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AN ESTIMATE OF WATER LOSS BY EVAPORATION IN PAKISTAN

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It included 46.2 maf as percolation and 30.1 maf as evaporation. In this estimate the losses through the river channels were also included.

Very recently in May 1979, Master Planning and Review Division of WAPDA has conducted water balance studies. The main deviation has been the losses through water courses assumed at 40% of the water let in at head. This has raised the estimate of evaporation loss from surface water resources equal to 33.1 maf. Had it been assumed equal to 15 or 20 percent as has been the estimate,adopted by previous workers, the total evaporation loss approaches 30 maf as determined by Harza. Their estimate of pre-1970 was 29.5 maf and post-1970 equal to 30 maf. It is thus assumed that about 30.0 maf of water is being lost through water conveyance system of rivers and canals.

Evaporation loss also occurs from ponded water. Out of fifteen storages of various sizes, thirteen small dams, some lakes of Sind, from the village ponds and those existing between the guide banks and marginal bunds of 20 barrages, it is estimated that nearly 6.5 maf of water is lost as evaporation out of these ponds. The evaporation loss from each source of free water surface is given in Table-* below:

Table * - Details of Water Lost as Evaporation from Storages, Lakes and Ponds.

S.No.	Source of Water Loss	Cusecs	maf
1	Loss from 15 storages and dams	2940	2.13
2	Loss from 13 small dams	140	0.101
3	Loss from Lakes in Sind	2630	1.91
4	Loss from village ponds	730	0.54
5	Loss from ponds along Barrages	2441	1.78
	Sub Total:	8881	6.5
6	Loss from soil surface with water table within 5.0 feet	136740	9.98

Water is also lost as evaporation from soil surface. If the groundwater exists say within ten feet of surface the loss is significant. It is estimated that out of the Indus plains from an area of 4.36 million acres in which the ground water lies between surface to 5 feet depth, nearly 10 maf of water is lost as evaporation from the soil surface.

If the soil evaporation from the areas with ground water deeper than 5 feet is also included, the figure rises to 16.8 maf.

In this study a brief resume of all the various formulae developed after the pioneer work of Dalton is given. The formulae put forth by Rohwer, Penman, Blaney Criddle, Hargreaves, etc. are also mentioned. Certain experimental method such as water budget, energy budget and mass transfer technique used on actual storages to determine evaporation loss are also explained.

The estimate of evaporation contained in this paper are based upon data of Class A Pan. The limitation of the results of pan evaporation depending upon the type of pan, its size, colour etc. are discussed. For converting the data of pan evaporation to actual lake reservoir, coefficients have been determined which have seasonal variation. An average coefficient has been determined and utilized to convert pan data to lake evaporation.

In this study ten years observed data of evaporation in Class A pan at 86 sites in Pakistan has been used to determine lake evaporation for all the twelve months of a year. Equi-evaporation contours for each month are plotted. Such evaporation contours from first April to 30th September and from first October to 31st March as well as for full year are also plotted. Based upon these contours evaporation loss

from storage dams, small dams, lakes, village ponds and ponds above barrages as given in the beginning was determined. This study shows the enormous order of water being lost as evaporation, a major component of which cannot be checked. There are innumerable small storage ponds, etc of which if evaporation is reduced the results will be a material gain to the country.

ACKNOWLEDGEMENT

The study on an estimate of evaporation from free water surface existing in Pakistan was undertaken on the advice of the Chairman, Irrigation, Drainages and Flood Control Research Council. The basic data of pan evaporation was collected from WAPDA Surface Water Hydrology Directorate and lake evaporation contours were plotted for whole of Pakistan. Data about big and small storages, lakes, village ponds and those existing above barrages was collected from various departments.

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I. WATER LOSS THROUGH RIVERS AND CANALS.

Surface water is lost both by seepage and evaporation. The seeped water generally gets accumulated in the granular unconsolidated formations or in cracks, fissures and pores of rocks. It flows out to lower elevations or saturates the underground formation and sometimes appears as springs. It is not completely lost. A major portion of the seeped water can be recovered. The evaporation component is, however, lost either

i) from the free water surface exposed to atmosphere,
ii) from land or soil formation possessing high ground water,
iii) by direct evaporation from snow and from precipitation and
iv) by transpiration of vegetations.

Unlike seepage, evaporation loss is invisible and cannot be recovered.

Since the construction of canals system, the engineers and other water users have been faced with the loss of water. A canal system consists of main canals, main and small branches, distributaries and minors, water courses and the irrigated fields. From the head of a canal down to the fields, the total loss due to seepage and evaporation is about 50 to 62 percent (Table 1). It includes about 23-25 percent loss through the main canals, branches, distributaries and minors. Water lost through water courses is estimated equal to 15 to 20 percent

of their head discharge and that through the irrigated fields also of the same order. Engineers have been estimating this loss since the start of irrigation practices. Estimate of losses commonly reported are given in Table 1.

Table-1 Estimate of Water Loss as Percentage of Canal Supplies at Head.

Canal System	Authorities					
	Kennedy	Benton	Blench	Khunger*	Revelle*	Harza
Main Canals & Branches.	5) 15)	16.4	5) 15)	15.5	-	-
Distributaries	6	6.1	7	5.4	-	-
Water Courses	21	20.2	20	6.5	-	-
Total	47	42.7	47	27.4 (32.88)	29.7 (35.64)	42.6
Farm losses, (Evaporation & Wastage)	25	19.1	15 (assumed)	20.0 (assumed)	14.65	15.6
Overall total including evaporation	72	61.8	62	52.9	50.3	58.2

* Khunger and Revelle gave seepage loss only while the estimate of the rest workers gives the total loss which also includes the loss by evaporation. In case of Khunger and Revelle if 20% is added as evaporation loss to 27.4 and 29.7 and adding farm losses, the overall loss becomes 52.9 and 50.3 respectively.

Majority of the workers have found the total loss between 50 to 62 per-cent of that let into a canal at its head.

1.1. Huntings Estimate of Evaporation and Seepage Loss.

Huntings Technical Services Consultant to Wapda conducted a field study in Lower Indus to determine seepage and evaporation loss from canals of different categories and capacities. Their findings are given in Table-2.

Table-2

Loss from canals in Lower Indus measured by Huntings Technical Services, (Seepage, Evaporation and total loss is measured in cu.ft. per sec. per mill. sq.ft. of area).

Sr. No.	Barrages	Canals	Location R.D.	Discharge (Cs.)	Seepage	Evaporation	Total Loss	Evaporation as % of total loss.
1	Sukkur	L.B.Rohri	180	12000	5.5	0.3	5.8	5.2
2	Sukkur	L.B.Nara	146	9000	4.1	0.3	4.4	6.8
3	G.M.	L.B.Pinyari	35	5500	2.5	0.2	2.7	7.4
4	Sukkur	R.B.North-West	100	3500	6.3	0.2	6.5	3.1
5	Sukkur	L.B.Jamrao	275	1900	3.8	0.2	4.0	5.0
6	Sukkur	L.B.Mithrao.	200	1600	4.0	0.3	4.3	7.0
7	Sukkur	L.B.Faizwah	21	200	4.5	0.2	4.7	4.3
8	Sukkur	L.B.Bhampar Dy.	0-0.2	120	2.1	0.3	2.4	12.5
9	Sukkur	L.B.Chiho MR	1	35	4.7	0.2	4.9	4.1
10	G.M.	L.B.Moho MR	0-1.2	20	2.5	0.3	2.8	10.7
11	Sukkur	L.B.Watercourse 2L	0-0.5	2.5	4.2	0.3	4.5	6.7
12	Guddu	L.B.Watercourse 17R (ex-Dingro Wah)	0.5	1.5	8.2	0.3	8.5	3.5

TABLE -5

Southern Zone	Seepage	Evaporation	Total loss
Rivers	0.1	6.9 (ET)	7.0 (ET)
Canals	6.3	3.6	9.9
Water courses	10.32	2.58	12.9
Private Tubewells	0.16	0.04	0.2
Field Losses	3.54	2.30	5.9
Total	20.42	15.42	35.9
Groundwater	12.4	9.8	22.2
Total Northern	38.18	26.02	64.2
Total Southern	20.42	15.42	35.9
Grand Total	58.60	41.50	100.1

In Table 5, the evaporation from rivers both in the northern and southern zones is worked out by estimating evaporation from free water surface and evapotranspiration from the active flood plains. Actual free water surface evaporation is as under;

Zone	f.w.s.	Evapotranspiration	Total
Northern	8.5	5.0	13.5
Southern	3.5	3.4	6.9
Total	11.0	8.4	20.4

The total loss by evaporation alone is thus

Northern zone	26.02 maf
Southern zone	15.42 maf
Total:	41.44 maf
Subtracting Evapotranspiration	8.40 maf
Balance	33.04 maf

Thus according to Revised Action Programme the evaporation loss is 33.04 maf. In these estimates the loss from water courses was assumed as 40 percent and evaporation equal to 20 percent of the total loss. This has increased the order of loss of f.w.s. evaporation by about 3 maf so that the previous estimate of Harza equal to 30 maf appear to be the correct figure.

1.3.1 Evaporation loss from soil surface

Evaporation loss from soil having water table at varying depths was also estimated.

Referring to Figure-5, the recharge and evaporation from the two zones was as under: (All figures are in maf).

Zone	Recharge to Groundwater	Evaporation from groundwater	Total Loss
Northern	26.5	7.0	33.5
Southern	12.4	9.8	22.2
Total	38.9	16.8	55.7

This estimate of evaporation loss from soil is worked out for all depths of water table. If the area is limited to that with water table at 5 feet depth, the soil evaporation figure is reduced to 10 maf. Thus 6.8 maf is additional loss by evaporation from soil having water table deeper than 5 feet.

2.0 FORMULAE DEVELOPED TO ESTIMATE FREE WATER SURFACE EVAPORATION.

2.1 Evaporation is a Result of Molecular Activity of Water.

Molecular activity of water is a result of several physical parameters which are;

i) The solar radiations which supply heat energy to the molecules;

ii) temperature of the water and air, variation of which changes the order of evaporation;

iii) humidity effects the water vapour absorption property of the air;

iv) atmosphere layer adjacent to water surface under certain conditions attains saturation causing decrease of evaporation. Wind intensity disturbs the water vapour saturated layer causing restart of evaporation;

v) evaporation is also related with barometric pressure;

vi) molecules of different liquids have different order of molecular activity and thus have different order of evaporation.

Molecules of liquid are in constant agitation, moving at high velocities. Some of the molecules escape the water surface. The energy needed by the molecules for this purpose is drawn from the liquid resulting in fall of its temperature. Actually for a change of state from liquid to vapour, one gram of water needs 597 calories which are drawn from the

liquid causing fall in its temperature.

The escaping molecules increase the vapour pressure in the air. This pressure is in addition to that which already exists in different gases. The pressure of water vapour is thus a partial pressure. The water vapour can attain saturation. The maximum saturation pressure for water for a given temperature has been determined. In Table-6 the saturation vapour pressure is given in inches of mercury.

Table-6 : Relation between temperature (Temp °F) and Saturation Vapour Pressure V_p

Temp. °F	V_p	Temp. °F	V_p	Temp. °F	V_p
-30	0.007	35	0.203	100	1.936
-25	0.101	40	0.248	105	2.246
-20	0.013	45	0.300	110	2.599
-15	0.017	50	0.363	115	2.999
-10	0.022	55	0.436	120	3.451
- 5	0.029	60	0.522	125	3.960
0	0.038	65	0.623		
5	0.049	70	0.740		
10	0.063	75	0.876		
15	0.081	80	1.033		
20	0.103	85	1.215		
25	0.131	90	1.423		
30	0.165	95	1.662		

During the process of evaporation some molecules continue to escape the water surface, while some other return back. If the returning molecules are in excess

Glossary of Terms in the Formulae

E = Evaporation in inches per 24 hours.

e_s = Mean vapour pressure of saturated vapour at the temperature of water surface, inches of mercury.

e_d = Mean vapour pressure of saturated air at the temperature of the dew point, inches of mercury.

$f(u)$ = A function of horizontal wind velocity.

W = Mean velocity of wind at ground, or water surface in miles per hour.

B = Mean barometer reading inches of mercury at 32°F.

t = Mean temperature for the day in °C.

t^1 = Mean temperature of wet bulb thermometer °C.

D = Percentage humidity at 8.0 am.

$\frac{d_e}{d_s}$ = The rate of change in maximum vapour pressure with temperature.

e_w = the same as e_d

U_2 = wind velocity at 2 metres height.

2.3 Evaporation Formulae Based upon Solar Radiations and percentage humidity.

Several workers have developed formulae to determine evaporation based upon Solar Radiation and Humidity. Well known formulae are due to Penman, Blaney Criddle, Hargreaves, Nazir, Cummings Richardson, Thornthwaite Lowry Johnson, etc.

Formula of Penman has already been mentioned. Blaney and Criddle in 1959 put forth a relation

$$f = C \frac{txP}{100} \quad \text{- - - - - - - - - - - - (13)}$$

Where f= evaporation in inches per month

t= mean monthly air temperature in °F

P= mean monthly percentage of day time hours and

C= a constant usually taken equal to 1 when determining evaporation from a free water surface.

For determining P, the percentage day light hours tables have been prepared for sites located at different latitudes.

Hargreaves put forth a relation of the type

$$e = m\,(t-32) \quad \text{---------- (14)}$$

in which e = monthly evaporation in inches

t = mean monthly temperature in °F

m = c d in which c is a climatic factor depending upon humidity and wind movement, and was found equal to (0.38-0.0038h)

h = mean monthly relative humidity at noon

d = a monthly day time coefficient depending upon latitude.

The ultimate shape of Hargreaves relation becomes:

$$E = (0.38-0.0038h) \times d(t-32) \quad \text{------ (15)}$$

Nazir working with Irrigation Research Institute in 1965 put forth a relation

$$E = \phi \frac{P}{H} (t-32) \quad \text{---------- (16)}$$

in which

E is the monthly free water surface evaporation in inches and H is mean monthly humidity observed at 8.00 a.m. P and t represent mean monthly percentage

sunshine hours and mean monthly temperature in °F. Ø is a constant found equal to 0.879.

Using the formulae put forth by Penman, Rohwer, Blaney Criddle, Hargreaves, Nazir, evaporation for certain sites in Pakistan was determined and compared with the actually observed values. These results are put forth in Table-8.

Similar information was worked out by Dr.Revelle and his associate for ten important stations in Pakistan. Comparative values of monthly evaporation worked out by the formulae derived by various workers are given in Table-9.

Formulae of Cummings and Richardson, Thornthwaite, Lowry Johnson, and several other workers are not so very common and for this reason not explained in the text.

3.0 EXPERIMENTAL METHODS TO DETERMINE EVAPORATION.

After the enunciation of fundamental relation of evaporation from free water surface by Dalton in 1802, for about hundred years scientists working in different countries and in different locations continued to determine the constant of the Dalton equation. Rohwer and later on Penman in 1948 tried to introduce other meteorological parameters. In the next few years Blaney Criddle, Hargreaves, Thornthwaite introduced temperature, humidity, bright day time hours etc. Besides these approaches attempts were made to base the estimate of evaporation on experimental measurements from storages and small pans. Some of the important methods utilized were:

i) water budget method often called storage equation;

ii) energy budget method,
iii) mass transfer techniques; and
iv) small size evaporation pans.

A brief description of the first three methods is given below before dealing in details with the use of small size pans.

3.1 Water Budget Method or Storage Equation.

A method called water budget technique has been developed to determine loss of water by evaporation from a storage. The method involves an accurate measurement of the inflow and outflow from a storage. During the measurement, if some precipitation occurs, it is also added to the storage:

Suppose:

E is the loss by evaporation from a storage,
I is the inflow into the storage,
Q is the outflow through the storage,
P is the addition from precipitation,
Q_s is the loss as a result of seepage,
S_1 is the storage at a certain period, and
S_2 is the storage at some other period during the measurement.

Then loss by evaporation is related with these parameters as given in equation:

$$E = (S_1 - S_2) + P + I - Q - Q_s \quad \text{-----} \quad (17)$$

This is generally called storage equation. The approach is simple in theory but its application rarely

produces reliable results because the parameters mentioned above are difficult to be accurately determined. Due to these difficulties evaporation from a storage by this technique cannot be estimated with reliance. In USA after a study of one hundred lakes and storages, only Lake Hefner in Oklahoma was found suitable to utilize this technique.

3.2 Energy Budget Method for Calculation of Evaporation.

This is another method by which energy conception is made use of. For changing water to gaseous state heat energy called the latent heat of vaporization of water is needed. The variation of latent heat with temperature of water is 596 calories per gram at 0 °C, 580 calories per gram for 27 °C and 540 calories per gram for 100°C.

Suppose the temperature of water of the lake is such for which 590 calories of heat energy are needed to vaporize one gram of water. The energy budget of water stored in the lake, 'Q_q' for some interval of time can be expressed by the following equation:

$$Q_q = Q_s - Q_{rs} - Q_{lw} - Q_h - Q_e - Q_v - Q_{ve} \quad \text{--- (18)}$$

In this equation

Q_q is the change of energy stored in the lake. It is equal to

Q_s the incoming solar radiation falling on the surface of water,

Q_{rs} the reflected short wave radiation;

Q_{lw} the net energy lost by the water body through exchange of long wave radiation with the atmosphere;

Q_h the sensible-heat transfer (conduction) by turbulent exchange from the water body to the atmosphere;

Q_e is the energy utilized for evaporation;

Q_v is the increase in energy stored in the lake by flow of water, and

Q_{ve} is the net energy advected out of the water body by the evaporated water.

The various forms of energies mentioned above are expressed as calories per square centimetre of lake surface. The detail of this method is contained in a report of U.S. Geological Survey of 1954.

In the energy budget approach the number of parameters to be recorded at site accurately is sometimes difficult. This method was also used at Lake Hefner.

3.3 Mass Transfer Approach

This is another method for estimation of evaporation. It is based upon the assumption that evaporation is controlled by the wind speed and the vapour pressure difference between the water surface and the atmosphere. The relation is as under:

$$E_o = N\, f(u)\, (e_s - e_a) \qquad \text{---------- (19)}$$

Where, N is a constant known as mass-transfer coefficient; f(u) is a function of wind speed; e_s is vapour pressure of water surface; e_a is vapour pressure of the air.

This method is a combination of water budget and energy budget. Several manipulations have to be made to estimate the evaporation. The detailed uses of the technique are not given. Actually only the name of the approach is mentioned.

3.4 Estimating Evaporation by Pans.

The techniques of estimating evaporation by water budget, energy budget and mass transfer are cumbersome, time consuming and full of several uncertain assumptions and factors. Direct measurement of water loss by evaporation by the use of small pans had always been found very attractive. Extensive work has been done by this method. The type of pans which have been standardized are:

a) Class A, U.S. Weather Bueeau (Land) Pan.

This is a circular pan, 4 feet in diameter and 10 inches deep. It is made of G.I.sheet, generally using gauges No.16 to 22. It is placed 6 inches above the ground on a platform made of wooden blocks. Water lost is measured by a twice bent pointer fixed to the rim of the pan.

b) Colorado Sunken Pan

Colorado Experimental Station has been using a pan which is 3 feet square in which

water upto 18 inches is poured. The pan is made of iron sheet painted on both sides to avoid rust. It is buried in the ground and its walls are kept 4 inches above the natural surface. The water inside the pan is kept either at the natural surface or one inch below this level.

c) U.S. Bureau of Plant Industry Sunken Pan.

This pan is 6 feet in diameter, 2 feet deep and buried in the ground so as to keep its top 4 inches above the ground. The water level in the pan is kept about half inch above or below the ground level.

d) U.S. Geological Survey Floating Pan.

It is always believed that the evaporation from a pan floating on the surface of a large body of water would be of the same order as the actual. The U.S. Geological Survey selected a pan, 3 feet square and 18 inches deep. It is supported by drum floats and is kept in the centre of a raft, 14 x 16 feet. The sides of the pan project 3 inches above the water surface. The water level in the pan is kept at the same level as that of reservoir. Very often a standard Class A Pan is also kept on the surface near the bank to compare the results of the two pans.

3.4.1 Conversion of Pan Evaporation Data to Lake Evaporation

The recording of evaporation by pan is very easy

North West Frontier Province the fall of temperature is much more in a pan than that of large and deep stretches of water contained in a lake. Thus due to cooler temperature of a pan as compared to a lake less evaporation is recorded. It reduces the pan coefficient. Similarly in high temperature areas such as Sind and Baluchistan near Drawat, Ganj, Jacobabad,Sibi, etc. the temperature of a pan increases as compared to a lake located close by. This fact increases the value of the Pan coefficient in those areas. Other parameters such as humidity and wind velocity also cause an incrdase in pan evaporation. For instance in Quetta region, inspite of the cold climate, the evaporation is high due to low humidity. In Sind due to high wind velocity in the coastal belt the evaporation increases.

Thus it is very difficult to fix a true pan coefficient unless lake type pan also exists at or near the site. This is practically impossible and therefore to overcome this difficult for a particular site and at a given time, it has been decided to fix a value of the coefficient equal to 0.71 irrespective of the period and the location of the site. WAPDA planned collection of climatological data at several sites in Pakistan. Presently evaporation is being recorded by Surface Water Hydrology Directorate of WAPDA at 86 sites. Evaporation from Class A Standard Pan is recorded daily at 8 A.M. In the annual reports issued by Surface Water Hydrology Directorate of WAPDA, actual pan evaporation is given. In our studies