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ESTIMATION OF EVAPORATION LOSSES FROM WATER SURFACE - A STUDY OF TAWA RESERVOIR

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ABSTRACT

In order to assess the adaptability of different methods for estimation of evaporation from free water surfaces in semi-arid areas, this study for Tawa reservoir is third in the series of evaporation studies. The estimates of evaporation from free water surface obtained by four methods namely Penman, Kohler, Van Bavel and Morton are compared with observed pan values on monthly, seasonal and annual basis. The estimates of the mean value of evaporation in winter months are lower than those of corrected pan values, whereas in spring and summer season differences are comparatively less and estimates are closer to pan values. All the methods gave comparable estimates of evaporation for spring and summer months. The comparison of monthly values indicated that the estimates of evaporation by both Kohler and Morton methods gave better correlation with corrected pan values for all the months. Also on the basis of comparison of annual values, the results of both Kohler and Morton methods are in good agreement as compared to Penman and Van Bavel models.

Earlies studies conducted for the Malprabha and the Bargi reservoir sites had also come up with more or less simillar results as that of the Tawa reservoir site. It may now be concluded that the both Kohler and Morton methods are reliable approaches for estimation of evaporation from reservoirs and lakes in semi arid areas. However, the coefficients used for adjusting Pan evaporation to lake are tentative and need confirmation by further studies for more places.

1.0 INTRODUCTION

Water evaporation is one of the obscure components of hydrologic cycle to measure accurately. There are two basic reasons for this obscurity. First, no instrumentation exists which can truly measure evaporation from a natural surface. Second, the indirect, none of the methods used for estimation of evaporation are universely accepted. Estimation of reliable or acceptable value of evaporation requires either a detailed instrumentation or a judicious application of climatic and physical data.

Semi arid areas in India, occupy a large stretch of land from north to south. Rainfall in these areas is highly variable. Information on evaporation is required in many hydrological studies. It is important in planning and development of water resources specially in drought prone areas where water is to be stored for specific purpose.

A review of various studies on evaporation losses in India indicate that the annual evaporation losses from reservoirs in arid and semi arid areas vary from 1.5 m to 3.0 m, which represents about 20 to 25% of their water budget. The National Commission on Agriculture (1976) and Central Water Commission (1990) reported that the evaporation losses from surface storages in India are in the order of 50,000 to 60,000 mcm. Also, the above losses would be adequate to meet the entire municipal and rural water needs of India by 2000 A.D. (Water Management Forum, 1988)

The literature suggests that energy budget method may provide better estimates of evaporation as compared to other methods. But it requires extensive instrumentation and frequent surveys of water body and making it an expensive deal. Several other methods are less accurate but reliable to estimate of evaporation from water surface. The pan evaporation does not represent the lake evaporation due to phase difference in the storage of heat due to solar radiation in pans and lakes. The other factor is the difference in way the pans and lakes are affected to advective heat transfer, which is due to their different areal extent and exposure to wind. Reliable and reasonable estimates of lake evaporation can, however, be obtained by application of the appropriate pan to lake coefficient. (WMO, 1973).

The objective of the study is to select the method which provides possibly realistic/accurate estimates of evaporation from free water surfaces of reservoir and lakes located in semi arid regions. There are more than 200 evaporation pans in India out of which about 100 are located in semi arid areas. The other objective of this study is to derive pan coefficients which may be useful to get reliable estimates of evaporation from free water surfaces.

2.0 REVIEW OF LITERATURE

A number of studies comparing techniques of estimating evaporation are found in the literature (Antal et al., 1973; Keijman and Koopmans, 1973; Ficke, 1972; Harbech, 1962; Winter, 1981 etc). WMO (1966) reported many examples of comparative studies of various types of pans and tanks done world over. Antal et. al. (1973) compared five evaporation formula to estimate evaporation from lake Balaton in Hungary and found that the monthly evaporation values differed by 10 to 15 percent from the average of all the methods, whereas annual values showed a deviation of 5 percent from mean value. Keijman et al.(1973) compared the energy budget, mass transfer, Penman and pan coefficient methods in lake studies conducted at Flevo, the Netherlands and found that the standard error of all the methods was 6 to 8 percent, except for the Pan coefficient which was found to be about 20 percent. Ficke (1972) reported that the energy budget estimates tend to be lower than other methods during spring and autumn seasons of moderate evaporation rates, and higher during the summer season. He stated that the short term energy budget data are perhaps less reliable as compared to mass transfer data.

Evaporation losses in tropical countries like India are high because of intense solar radiation, greater number of sunshine hours and days of clear skies, high wind speeds and long rainless periods. Various studies on evaporation in India indicated that the annual evaporation losses from the reservoirs in arid and semi arid areas vary from 1.5 m to 3.0 m (CWC, 1988). Khan and Bhora (1990) reported that the annual water loss in the form of evaporation from Sardar Samand Reservoir amounts to 2183 mm and this constitute to 84.6% of total water loss from the reservoir.

Monthly and annual evaporation charts based on Rowher's empirical formulae are usually used in India for the purpose of estimating evaporation losses from reservoirs. Sharma (1973) conducted a comparative study of observed and estimated values of evaporation in India. He described with an explanation of the anomalies between the observed and empirically estimated Rowher's values. Gangopadhyaya (1970) discussed the importance of global radiation in estimating pan evaporation from meteorological factors and presented computations of monthly values of pan evaporation for 9 stations located in different Agroclimatic Zones of India, to demonstrate the practical applicability of the method suggested. He concluded that the Kohler's formula by and large gave acceptable evaporation estimates.

In an attempt for estimating evaporation losses from large reservoirs in India, Venkataraman & Krishnamurthy (1973) also compared few methods of estimating mean daily shallow lake evaporation. They reported that Penman's classical equation gives rational estimates and Kohler's coaxial graphical technique using climatologically derived estimates of radiation term also seems to be adequate.

The rate of evaporation from a pan is greater than that from large water bodies. So a suitable pan coefficient may be used to adjust the pan evaporation to get an estimated value of evaporation for a lake. Kohler (1959) and Andersen et al. (1982) had calculated evaporation from lakes by converting measured evaporation from pans by applying a coefficient. Blaney had studied the effects of high altitude on evaporation from pans and determined suitable coefficients. Studies by Bigelow has shown that the location of pans relative to the water of a reservoir has significant effect on the calculated evaporation. He concluded that evaporation from natural lakes or reservoirs is about five eighth of that measured from an isolated pan placed outside the vapour blanket. Further studies by Rohwer, Kohler, Mansfield showed that the evaporation coefficient ranges anywhere between 0.2 to 1.5 and this factor is dependent upon the size, depth and location of pan. With this kind of evaporation measurement, it is essential that the coefficient of evaporation be measured under all different conditions, which is not practically feasible in large water storage systems. The ratios of annual reservoir evaporation to pan evaporation are found to be consistent from year to year and region to region but exhibit considerable variation from month to month.

The most commonly used coefficient to estimate annual or seasonal lake evaporation from a Class A pan data is 0.7. It is widely recognized that the coefficient should be lower for lakes in arid regions than for lakes in humid climates. Khan and Bohra (1990) suggested that the pan coefficient value of o.67 can be used in estimating reservoir evaporation in the region of western Rajasthan. A value of 0.52 was obtained for the Salton Sea, California and 0.81 for Lake Okeechobee, Florida (Hounam, 1973 vide Kuusisto, 1985). The annual average Class A pan coefficient to be 0.69 for lake Hefner, Oklahoma. This is in fair agreement with the results of other investigations indicating that the use of pan for determining annual lake evaporation may be accurate to within perhaps 10 or 15 percent, provided care is taken in measuring pan evaporation and selecting the coefficient to be used. In cold climates where lakes are ice covered in winter, the Class A pan coefficient for the open water season also tends to be large (Jarvinen, 1978). In addition to the regional variation of pan coefficients, there is a remarkable seasonal variation for many climates. The pan to lake coefficients for monthly evaporation vary more widely and with a greater range of probable error than the annual coefficients. The coefficients tend to be smaller than the annual average in the winter and spring and larger in summer because of the lag between lake water temperature and the pan water temperature. Since the temperature lag is greater for deep lakes, it is expected that the monthly variation in the coefficients is greater for deep lakes for a climate which has large seasonal variations in temperature. Obviously, the use of constant value for each month can lead to serious error.

The studies conducted in India also indicated that the pan to lake coefficients show considerable variation both in space and time. Ramdas (1957) has described how estimates of natural evaporation may be made from pan evaporation. He reported that pan coefficients may vary somewhat with the season (and even monthly), locality and difference in exposure. He suggested the pan coefficient of the order of 0.87 for wet period (when ground saturated, after rain). Once a rainy spell is over, the pan coefficient drops down between 0.87 to 0.60, and for dry weather period it is lower, of the order of 0.60. In order to account for variation of the lake-pan relationship under different climatic regions in India, Bureau of Indian standard (IS:6939-1973) recommended the pan factor (for India) between 1.10 to 0.9 for lake evaporation of the order of 4 to 5 mm/day, between 0.75 to 0.65 for lake evaporation of the order of 10 mm/day and about 0.8 for transition months. Sarma (1973) concluded that for class A Pan, the coefficient range from 0.60 in winter to 0.82 in summer. Ramasastri (1987) recommended pan factor as 0.7 for the conditions when the pan water temperature and air temperature is on the average equal. In warm and arid areas, the pan water temperature is on the average less than the air temperature and, when compared with evaporation from lakes or tanks the coefficient would approach 0.60. In humid areas, the average pan water temperature exceeds air temperature and coefficient would tend to be nearly 0.80 (Ramasastri, 1987).

Penman in (1948) first derived the an equation (1) based on latent heat supply of the evaporating surface. This equation was modified considering that water is not limited and vapour Pressure is at the saturation vapour pressure at the surface. He suggested equation (2) for estimation of daily potential evaporation, which is the original Penman formula.

$$kE = \frac{D(Rn+G) + qCp(e^{o}_{z} - e_{z})/ra}{D+c} \qquad \ldots (1)$$

$$Ep = \frac{D}{D+C}(Rn+G) + \frac{C}{D+C}15.36(1.0-0.0062u_2)(e^{o}_{z} - e_{z}) \qquad \ldots (2)$$

where,

Ep = Evaporation from a free water surface,

ra = Diffusion resistance of air layer

Following the evaporation studies at Lake Hefner, Oklahoma, Penman (1963) suggested that the wind term in equation (2) be replaced by $(0.5+0.01\ u_2)$ for estimation of evaporation from large water surfaces. Finally the equation (3) is considered with all recommended modification

$$Ep=[\frac{D}{D+C}(Rn+G)+\frac{C}{D+C}15.36(0.5-0.01u_2)(e_z^o-e_z)]/59 \qquad ...(3)$$

Where,

Ep = Evaporation (mm day^{-1}); Rn = Net radiation (langley day^{-1}); G = soil heat flux(considered as zero for water surface); c = Psychrometric constant; D = slope of saturation vapour pressure - temperature curve (de/dT) (mb C^{-1}); $e_z^o-e_z$= Vapour pressure deficit (mb.); and u_2= Wind speed (mile day^{-1}).

Kohler, Nordenson and Fox (1955) adopted the Penman equation to class A Pan evaporation by using c_p = 0.00157P, mb C^{-1} , and for lake or open water evaporation by multiplying the solution by 0.7 with c_i= 0.000661P, mb C^{-1} . The Kohler et al. suggested the following equation for estimation of evaporation losses from lake/reservoir. They recommended this model for evaporation estimation on daily basis.

$$EK=0.7[\frac{Rn\ D}{D+c_i}+\frac{c_i}{D+c_i}Ea] \qquad ...(4)$$

Where,

$$Ea=(e_z^o-e_z)^{0.88}(0.37+0.0041u_2) \qquad ...(5)$$

EK = Evaporation from lake/reservoir (inches day^{-1}); Rn = Net radiation (equivalent to inches of water); D & c_i= Psychrometric constants (inches of Hg ^oF); e_z^o- e_z= Vapour pressure deficit (inches of Hg.); and u_2 = Wind speed (mile day^{-1}).

A modification of the transfer coefficient in Thornthwaite and Haltzman (1939) equation was proposed by Businger (1956) and the equation was finally presented by Van Bavel (1966). He assumed adiabatic conditions ie. transfer coefficient for heat equals to transfer coefficient for vapour (h_h= h_v), and suggested the following equation for estimation of evaporation from free water surface.

$$Ev=[\frac{D}{D+c}(Rn+G)+\frac{c}{D+c}[\frac{0.622kqk^2}{p}\frac{u_z}{[\ln z/z_o]^2}(e_z^o-e_z)]/59 \qquad ...(6)$$

Where, Ev = Evaporation (mm day^{-1}); Rn = Net radiation (langley day^{-1}); G = soil heat flux (considered as zero for water surface); c = Psychrometric constant; D = slope of saturation vapour pressure - temperature curve (de/dT) (mb C^{-1}); e_z^o- e_z= Vapour pressure deficit (mb.); and u_z = Wind speed (Km day^{-1}).

since q and p decrease with increase in elevation with k =585 cal g^{-1} and p = 1000 , the factor $0.622kqk^2/p$ is considered as constant. Where,k= latent heat of vaporization(cal $gm.^{-1}$); q= air density(gm. cm^{-3}); p = atmospheric pressure (mb); and k = Von Karman's constant.

Morton (1979) stated that lake evaporation or evaporation form a water surfaces is so large and the effects of the up wind share line transition can be ignored. He used the following equations as the basis for the model that provides monthly estimates of lake evaporation from climatological observations. This model was recommended to estimate evaporation from lakes in anywhere in the world.

$$E_w = w\ (R_n + M) \qquad \ldots(7)$$

In which E_w = lake evaporation, R_n is net radiation if the surface were at air temperature, and the energy weighting factor w and advection energy M is defined by

$$w = 0.26 w_a^{\,1+\frac{k}{D}\left(\frac{0.5+5r+k/D}{r+k/D}\right)} p_w^{-1} q \qquad \ldots(8)$$

$$M = 0.66\ B - 0.44\ R_n \qquad \ldots\ldots\ldots\ldots(9)$$

$$M \ \hat{}\ 0 \qquad \ldots\ldots\ldots\ldots\ldots(10)$$

Where r is relative humidity, equal to V_D/V. V_D and V are saturation vapour pressure at due point and air temperature respectively, B is net long wave radiation loss if the surface were at air temperature, k is heat transfer coefficient and D is rate of change of saturation vapour pressure with respect to air temperature.

The procedure used in applying this model has been already described in the previous report No. CS(AR)- 180, NIH (1995).

3.0 DESCRIPTION OF THE STUDY AREA

3.1 General

The Tawa reservoir is located in semi-arid agro-climatic zone. Location of study area can be seen in Fig. 1. The Tawa reservoir is constructed across river Tawa, which is a major tributary of holy river Narmada in central India. It is located near village Ranipur between 22° 30′ 40′′N latitude and 77° 58′ 30′′E longitude. The reservoir has the grass capacity of about 2310.64 mcm (1.874 m acre-ft.). at FRL 355.397 m with live storage of 2058.01 mcm (1.661 m acre-ft.). In this region the maximum and minimum value of humidity and temperature ranges from 96% to 23% and 40°C to 15°C respectively. The average annual rainfall of this region is about 1546 mm. This study has been carried out using the meteorological data of observatory located at Pawarkhera in Hoshangabad district in Madhya Pradesh. This is a well equipped meteorological observatory nearest to the Tawa dam site.

3.2 The data

In this study, the meteorological and pan evaporation data were collected from the Zonal Agricultural Research Station (ZARS), Jawaharlal Nehru Krishi Vishwa Vidhyalaya (JNKVV), Pawarkherah, Hoshangabad (M.P.). This one is the nearest observatory located at ZARS's Agriculture Farm. The data include air temperature (maximum & minimum), dry bulb and wet bulb point temperature, actual sun shine hours, wind speed, humidity, and pan evaporation records. The other hydrological data for Tawa dam site were made available Tawa dam authorities of Department of Water Resources, Govt. of M.P.

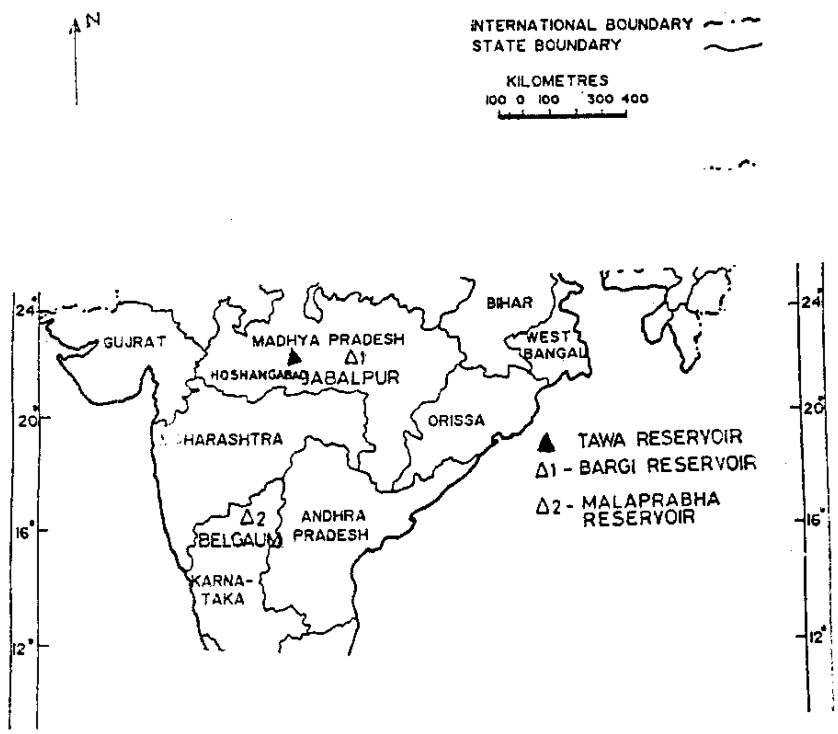

FIG. 1- THE STUDY AREA

4.0 METHODOLOGY

There are several well recognized methods available for estimation of potential evaporation. These methods include various equations primarily based on solar radiation, humidity, temperature, wind and miscellaneous principles. The selection of any method for a particular use would depend on the accuracy of available meteorological data and the general acceptance of previous estimates. In this study, four well known and widely used methods have been selected for estimation of evaporation from free water surface in Tawa reservoir. These methods are (1) Penman (1963) (2) Kohler et. al (1954) (3) Van-Bavel Businger (1966) and (4) Morton (1979). The methods used to estimate governing parameters (i.e. net radiation, vapour pressure deficit and psychrometric conatants etc.) of evaporation equations (Equn.NO. 3, 4 and 6) have been discussed in chapter 5.0. The meteorological data on daily basis has been used to estimate daily evaporation from water surface. The results are then converted in to monthly evaporation for further analysis.

The measured pan evaporation at the dam site has been utilized to derive Pan-to-lake coefficients for winter (December to February), monsoon (June to September), post monsoon (October and November) and summer (March to May) seasons. In present study a correction factor of 1.144 for the mesh cover on pan (WMO 1966) has been considered separately.

The pan evaporation values and evaporation estimates are compared on monthly, seasonal and annual basis. The linear regression analysis were carried out in order to derive relationship between estimates and pan values. The estimated values results are also subjected to statistical analysis to evaluate the adaptability of the methods for arriving at acceptable estimates. The results are also compared with that of the previous similar studies for Naviluteerth reservoir in Karnataka and Bargi reservoir in Madhya Predesh.

5.0 ESTIMATION OF EVAPORATION PARAMETERS

This section discusses the controlling characteristics and variables of atmospheric system which governs the physical properties of evaporation process at water-air interface. The weather data collected at the bank of the reservoir have been utilized for this purpose.

5.1 Net Radiation (Rn):

Net radiation is the difference between all incoming and outgoing radiations. It can be measured, but such records were not available. It has been calculated from sun shine hours, temperature, and humidity data using following relationships.

$$R_{bo} = e' r (T+273)^4 \qquad \ldots(11)$$

$$R_{so} = \frac{R_s}{[0.35+0.6(\frac{SSH}{MSH})]} \qquad \ldots(12)$$

$$R_b = R_{bo}[(\frac{1.2\ R_s}{R_{so}}) - 0.2] \qquad \ldots(13)$$

$$R_s = 59[0.31+0.49(\frac{SSH}{MSH})]R_A \qquad \ldots(14)$$

$$R_n = (1.0-a)R_s - R_b \qquad \ldots(15)$$

Where, R_n=Net Radiation (langley day^{-1}); a = Short wave reflectance (a =0.5 for free water surface); SSH=Actual sun shine hours (hours day^{-1}); MSH=Maximum possible sun shine hours based on latitude and the time of the year (hours day^{-1}); e' = Emissivity constant = (0.39-0.05 $\sqrt{e_d}$); r = Stefan-Boltzmann constant = (11.71×10^{-8}) cal cm^{-2} $^{o}k^{-4}$ day^{-1}; e_d= Saturation vapour pressure at due point temperature (mb); T = Temperature (^{o}k); and R_A = Extraterrestrial solar radiation based on latitude and the time of the year (equivalent to mm day^{-1}).

Values of MSH and R_A have been taken from published tables.

5.2 Vapour Pressure Deficit:

The difference between mean saturation water vapour pressure (e_z^o) and mean actual vapour pressure (e_z) is expressed as vapour pressure deficit. Actual air-vapour pressure can either be computed using relative humidity times the saturation vapour pressure at the air temperature or as the saturation vapour pressure at due point temperature. Since the data for due point temperature was not available, therefore the actual vapour pressure has been estimated using relative humidity records. The saturation vapour pressure at a given temperature has been estimated using following relationship.

$$e_z^o = 33.86[0.000738T+0.8072)^8 - 0.000019w1.8T+48w+0.00136] \quad ...(16)$$

$$e_z = e_z^o \times \frac{Rh}{100} \quad ...(17)$$

where, e_z^o = Saturation vapour pressure (mb); e_z= Actual vapour pressure at temperature (mb); Rh = Relative humidity (%); T = Temperature (^{o}C).

5.3 Common parameters

a) Psychrometric constant (c): Psychrometric constant represents a balance between the sensible heat gained from air flowing past a wet bulb temperature and the sensible heat transformed in to latent heat (Brunt, 1952). It is calculated as

$$c = \frac{C_p P}{0.622\ k} \qquad \text{...(18)}$$
(c in mb $^{o}C^{-1}$)

$$k = 595 - 0.51\ T \qquad \text{...(19)}$$

Where, k = Latent heat of vaporization (cal g^{-1})

C_p = Specific heat at constant pressure (cal g^{-1} ^{o}C)

b) **Slope of saturation vapour pressure curve** (D): Change in saturation vapour pressure (D) with temperature is evaluated using Bosen's formula for saturation vapour pressure.

$$D = \frac{de^{o}}{dT} = 33.8639[0.05904(0.00738T+0.8072)^{7}-0.0000342] \qquad \text{...(20)}$$
(D in mb $^{o}C^{-1}$)

c) **Atmospheric pressure** (P) **and density** (q): The following linear relationships which are based on NACA (National Advisory Committee for Aeronautics, USA) standard atmosphere, are used to estimate atmospheric pressure and density.

$$P = 1013 - 0.1055EL \qquad \text{...(21)}$$
(P in mb)

$$q = 0.00123 - 0.000034E\ /1000 \qquad \text{...(22)}$$
(q in g cm^{-3})

where, EL = Elevation (m)

6.0 RESULTS AND DISCUSSION

The estimates of average monthly evaporation from free water surface for a period of 9 years are presented in appendix - I. The estimates obtained by Penman and Van Bavel methods appear to be lower . Specially in winter months, these estimates are lower on average by 98% oreven more where as the variations are in The estimates based on Kohler and Morton methods are closer to pan values, (on average within ±12% for all the months) and results are comparable. Also, on the basis comparison of annual values, the results of estimates by Kohler and Morton methods are closer to observed pan values. However, Gangopadhaya et al. (1970) found the estimates of evaporation determined by Penman's or Kohler's method in parts of India to be considerably under estimated. A comparison of average monthly and annual estimates by the different methods is shown in Table 1.

To come out with accepteable seasonalvalue of pan to lake coefficients, the year has been divided into four different seasons namely winter, monsoon , post monsoon and summer as shown in Table 2. The estimates of evaporation from water surface obtained by Penman, Kohler, Van Bavel and Morton equations,and the observed pan values have been used to derive pan to lake coefficient for four different seasons. The results indicate a large seasonal variation in the pan coefficient values (Table 2). The spatial variation is also pronounced because of high temperature and large diurnal variation on account of differential heating of the water in pan and lake, and consequent water temperature difference over the two surfaces. A comparison of calculated pan to lake coefficient with that of ISI (1973), Sharma (1973) and Ramasastri (1987) shows that the values derived with Kohler method are in good agreement. Also, the pan to lake coefficients derived for Bargi reservoir site (please see Appendix- II) are more or less simillar to that of Tawa reservoir site.

Table: 1 Average Monthly Evaporation in mm/month
(Monthly Totals Averaged Over 9 Years)

Month	Obserbed Pan Value	Penmen method	Kohler method	Van Vabel method	Morton method
JAN.	114.94	56.04	102.69	61.42	107.22
FEB.	130.84	67.61	114.91	71.45	113.00
MAR.	198.61	105.57	170.06	114.42	169.67
APR.	262.77	139.60	210.71	152.85	196.56
MAY	317.94	186.91	254.80	221.92	240.78
JUN.	248.97	157.29	199.25	192.96	178.00
JUL.	184.36	112.15	140.67	130.17	133.78
AUG.	167.65	91.98	120.38	99.94	130.11
SEP.	160.17	92.71	128.44	100.75	143.56
OCT.	145.96	85.33	131.63	89.64	146.22
NOV.	132.91	69.01	117.27	70.60	115.11
DEC.	115.86	56.33	103.61	61.18	101.11

Table: 2. Calculated pan correction factor for Tawa reservoir site using four different methods

Sl No.	Season	Penmen method	Kohler method	Van Bavel method	Morton method
1	Winter	.50	.89	.54	.89
2	Monsoon	.62	.79	.70	.80
3	Post monsoon	.56	.90	.58	.95
4	Summer	.56	.84	.63	.81

The statistics of monthly values presented in Table 3, also indicate relatively better performance of Kohler and Morton methods. The statistical parameters such as Variance, standard deviation and range, are observed to be relatively higher for Van Bavel and Kohler methods. This indicate that the estimated monthly values by Van Bavel method and Kohler method have greater dispersion. The skewness of the data series is different from zero, and are positive indicating that the data/estimates do not follow the normal distribution, but is skewed positively. Linear regression analysis has been carried out to determine the degree of relationship among estimates obtained from all the above methods. The cross correlation matrix for the estimated evaporation and pan to lake coefficients are shown in Table 4 and 5 respectively.

Table:3 Comperative Statistical Summary of monthly evaporation estimates of different methods

Variable:	Pan	Penmen	Kohler	V Bavel	Morton
Sample size	108	108	108	108	108
Average	181.298	101.71	149.534	113.932	148.343
Median	160.995	92.19	128.935	96.305	141
Mode	201.99	89.02	127.87	95.3	101
Geometric mean	170.061	94.1097	142.837	103.03	143.091
Variance	4983.29	1725.73	2316.59	2961.18	1733.5
Standard deviation	70.5924	41.5419	48.1309	54.4168	41.6353
Standard error	6.7927	3.9974	4.6314	5.2362	4.00636
Minimum	105.00	47.47	90.2	47.87	99
Maximum	393.74	213.42	271.66	273.02	262
Range	288.74	165.95	181.46	225.15	163
Lower quartile	125.715	66.975	113.39	72.865	113
Upper quartile	212.015	127.865	181.725	139.81	173
Interquartile range	86.3	60.89	68.335	66.945	60
Skewness	1.31084	0.86977	0.99729	1.12335	0.88483
Standardized skewness	5.56144	3.69015	4.23116	4.76595	3.75402
Kurtosis	1.18683	-0.07859	-0.12710	0.52163	0.03941
Standardized kurtosis	2.51765	-0.16671	-0.26963	1.10655	0.08361

Table: 4 Cross Correlations coefficient for monthly estimates of evaporation (sample size = 108)

Methods	Pan	Penmen	Kohler	Van Bavel	Morton
Pan	1.0000	.8673	.8845	.8265	.8505
Penmen	.8673	1.0000	.9525	.9844	.8802
Kohler	.8845	.9525	1.0000	.9251	.9404
V Bavel	.8265	.9844	.9251	1.0000	.8160
Morton	.8505	.8802	.9404	.8160	1.0000

Table: 5 Cross Correlations Matrix for Pan Correction Factor

Methods	Penman	Kohlar	Van Bavel	Morton
Penman	1.0000	.5737	.9282	.3765
Kohlar	.5737	1.0000	.4993	.8064
Van Bavel	.9282	.4993	1.0000	.1954
Morton	.3765	.8064	.1954	1.0000

Based on the above results it may be said that both Kohler and Morton methods may be considered as comparatively better approaches for reliable estimation of evaporation from free water surfaces.

7.0 CONCLUSIONS

The comparison of pan values and estimated evaporation values indicate that the Penman and Van Bavel methods provide under estimates of evaporation from free water surface, where as, the estimates obtained by Kohler and Morton methods are better related to observed pan values during all the months. Also, on the basis of comparison of annual values, the results of both Kohler and Morton methods are in good agreement. than those of Penman and Van Bavel methods. it is therefore, concluded that the Kohler and Morton methods are better suited for estimation of evaporation from free water surface. The coefficients obtained for adjusting pan evaporation to lake are still subjective and experimental studies are needed to arrive at more realistic values.

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APPENDIX - I

Estimated Monthly Evaporation fron free water surface for the period from 1987 to 1995

Year	Month	Observed Pan Value	Penmen Method	Kohler method	V Bavel Method	Morton Method
1987	Jan.	116.08	63.95	91.84	55.22	108.00
	Feb.	142.86	95.89	122.36	85.64	123.00
	Mar.	200.42	113.91	179.54	127.70	180.00
	Apr.	258.19	154.61	223.91	183.06	203.00
	May	234.40	171.33	228.99	208.72	203.00
	June	144.41	187.35	217.73	256.13	172.00
	July	244.08	174.65	201.31	238.81	113.00
	Aug.	224.60	102.47	132.23	123.86	132.00
	Sept.	183.93	104.55	144.63	129.33	141.00
	Oct.	128.26	81.35	127.55	80.13	149.00
	Nov.	149.00	64.13	111.89	67.37	110.00
	Dec.	105.00	55.45	107.83	62.77	101.00
1988	Jan.	113.49	63.11	116.31	77.49	110.00
	Feb.	133.99	64.40	117.79	69.54	117.00
	Mar.	205.04	108.31	173.12	117.79	169.00
	Apr.	266.76	144.35	210.53	160.71	200.00
	May	263.62	185.57	252.20	215.21	249.00
	June	214.04	142.10	187.75	165.69	181.00
	July	123.14	98.60	127.87	107.01	137.00
	Aug.	137.74	86.15	107.67	93.13	114.00
	Sept.	124.60	85.37	113.37	90.04	128.00
	Oct.	137.25	84.29	138.90	87.91	156.00
	Nov.	123.16	59.42	117.18	61.57	117.00
	Dec.	113.11	48.99	102.65	54.28	101.00
1989	Jan.	115.82	56.70	111.20	66.35	107.00
	Feb.	150.27	67.48	123.77	76.26	113.00
	Mar.	184.47	107.84	170.66	120.15	170.00
	Apr.	229.85	136.16	210.50	147.91	195.00
	May	295.20	187.77	262.64	213.84	262.00
	June	109.99	138.06	180.12	160.54	166.00
	July	280.24	98.43	122.96	109.09	113.00
	Aug.	153.38	89.02	113.41	96.17	130.00
	Sept.	165.45	92.62	138.19	96.83	169.00
	Oct.	165.88	79.67	128.35	81.56	146.00
	Nov.	132.07	67.68	125.69	71.29	120.00
	Dec.	106.34	47.47	98.86	53.34	99.00

1990	Jan.	115.52	50.28	108.08	51.98	111.00
	Feb.	117.12	58.49	110.02	64.20	110.00
	Mar.	198.43	88.71	160.40	86.82	173.00
	Apr.	308.58	127.05	208.25	128.11	204.00
	May	331.36	170.93	237.76	198.92	236.00
	June	187.15	151.64	199.60	191.15	184.00
	July	137.57	106.79	139.67	125.25	147.00
	Aug.	141.45	99.07	122.48	118.72	120.00
	Sept.	117.48	99.53	130.24	120.29	126.00
	Oct.	118.49	96.19	141.06	114.44	153.00
	Nov.	120.15	60.70	115.57	57.98	117.00
	Dec.	105.01	49.23	100.41	48.90	104.00
1991	Jan.	106.36	50.70	104.42	54.18	108.00
	Feb.	124.94	66.77	119.44	73.51	113.00
	Mar.	214.29	121.32	176.44	143.26	160.00
	Apr.	268.96	142.07	210.13	156.40	189.00
	May	375.37	201.66	271.36	246.45	251.00
	June	258.75	161.42	198.89	199.57	186.00
	July	175.37	117.92	145.59	136.36	138.00
	Aug.	162.41	91.49	119.76	98.59	144.00
	Sept.	173.31	89.02	131.73	90.95	157.00
	Oct.	137.13	74.70	122.74	70.92	142.00
	Nov.	131.47	72.16	126.82	77.88	116.00
	Dec.	118.04	66.64	99.43	68.34	101.00
1992	Jan.	125.92	63.09	102.92	68.28	101.00
	Feb.	126.50	67.18	107.47	69.46	111.00
	Mar.	208.49	102.02	168.94	105.14	169.00
	Apr.	323.50	144.55	217.04	156.33	201.00
	May	360.50	177.22	251.62	202.57	240.00
	June	312.77	147.58	190.66	173.06	179.00
	July	246.50	106.45	133.50	117.34	130.00
	Aug.	161.63	95.30	119.78	90.25	126.00
	Sept.	179.70	98.38	130.78	86.89	163.00
	Oct.	149.56	75.71	120.57	73.87	147.00
	Nov.	146.40	65.27	110.48	66.18	117.00
	Dec.	122.29	59.63	101.79	61.67	100.00
1993	Jan.	108.84	48.73	101.49	58.04	108.00
	Feb.	130.53	54.55	109.39	62.92	111.00
	Mar.	188.32	98.72	165.12	101.69	169.00
	Apr.	255.74	129.61	201.45	134.83	194.00
	May	393.74	176.37	253.92	196.07	254.00
	June	273.78	144.50	196.15	162.53	202.00
	July	176.54	96.86	125.34	103.57	136.00
	Aug.	151.39	82.10	111.72	80.34	146.00
	Sept.	157.98	75.95	116.61	74.02	141.00

	Oct.	160.35	91.22	130.43	96.44	151.00
	Nov.	125.51	74.29	121.30	86.73	118.00
	Dec.	119.11	64.58	118.01	83.05	100.00
1994	Jan.	116.18	57.83	97.72	73.41	108.00
	Feb.	121.12	64.43	113.64	75.31	110.00
	Mar.	201.99	94.05	164.03	90.91	173.00
	Apr.	214.69	128.68	203.08	129.92	199.00
	May	324.98	197.88	263.02	242.52	239.00
	June	239.06	144.04	183.33	168.74	178.00
	July	160.36	88.60	118.16	87.90	141.00
	Aug.	201.99	90.44	143.90	91.96	146.00
	Sept.	171.53	99.05	134.55	113.41	141.00
	Oct.	132.44	89.40	129.52	95.30	109.00
	Nov.	129.30	85.02	106.12	74.06	104.00
	Dec.	124.85	57.22	102.01	62.40	101.00
1995	Jan.	112.56	49.98	90.20	47.87	104.00
	Feb.	126.15	69.30	110.31	66.19	109.00
	Mar.	199.78	115.21	172.25	136.28	164.00
	Apr.	230.39	149.36	211.53	178.40	184.00
	May	372.37	213.42	271.66	273.02	233.00
	June	393.02	198.93	239.01	259.20	199.00
	July	209.63	121.01	151.64	145.21	149.00
	Aug.	169.43	91.76	112.51	106.42	113.00
	Sept.	162.41	89.91	115.86	104.96	126.00
	Oct.	179.68	95.41	145.52	106.20	163.00
	Nov.	134.94	72.39	120.37	72.32	117.00
	Dec.	124.88	57.78	101.50	55.87	103.00

APPENDIX - II

Calculated pan correction factorfor Bargi reservoir site using four different methods

(Quoted from NIH Report No. CS(AR)-180, 1995)

Sl No.	Season	Penmen method	Kohler method	Van Bavel method	Morton method
1	Winter	.44	.80	.40	1.10
2	Monsoon	.70	.91	.76	.96
3	Post monsoon	.50	.99	.53	1.15
4	Summer	.50	.76	.53	.70

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