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Pan evaporation and potential evapotranspiration

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1. Evaporation is an important means of energy transfer and is a reverse flow to the downward stream of radiation from the sun and the atmosphere. Pans or tanks, because of the ease of operation, have become the most widely-adopted evaporation instruments in all parts of the world. Past work, however, on evaporation has shown that the rate of evaporaton varies inversely as the area of the evaporating surface and Fig. 1 (from Thornthwaite 1954) substantiates this statement. Penman (1948) points out that this should be expected mainly from the progressive moistening of the air while passing over the surface. This limitation, therefore, makes pans or other similar instruments unsuitable for evaporation measurement except under conditions of high atmospheric humidity. A great deal of effort has gone into the search for a satisfactory "coefficient", *i.e.*, a multiplying factor to be applied to an evaporimeter reading to give the appropriate value of evaporation for a large water surface subjected to the same weather conditions. Kohler's (1952) summary of *Lake Hefner Report* shows large variations in the monthly and annual coefficients but the discrepancies have subsequently been found to be not entirely due to the sizes of the pans, but the incoming radiant energy as well as the moisture condition of the overlying air have their own contributions. Water losses due to evapotranspiration bear no direct or simple relation to evaporation from free water surfaces, for, transpiration is a process that is, to a large extent, physiological in nature. To eliminate the moisture advection from consideration in evapotranspiration measurements, the tanks must be in a field planted to the same vegetation as in the tanks and which receives the same watering treatment as the tank itself; especial care should be exercised also in respect of the maintenance of the optimum conditions of soil moisture and the uniformity of vegetation characteristics both inside and outside the tanks. The need for reliable observations in arid and semi-arid areas is very great but these are also the regions where it is most difficult to establish and maintain satisfactory conditions. It should be appreciated in this connection that there is no relation between the potential evapotranspiration and such factors relating to the "evaporating power of the air" as the relative humidity or saturation deficit because of the reciprocal effect of the evaporation regime on the humidity condition of the atmosphere. For almost similar reasons pan evaporation too is influenced by the moisture content of the air and so it is not possible to determine P.E. (Potential Evapotranspiration) from pan data.

2. Alternative attempts were, therefore, made for determining this important climatic parameter (P.E.) from emperical formulae. Thornthwaite (Thornthwaite, Wilm *et al* 1944) to whom the credit goes for introducing this parameter into climatological literature has also evolved a semi-empirical formula for the evaluation of P.E. from easily available meteorological data, namely, air temperature and length of the day, the latter being essentially geographical in nature depending for its magnitude on the latitudinal location of the station and the time of the year. In the development of this formula, Thornthwaite

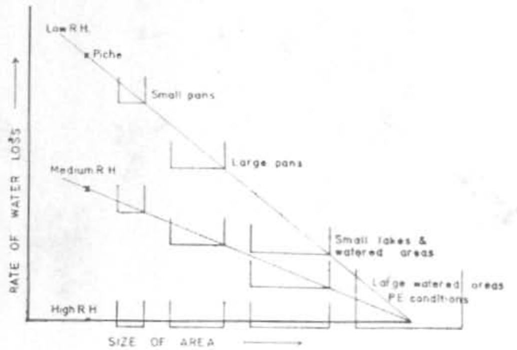

Fig. 1

(1948) thoroughly investigated the hydro-climatological implications of water balance on the one hand and the purely meteorological conditions like the influence of the wind and the diurnal temperature variations on the other and arrived at the final form containing the mean temperature and the latitude of the station under question. Evidence accumulated in recent years (Bernard 1945, Sanderson 1950) showed that this formula used in diverse climatic situations from high Arctic latitudes to equatorial regions has yielded satisfactory results. Work in India by Khosla (1949) confirmed that in a climatic sense temperature can be taken to be a complete measure of all the factors responsible for the loss of water to the atmosphere primarily by evaporation.

3. Recently, Mather (1954) compiled all available work on the measurement of P. E. and produced a valuable pamphlet in which the many aspects of potential evapotranspiration were discussed by workers from different parts of the world. The main conclusion from this compilation has been that, Thornthwaite's formula, in its present form, has the property of under-estimating P.E. in winter and over-estimating in summer. In spite of this the values, particularly on a monthly basis, are not very different from the computed data and thus, as an interim measure, it is not improper to use the formula for the determination of P.E. when measured data are not available. It is unfortunate that in India we are still thinking in terms of pan evaporation when the full implications and significance of the data of evapotranspiration have been emphasized by all workers in this field. As Thornthwaite (Thornthwaite and Mather 1955) himself has pointed out, his formula needs modification, probably seriously, in the tropics but this, as Ramdas (1957) says, has to await accumulation of reliable data of measured P.E. (not certainly of pan evaporation) for a number of years at different places.

4. It appears, therefore, that it is not proper to compare the P.E. data of Thornthwaite with the data of evaporation of Raman and Satakopan (1934). For one thing, Raman and Satakopan's formula (*i.e.*, Rohwer's) has been developed to give pan evaporation while Thornthwaite's is based on observations of hydrologic balance over extensive irrigated valleys and water-sheds and is, therefore, highly representative of field conditions. Regarding the humidity term in Rohwer's equation again there seems to be some divergence of opinion; if one accepts the vapour transport hypothesis of evaporation (Thornthwaite and Holzman 1942) it is clear that over a free water surface or moist land area, *i.e.*, under potential conditions, the distribution of moisture in the air column above will be such as to produce a moisture gradient of the same sign and magnitude under the same conditions of surface temperature. The rate of evaporation under such circumstances will be the same as P.E. which, therefore, is directly related to temperature.

5. The above considerations go to show that the pan (or Rohwer's equation) gives neither the actual evapotranspiration nor P.E.; it is not actual evapotranspiration since there is always undiminished water supply and is not P.E., for, the moisture conditions of the surroundings are, in general, not in conformity with the potential requirements. In agricultural or other similar operations, the direct use of Raman and Satakopan's data is, therefore, unwarranted.

6. Ramdas' attempt to derive P.E. from pan records deserves mention here; the

procedure (Ramdas 1957) involves two stages: firstly the reduction of the pan observations from the pan level to the ground level and secondly the correction for the departure of the surroundings from the potential conditions. The approach is noteworthy but one is not sure if it is justifiable to start directly with the pan data for this purpose. It would be highly important and very interesting to carry out such experiments on a much larger scale to make sure that the local conditions exercise no influence on the recorded data; the evapotranspirometers for this purpose should be maintained and operated strictly in accordance with the specifications in regard to size, installation and exposure. One thing that emerges from Ramdas' work is that his P.E. ($E_{OR\infty}$) is related to the pan evaporation (E) as

$$E_{OR\infty} = 0{\cdot}60\ E$$

Although Ramdas claims that these relations have been confirmed from experiments at Poona with pots having growing plants and saturated with water, this does not constitute a field check. For such a purpose there should only be an evapotranspirometer installation with ideal conditions of maintenance.

7. Ramdas prepared the P.E. map of India according to his formula starting with Raman and Satakopan's data of evaporation and he states that the map exhibits the same general features as the map of evaporation of Raman and Satakopan. For the obvious reason that his P.E. is linearly related to Raman and Satakopan's evaporation by only a constant coefficient, the two maps cannot but resemble each other; one fails to understand how this similarity can be taken as evidence for the validity of his P.E. formula.

8. For the map presented by Ramdas in Fig. 4 of his above-referred paper (1957), only the data of P.E. according to the 1948 scheme of Thornthwaite were supplied to him by the present author while the latter was in the U.S.A. This map is, in many respects, different from the maps prepared by the Laboratory of Climatology; apart from the

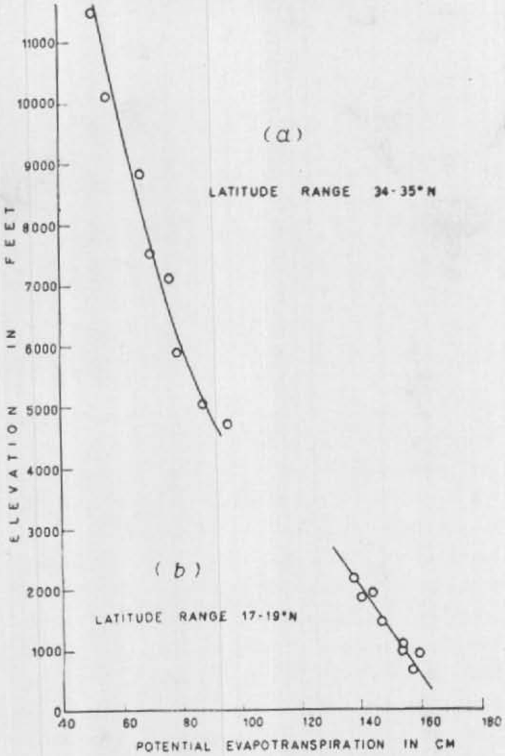

Fig. 2. Variation of P.E. with height

actual values this is due mainly to the very technique (Carter 1954) employed by the Laboratory in the preparation of the climatic maps. Objective interpolation among station values for the purpose of drawing isopleths of climatic parameters is basic to an accurate presentation of any climatic distribution. Every climatic pattern takes its major alignment from the principal topographic outlines. Regions of notable relief have thus the greatest climatic diversity while low lands are distinguished for their relative uniformity. Consequently, the topographic map is to some degree a guide to interpolation among climatic values. For example, as can be seen from Fig. 2 elevation is usually correlated with lowered P.E. and, therefore, smaller water deficit and greater water surplus. The pattern of P.E. thus closely reflects the topographic characteristics of a region although it does not usually correspond exactly with elevation contours. Although climatic data are often scanty in mountainous areas the correlation of elevation and climatic parameters improves with height; thus interpolated data are usually much more representative in mountains than in regions of lower relief. These considerations have dictated the type of base maps to be employed. A relief map with reliable contours was needed and the number of stations for which good data were available suggested a map of the scale of 1 : 5,000,000; the maps presented in the publication referred to by Ramdas are only the reduced versions of the above large scales ones (Subrahmanyam 1952-1954).

9. The similarities or dissimilarities between Ramdas' maps and Thornthwaite's maps should, therefore, be discussed in the light of what all that has been said above. It would appear that the actual features exhibited by the maps are dependent on the influence of the various factors used in the formulæ. The reason why Ramdas' maps show *highs* where Thornthwaite's maps show *lows* and *vice versa* is because of the altitudinal variations of the parameters employed in the two formulæ. It is, therefore, not correct to assume that one formula is superior to another in the absence of reliable measured data. We do not yet know how strong the influence of these various factors is on the loss of water from the ground to the atmosphere. Our understanding of the meteorological or climatic water balance will remain hazy unless extensive field measurements of evaportranspiration under the most representative conditions become available; until the arrival of that day, these controversies are bound to persist.

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