Technical Assistance
HYDROLOGY PROJECT

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Training module # SWDP - 19

How to analyse climatic data

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Table of contents

		<u>Page</u>
1.	Module context	2
2.	Module profile	3
3.	Session plan	4
4.	Overhead/flipchart master	5
5.	Handout	6
6.	Additional handout	8
7.	Main text	9

1. Module context

While designing a training course, the relationship between this module and the others, would be maintained by keeping them close together in the syllabus and place them in a logical sequence. The actual selection of the topics and the depth of training would, of course, depend on the training needs of the participants, i.e. their knowledge level and skills performance upon the start of the course.

2. Module profile

Title	:	How to analyse climatic data
Target group	:	Assistant Hydrologists, Hydrologists, Data Processing Centre Managers
Duration	:	60 min.
Objectives	:	After training, the participants will be able to • analyse climatic data
Key concepts	:	• basic statistics
Training methods	:	Lecture, software
Training tools required	:	Board, computer
Handouts	:	As provided in this module
Further reading and references	:	

3. Session plan

No	Activities	Time	Tools
1	***General*** • Analysis of climatic data	5 min	 OHS 1 OHS 2
2	***Analysis of pan evaporation*** • Pans for estimating open water evaporation • Effects of mesh screening • Pans for estimating reference crop evapotranspiration	10 min	 OHS 3 OHS 4 OHS 5
3.	***Estimation of potential evapotranspiration*** • General • The Penman method • Other potential evapotranspiration formulae	40 min	 OHS 6 OHS 7 OHS 8 OHS 9 OHS 10 OHS 11 OHS 12 OHS 13 OHS 14 OHS 15 OHS 16

4. Overhead/flipchart master

5. Handout

Add copy of Main text in chapter 19, for all participants.

6. Additional handout

These handouts are distributed during delivery and contain test questions, answers to questions, special worksheets, optional information, and other matters you would not like to be seen in the regular handouts.

It is a good practice to pre-punch these additional handouts, so the participants can easily insert them in the main handout folder.

7. Main text

Contents

1.	General	1
2.	Analysis of pan evaporation	1
2.1	Pans for estimating open water evaporation	1
3.	Other potential evapotranspiration formulae	7

How to analyse climatic data

1. General

- **Evaporation is the process by which water is lost to the atmosphere in the form of vapour from large open free water bodies like ponds, rivers, lakes and reservoirs.**

- **Transpiration is the process by which water leaves the body of a living plant and reaches the atmosphere as water vapour.** The water present as soil moisture in the root zone is extracted by the vegetation through its roots and is passed through the stem and branches and is eventually lost as transpiration from the leaves. **For hydrological purposes, evaporation and transpiration processes are commonly considered together as evapotranspiration**

- **Potential evapotranspiration (PE) is usually defined as the water loss which will occur from a surface fully covered by green vegetation if at no time there is a deficiency of water in the soil for the use of vegetation. It is primarily dependent on climatic conditions.**

- **Actual evapotranspiration (AE) is the real evapotranspiration at a location dependent on the available moisture in the soil which is in turn dependent on soil characteristics. It may be calculated from PE for the specific conditions at the site.**

- **Evaporation from a free water surface and potential evapotranspiration are the principal variables of interest in hydrology. Evaporation estimates may be based on measurement of losses from an evaporation pan or on theoretical and empirical methods based on climatological measurements.** Practical estimation of potential evapotranspiration depends on estimation from climatological data. Several researchers have developed empirical formulae for estimation of evaporation and evapotranspiration from climatic data. These formulae range from simple regression type equations to more detailed methods such as those representing water budget, energy budget and mass transfer approaches**; the principal methods in use are based on the Penman equation and methodology as discussed in full.**

- **Climatic data (with the exception of measured pan evapotranspiration) are thus not themselves of interest in hydrology but they are required for the estimation of evaporation from open water and evapotranspiration.**

2. Analysis of pan evaporation

2.1 Pans for estimating open water evaporation

The standard Class A pan used in India, the method of measurement, typical errors and error detection have been described in Module 16. Evaporation measured by pans does not represent the evaporation from large water bodies such as lakes and reservoirs. Pans have the following limitations:

- Pans differ from lakes and reservoirs in the heat storage characteristics and heat transfer. Pans exposed above ground are subject to heat exchange through the sides

- The height of rim in an evaporation pan affects the wind action over the surface.
- The heat transfer characteristics of the pan material is different from that of the reservoir

Since heat storage in pans is small, pan evaporation is nearly in phase with climate, but in the case of very large and deep lakes the time lag in lake evaporation may be up to several months. Estimates of annual lake evaporation can be obtained by application of the appropriate lake – pan coefficient to observed pan evaporation.

The lake – pan coefficient is given by E_l / E_p where E_l is the evaporation from the lake and E_p is the evaporation from the pan. Pan - lake coefficients show considerable variation from place to place and from month to month for the same location (WMO Technical Note 126). The variation from month to month precludes the use of a constant pan coefficient.

Monthly pan coefficient depends on climate, and lake size and depth, and range will generally vary from 0.6 to 0.8. For dry seasons and arid climates the pan water temperature is less than the air temperature and the coefficient may be 0.60 or less whilst for humid seasons and climates where the pan water temperature is higher than air temperature pan coefficients may be 0.80 or higher. The average value used is generally 0.7. Based on the studies carried out in India, the average pan - lake coefficient for the Indian Standard pan was found to be 0.8 ranging from 0.65 to 1.10. Ramasastri (1987) computed open water evaporation using pan – lake coefficients for whole of India based on the evaporation data of 104 US Class A pan evaporimeters.

2.2 Effects of mesh screening

The top of the standard pan in use in India is covered fully with a hexagonal wire netting of galvanised iron to protect the water in the pan from birds. The screen has an effect to reduce pan evaporation by about 14 % as compared to that from an un-screened pan. Although a correction factor of 1.144 is commonly applied, it seems preferable, to retain the originally measured values in the archive, to indicate that this is the case in reports, and to leave mesh corrections to users. This is to allow for the possibility that future amendments may be made to the correction factor.

2.3 Pans for estimating reference crop evapotranspiration

Provision is made in HYMOS for the estimation of reference crop evapotranspiration from:

$$E_t = K_P \, .E_{pan} \qquad 1$$

where

K_P = pan coefficient (FAO (1977) publication No 24)
E_{pan} = pan evaporation in mm / day

The pan coefficient is a function of relative humidity, daily windrun and the fetch. The fetch depends on the dryness or wetness of the upwind land surface as illustrated in Fig. 1. There are two cases:

- for case 1 the fetch is the length of the upwind green crop from the pan
- for case 2 the fetch is the length of the upwind dry surface between the crop and the pan

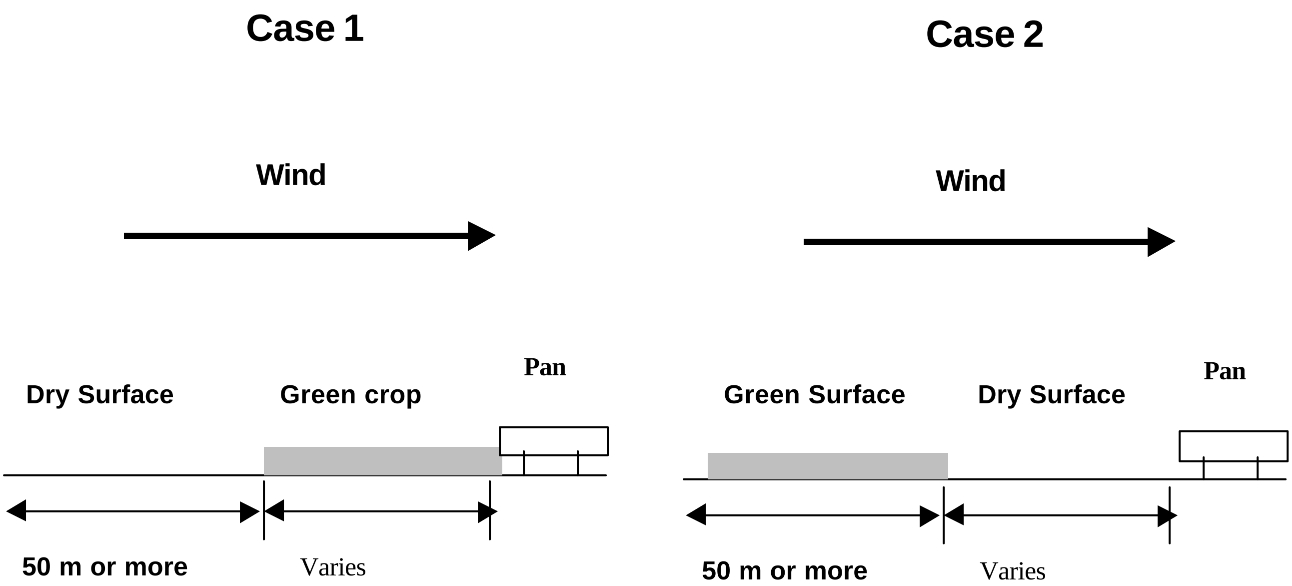

Fig. 2.1: Definition sketch for computing pan coefficient

2.4 Pan evaporation references

Gupta, Shekhar; Vasudev and P. N. Modi (1991) ‘A regression model for potential evapotranspiration estimation’, Journal of Indian Water Resources Society, Vol 11, No 4, pp 30 – 32

Ramasastri, K. S. (1987) ‘Estimation of evaporation from free water surfaces’ Proceedings of National Symposium on Hydrology Roorkee (India), pp II – 16 to II – 27

Venkataraman, S. and V. Krishnamurthy (1965) ‘Studies on the estimation of Pan evaporation from meteorological parameters’, Indian Journal of Meteorology and Geophysics, Vol.16 , No.4 pp 585 - 602

World Meteorological Organisation (1966) ‘Measurement and estimation of evaporation and evapo-transpiration’ WMO Technical Note No. 83

World Meteorological Organisation (1973) ‘Comparison between pan and lake evaporation WMO Technical Note No. 126

3. Estimation of potential evapotranspiration

3.1 General

The Penman method, in wide use for estimation of potential evapotranspiration arose from earlier studies of methods to estimate open water evaporation. In turn, both depend on the combination of two physical approaches which have been used in calculating evaporation from open water:

- the mass transfer method, sometimes called the vapour flux method, which calculates the upward flux of water vapour from the evaporating surface
- the energy budget method which considers the heat sources and sinks of the water body and air and isolates the energy required for the evaporating process

The disadvantage of these methods is the requirement for data not normally measured at standard climatological stations. To overcome this difficulty Penman (1948) developed a formula for calculating open water evaporation, combining the physical principles of the mass transfer and energy budget methods with some empirical concepts incorporated, to enable standard meteorological observations to be used. The method was subsequently adapted to estimate potential evapotranspiration and to substitute alternative more commonly measured climatic variables for those less commonly measured.

3.2 The Penman method

The Penman formula may be presented in a number of formats but may be conveniently expressed as follows:

$$E = \frac{\Delta}{\Delta + g} R_n + \frac{g}{\Delta + g} f(u)(e_s - e_a) \qquad 2$$

where:

E = reference crop evapotranspiration (mm/day)
Δ = slope of e_s - t curve at temperature t (mb/°C)
γ = psychometric constant (mb/°C)
R_n = net radiation (mm/day)
$f(u)$ = wind related function
e_s = saturation vapour pressure at mean air temperature (mb)
e_a = actual vapour pressure (mb)

The vapour pressure-temperature gradient D is computed from:

$$\Delta = \frac{de_s}{dT} = \frac{4098\, e_s}{(237.3 + T)^2} \qquad 3$$

where:

T = t + 273.16 (°Kelvin)
t = air temperature (°C)

and

$$e_s(T) = 0.6108 \exp\left(\frac{17.27\, T}{T + 237.3}\right) \qquad 4$$

The psychometric constant g is computed from:

$$g \quad = \quad \frac{e_s\ (T_w) \quad - \quad e_a\ (T_a)}{T \quad - \quad T_w} \quad = \quad \frac{c_p\ p}{e\ l} \qquad 5$$

where:

c_p = specific heat of air (=1.005 $kJkg^{-1}$)
p = atmospheric pressure (kPa)
ε = ratio of molecular masses of water vapour and dry air = 0.622
λ = latent heat of vaporisation ($kJkg^{-1}$)

Where the air pressure is not measured, it is estimated as:

$$p \quad = \quad 101.3 \left(\frac{T \quad - \quad 0.0065\,H}{T} \right)^{5.256} \qquad 6$$

Where

H = elevation relative to m.s.l (m)

Where net radiation R_n is not available (as is normally the case in India), it can be substituted in turn by net shortwave and net longwave radiation, and then by bright sunshine totals which are more commonly measured at standard climatological stations. Thus net radiation can be computed from:

$$R_n = R_{ns} - R_{nl} \qquad 7$$

where:

R_{ns} = net shortwave radiation
R_{nl} = net longwave radiation

and in turn net shortwave radiation is:

$$R_{ns} = (1 - a\,)\,R_s \qquad 8$$

where:

α = albedo
R_s = shortwave radiation

If the shortwave radiation is not available it is computed from:

$$R_s = R_a\ (a_1 + b_1\ n / N) \qquad 9$$

where:

R_a = extra terrestrial radiation (available from tables dependent on latitude and time of year)
n/N = actual to maximum bright sunshine duration (from Campbell Stokes sunshine recorder)
a_1 , b_1 = coefficients

If the net longwave radiation is not available it is estimated from:

$$R_{nl} = sT^4 (a_2 - b_2 \sqrt{e_a})(a_3 + b_3\, n / N) \qquad 10$$

where:

σ = Boltzmann constant (σ = 2.10^{-9})
a_2, b_2 = coefficients in vapour term
a_3, b_3 = coefficients in radiation term

The wind function f(u), as proposed by FAO is given by:

$$f(u) = 0.26(1 + U_{24} / 100) \qquad 11$$

where:

U_{24} = 24 hour wind run (km/day) measured at 2 m above ground level

The actual vapour pressure is computed by one of the following three formulae depending on which time series is available. For current data the formula using wet and dry bulb temperature is used even if relative humidity and dew point have already been calculated by the observer; this is to avoid incorporating observer's calculation errors. The other formulae may be required for historic data where wet and dry bulb temperatures are no longer available.

$$e_a = e_s\, .rh / 100 \qquad 12$$

$$e_a = e_s(t_{wb}) - g(t_{db} - t_{wb}) \qquad 13$$

$$e_a = e_s\,(t_{dew}) \qquad 14$$

where:

rh = relative humidity in %
t_{wb}, t_{db} = wet and dry bulb temperature (°C)
t_{dew} = dew point temperature (°C)

Daily potential evapotranspiration using the Penman formula may thus be computed using the following observations at standard Indian climatological stations:

t_{max} , t_{min} to obtain t_{mean} as (t_{max} ,+ t_{min})/2 in (°C)

t_{wb}, t_{db} to obtain actual and saturated vapour pressures (e_a , e_s)

U_{24} to obtain the wind function $f(u)$

n actual daily bright sunshine duration using Campbell Stokes sunshine recorder to compute net shortwave and net longwave radiation (R_{ns} , R_{nl})

For current data these series must be available for calculation of evapotranspiration to be carried out. Other constants and coefficients required by the method are held in HYMOS.

3. Other potential evapotranspiration formulae

A large number of empirical and theoretical formulae have been proposed for the calculation of potential evapotranspiration and several of these are available in HYMOS. These will not form a part of routine processing but may be used for special applications. **The following methods are available:**

- Christiansen method
- FAO radiation method
- Makkink radiation method
- Jensen-Haise method
- Blaney-Criddle method
- Mass transfer method

The minimum requirements of observed variables to obtain estimates using the above methods is shown in Table 1.

Table 1: Minimum series requirements to obtain PE estimates by various methods

	Christian sen	Radiation	Makkink	Jensen-Haise	Blaney-Criddle	Mass Transfer
Air pressure						
Temp. max.	✓	✓	✓	✓	✓	
Temp. min.	✓	✓	✓	✓	✓	
Temp. db.	✓	✓			✓	✓
Temp. wb.	✓	✓			✓	✓
Wind run	✓	✓			✓	✓
Sunshine hrs	✓	✓	✓	✓	✓	
Altitude	✓			✓		