it brings qualitative change in the environment and quantitative changes in the weather parameters as also interaction among them. At New Delhi (Table 4) for instance, radiation's direct contribution is low but indirectly through maximum temperature and sunshine it helps considerably (r = 0.48 and 0.19 respectively). But direct effect of radiation (r = 0.39) at Calcutta is prominent (Table 4) which accounts for nearly 87% of its total effect (as reflected in the correlation). Predominant direct effect is

TABLE 5

Direct and indirect effects by various parameters during July

Element/Effect	x_2	x_3	x_4	x_5	x_6
			New Delhi		
Direct effect	0.12	0.32	-0.09	-0.52	0.23
Indirect effects					
through x_2	-	0.05	0.02	-0.04	0.04
through x_3	0.14	-	0.10	-0.27	0.17
through x_4	-0.02	-0.03	-	0.06	-0.01
through x_5	0.19	0.43	0.32	-	0.24
through x_6	0.08	0.13	0.04	-0.11	-
Corr. Coeff. with x_1	0.51	0.90	0.39	-0.88	0.67
			Calcutta		
Direct effect	0.44	0.40	0.17	-0.08	0.06
Indirect effects					
through x_2	-	0.09	0.01	0.11	0.14
through x_3	0.08	-	-0.02	0.02	0.03
through x_4	0.01	-0.01	-	-0.04	0.07
through x_5	-0.02	0.00	0.02	-	0.00
through x_6	0.02	0.00	0.02	0.00	-
Corr. Coeff. with x_1	0.53	0.48	0.20	0.01	0.30
			Pune		
Direct effect	0.05	0.58	0.25	0.14	0.32
Indirect effects					
through x_2	-	0.06	0.01	0.01	0.04
through x_3	0.24	-	0.29	-0.32	0.12
through x_4	0.02	0.13	-	-0.18	0.08
through x_5	0.01	-0.08	-0.10	-	-0.02
through x_6	0.09	0.07	0.11	-0.05	-
Corr. Coeff. with x_1	0.51	0.76	0.56	-0.40	0.54

also seen at Pune though indirectly also radiation helps evaporation through maximum temperature by nearly same proportion.

Direct effect (r = 0.67) of maximum temperature is prominently seen at all the three locations although indirectly maximum temperature affects evaporation through sunshine at New Delhi and relative humidity at Calcutta also. Similar observation also holds good for sunshine at New Delhi and Calcutta. Surprisingly at Pune, the direct effect of sunshine is negative which is rather hard to explain. It is the indirect effect through maximum temperature, humidity and wind which helps sunshine towards enhancing evaporation at this station.

Direct effect of humidity on evaporation is not large and is negative at Calcutta and Pune but amazingly, positive at New Delhi. Its effect is mostly realized indirectly (and prominently) at New Delhi and Calcutta (r = -0.33 and -0.18 respectively) and maximum temperature and wind at Pune.

Influence of wind towards increased evaporation in June is marked at New Delhi and Calcutta where, infact, the direct influence as reflected in correlation, slightly exceeds its total correlation with evaporation. The excess amount gets neutralized due to indirect interaction of wind with other parameters.

4.2.4. *July*

The direct and indirect effects for this month are shown in Table 5. Peak rainfall activities with nearly overcast skies is the chief feature during this month. The thick clouds

TABLE 6

Direct and indirect effects by various parameters during October

Element/Effect	x_2	x_3	x_4	x_5	x_6
			New Delhi		
Direct effect	0.46	0.43	0.23	0.15	0.29
Indirect effects					
through x_2	-	0.21	0.18	-0.05	0.14
through x_3	0.20	-	0.01	-0.05	-0.13
through x_4	0.09	0.01	-	-0.11	0.01
through x_5	-0.02	-0.02	-0.07	-	0.02
through x_6	0.09	-0.09	0.01	0.03	-
Corr. Coeff. with x_1	0.82	0.54	0.36	-0.03	0.33
			Calcutta		
Direct effect	0.19	0.48	0.05	-0.33	0.19
Indirect effects					
through x_2	-	0.02	-0.01	0.02	0.06
through x_3	0.05	-	0.03	-0.03	0.10
through x_4	0.00	0.00	-	-0.01	0.01
through x_5	-0.03	0.02	0.05	-	-0.03
through x_6	0.06	0.04	0.05	0.02	-
Corr. Coeff. with x_1	0.27	0.56	0.17	-0.33	0.33
			Pune		
Direct effect	0.25	0.40	0.13	-0.14	0.37
Indirect effects					
through x_2	-	0.08	0.04	-0.05	-0.02
through x_3	0.12	-	0.09	-0.22	-0.12
through x_4	0.02	0.03	-	-0.07	-0.04
through x_5	0.03	0.08	0.08	-	-0.02
through x_6	-0.03	-0.11	-0.10	0.04	-
Corr. Coeff. with x_1	0.39	0.48	0.24	-0.44	0.17

seldom permit deep penetration of insolation on the surface. Thus, the direct effect is not large except at Calcutta where radiation bears a correlation of $r = 0.44$ with evaporation and accounts for over 80% of indirect and direct effects. Again at Calcutta as also at Pune, direct effect of maximum temperature overshadows the indirect effect. New Delhi presents an interesting picture. Here, no doubt directly maximum temperature contributes nearly a third of its total effect but it is its interaction through humidity that contributes about half of its total effect on evaporation.

Direct effect of sunshine at New Delhi is low; in fact it is negative. Whatever effect it exerts, it is indirect through interaction *via* humidity. Effect of sunshine at Calcutta, though negligible, is mostly direct and indirect effect (*via* maximum temperature) at Pune are nearly equal.

Effect of humidity at Calcutta on evaporation directly by the weather parameters or indirectly though interaction with other elements is found negligible in July. A marked direct effect of humidity (r = -0.52) is seen at New Delhi, though its indirect effect through maximum temperature is also substantial. At Pune also, indirect effect *via* maximum temperature is very large and accounts for 80% of the total effect.

Wind affects evaporation conspicuously at New Delhi and Pune, mostly directly. At the former location indirect effect *via* humidity is equally significant (r = 0.24). Like humidity, wind has minimal influence on evaporation at Calcutta during the month.

4.2.5. *October*

With the withdrawal of monsoon over most parts, the sky remains mainly cloud free particularly in north India during October. Radiation directly plays a major part in enhancing evaporation at New Delhi ($r = 0.46$) and to some extent at Pune ($r = 0.25$). It also contributes directly about 70% of whatever little effect it has on evaporation at Calcutta (Table 6). In association with maximum temperature too, radiation indirectly influences, to a great extent at New Delhi and Pune. Maximum temperature, like radiation exerts direct effect on evaporation but much more prominently, with correlation equal to 0.43, 0.48 and 0.40 at New Delhi, Calcutta and Pune respectively. Surprisingly, sunshine either directly or indirectly does not contribute much towards enhancing evaporation.

Pune and Calcutta being comparatively more moist than New Delhi during October (India Meteorological Department, 1967), its influence is seen only at these locations. Nearly whole of its effect is direct ($r = -0.33$) and half of the total effect at Pune is due to interaction of humidity with maximum temperature.

Wind contributes largely and directly at New Delhi and significantly at Calcutta. The direct effect of wind at Pune in increasing evaporation ($r = 0.37$) far exceeds the total correlation it has with the latter. However, the indirect effect through interaction with remaining elements being all negative, the net correlation ($r = 0.17$) attains nearly half of the correlation due to direct effect at Pune.

4.3. *Multiple regression analysis*

The data was also subjected to multiple regression analysis with evaporation (x_1) as dependent parameter and radiation (x_2), maximum temperature (x_3), sunshine (x_4), relative humidity (x_5) and wind speed (x_6) as independent variables. In developing the regression equation, only those parameters were retained whose partial t values were significant at 5% level. The equations obtained are given below:

(*i*) New Delhi

$$x_1 = 1.18 + 0.10\, x_2 + 0.06 x_3 + 0.02\, x_4 - 0.03 x_5 \quad [R^2 = 0.79]$$

$$x_1 = -2.4 + 0.01\, x_2 + 0.23\, x_3 + 0.12\, x_6 \quad [R^2 = 0.90]$$

$$x_1 = -19.55 + 0.50\, x_3 + 0.04\, x_4 - 0.05\, x_5 + 0.41\, x_6 \quad [R^2 = 0.96]$$

$$x_1 = -1.19 + 0.01\, x_2 + 0.36\, x_3 - 0.08\, x_5 \quad [R^2 = 0.96]$$

$$x_1 = -6.90 + 0.09\, x_2 + 0.21\, x_3 + 0.02\, x_4 - 0.13\, x_6 \quad [R^2 = 0.88]$$

(*ii*) Calcutta

$$x_1 = -0.78 + 0.01\, x_2 + 0.14\, x_3 - 0.02\, x_5 + 0.09\, x_6 \quad [R^2 = 0.73]$$

$$x_1 = -2.72 + 0.33\, x_3 + 0.06\, x_5 + 0.17\, x_6 \quad [R^2 = 0.92]$$

$$x_1 = -9.22 + 0.02\, x_2 + 0.33\, x_3 + 0.13\, x_6 \quad [R^2 = 0.71]$$

$$x_1 = -9.49 + 0.03\, x_2 + 0.38\, x_3 \quad [R^2 = 0.66]$$

$$x_1 = -2.12 + 0.01\, x_2 + 0.21\, x_3 - 0.02\, x_5 \quad [R^2 = 0.63]$$

(*iii*) Pune

$$x_1 = 0.10 + 0.15\, x_2 + 0.01\, x_4 + 0.04\, x_5 + 0.30\, x_6 \quad [R^2 = 0.85]$$

$$x_1 = -7.02 + 0.12\, x_2 + 0.29\, x_3 + 0.09\, x_6 \quad [R^2 = 0.91]$$

$$x_1 = -13.40 + 0.01\, x_2 + 0.50\, x_3 + 0.23\, x_6 \quad [R^2 = 0.88]$$

$$x_1 = -21.61 + 0.02\, x_2 + 0.75\, x_3 + 0.01\, x_4 + 0.33\, x_6 \quad [R^2 = 0.86]$$

$$x_1 = -7.02 + 0.33\, x_3 + 0.13\, x_6 \quad [R^2 = 0.58]$$

It can be seen that the MCC in majority of cases is significant and explained more than 80% of the variance thus demonstrating their efficacy. Role of maximum temperature in enhancing evaporation is clearly evident from the equations. The equations also bring out contribution of surface wind in all months at Pune; May, June and July at New Delhi and January, May and June at Calcutta. Negative impact of relative humidity is confined to a few months *viz*. January and October at Calcutta, January and June at New Delhi and January at Pune.

5. Conclusions

(*i*) High correlation ranging from $r = 0.76$ to $r = 0.85$ is generally found between evaporation and radiation, reflecting its basic dependence on the available radiant energy.

(*ii*) In majority of the cases, radiation directly contributes to evaporation though in few cases its impact on evaporation is through its interaction with maximum temperature.

(*iii*) Like radiation, maximum temperature also bears high correlation with evaporation, mostly directly. In some instances it helps increased evaporation indirectly through radiation and humidity or in rare cases with wind.

(*iv*) Relative humidity is negatively correlated with evaporation; high humidity thus suppresses evaporation rates. Generally its direct influence on evaporation is much less than indirect effect *via* maximum temperature.

(*v*) Wind seems to have marginal influence on evaporation either directly or indirectly.

Acknowledgement

The authors are thankful to Shri U.K. Pande and A.N. Kale for computational support and Ms. Geeta Ramachandran for typing the text.

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