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EVAPORATION LOSSES FROM RESERVOIR - STUDY FOR SEMI ARID REGION

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PREFACE

Evaporation and evapotranspiration are the key element of hydrological cycle from the time water fall up on the land as precipitation until it reaches or returned to atmosphere. The subject of evaporation which includes evaporation from free water surfaces, land surfaces, soils, man made surfaces etc. is becoming increasingly important for water resources planning especialy in arid and semi arid areas. The main application of free water surface evaporation is for determining the amount of water supply that may be lost from a lake or reservoir. Evaporation over a reservoir can be a major water management problem, more so if the reservoir is shallow or is meantfor storing water for a specific use over a period of several years.For the efficient management of available water in the reservoirs, reasonably accurate estimates of monthly or weekly evaporation are needed. The estimation of such evaporation requires either detailed instrumentation of the reservoir or an intuitive application of local physical and climatic data. This study deals with the estimation of evaporation losses from Navil Tirth reservoir located in Belgaum district in Karnatka state. It is expected that the methods presented in this report will be use full for field engineers for planing and management of water resources in semi-arid areas.

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1.0 INTRODUCTION

Evaporation and evapotranspiration are the key element of hydrological cycle from the time water fall up on the land as precipitation until it reaches or returned to atmosphere. The major application of free water surface evaporation is for determining the amount of water supply that may be lost from a lack or reservoir. Evaporation over a reservoir can be a major water managaement problem, specially if the reservoir is shallow or must store water for a specific use over a period of several years. The design of reservoirs in arid and semi arid areas, require estimates of total evaporation over a long period involving several years, commonly available estimates of average annual evaporation may not be sufficient. However, reasonably accurate estimates of monthly or weekly evaporation are very important while designing the reservoir/tank for specific purposes The estimation of such information requires either detailed instrumentation of the reservoir or an intuitive application of local physical and climatic data.

Evaporation is involved to some degree in nearly all hydrologic studies. It is specially important in the planning and development of river basin or national water resources. It forms the foundation for the planning and design of most irrigation projects, since it is usually the starting point in determining surface and sub surface storage requirements, the capacity of delivery system and general operation practices.

The availability of water over the year depends upon the spatial and temporal variation of precipitation. Because of the nature of recourse over India, water may be abundant during the monsoon season viz. June to October and scare during the non monsoon season 1 Nov. to May 1, when it is most needed. The ingenuity of man, therefore, lies in his ability to modify the pattern of availability of water to suit needs. One of the commonest forms of such modification is storage of water during monsoon season for its eventual use in lean season. However, storage over ground for irrigation, domestic and industrial consumption necessarily involves large losses, of which the most important are evaporation and seepage. The seepage losses which do not generally exceed 5% depend on geology and other local features from place to place and are to a large extent controllable with the present day seepage control technology. (MAKWANA 1992). Evaporation losses, on the other land, are very high in a tropical country like India because of higher temperature, large overall aridity and a large number of sun shine days. The common man often fails to appreciate the magnitude of evaporation losses as they take place gradually. The annual evaporation losses from the reservoirs in arid and semi arid areas vary from 1.5m to 3.0m out of which about 50% of evaporation may be in summer months. Thus it is evident that evaporation is the prime cause of water loss from all water storages. In view of the scarcity of this vital resource in most part of arid and semi arid regions and present scenario of utmot strain in the water resources of the country, it is most essential to make possibly correct estimate of evaporation losses and consider it at the time water resources planning in the respective regions.

The objectives of this study is to evaluate the accuracy of various evaporation estimating procedures and to select the method which provides realistic estimates of evaporation from reservoirs in semi arid region This report provides the practicing engineer with an easy understanding of engineering requirement of evaporation data and a practical approach to select the methods best suited for solving a particular hydrology, irrigation or water supply problem.

2.0 DISCRIPTION OF THE STUDY AREA:

The Navil Thirth reservoir is located at Naviluteerth in saundatti taluk of Belgaum district (between $15^{o}45'$ N latitude and $75^{o}\ 07'$ E longitude). The district Belgaum falls in semi-arid agro-climatic zone. The dam is constructed across river Malprabha, which is a major tributory of Krishna river. It is a composite dam of 254.53 m length and 40.32 m height. The reservoir has the grass capacity of 1068 MCM at FRL 633.83 m. The catchment of the reservoir incompasses an area of about 2564 sq km. The Navil Tirth reservoir is situated at the upstreams of Malprabha reservoir.

3.0 FACTORS AFFECTING EVAPORATION

Evaporation is a process by which liquid changes into vapour form. Water molecules are in constant motion and some have the energy to break through water surface and escape into air as vapour. Evaporation in general is a beneficial phenomenon in regulating global water balance through the hydrological cycle and it is also the same phenomenon contributing to massive losses from water bodies. Control of evaporation from land based water bodies has thus remained one of the main strategies of water conservation schemes. This assumes greater significance in arid regions, where scarcity of water is a common problem. The major factors influencing evaporation are:

a) Vapour pressure difference.

b) Temperature

c) Wind

d) Atmospheric pressure and

e) Quality of water

The rate of evaporation depends on the difference between saturation vapour pressure at the water temperature and at the dew point of the air. Similarly, evaporation increases with increased temperature of the air surface. In the case of wind, it was found that higher wind speeds accelerate evaporation but experimental data do not indicate the exact nature of this relationship. The effect and the dimensions probably depends on surface roughness and the dimensions of the water body. Atmospheric pressure is so closely related to other factors affecting evaporation that it practically impossible to study the effect of variation under natural conditions. Evaporation loss are observed higher at higher elevations. However, this higher loss may be compensated to a large extent by lower temperatures in higher locations. Regarding water quality, the rate of evaporation is less for salt or saline water than for fresh water and this thus decreases as the specific gravity of the water body increases.

4. REVIEW OF LITERATURE

Comparison of various Evaporation Estimation Methods

Monthly and annual evaporation charts based Rowher's empirical formulae have been in use in India for the purpose of estimating evaporation losses from reservoirs. Sarma (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 for one year to demonstrate the practical applicability of the method suggested. In his study he also concluded that the

Kohler's formula by and large gave evaporation estimates.

Some interesting studies in Europe and the U.S.A. comparing techniques of estimating evaporation can be found in the literature (Antal et al., 1973; Keijman and Koopmans, 1973; Ficke, 1972; Winter, 1981 etc). Gangopadhyaya et al.(1966) reported many examples of comparative studies of various types of pans and tanks done world over. It was reported that the GGI-3000 pan and the class A pan showed as much as 10 percent and 35 percent less evaporation respectively for a given month of the year when compared to the control tank. Winter (1981) observed that evaporation from a rinsed floating pan differed from class A pan by 14 to 29 percent on a monthly basis, and 22 percent for a six-month period. 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 and Koopmans (1973) compared the energy budget, mass transfer, panman and pan coefficient methods in lake studies conducted at Flevo, the Netherlands using 13 periods of seven days average duration, they 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.

It will be interesting to examine the results of comparative studies of estimating lake evaporation made by several workers as reported in Table (A) cited from Winter (1981). The evaporation estimates as obtained by various method have been compared with the Energy Budget method and the comparison has been made for the period during which energy budget calculations were done. Since the energy budget is supposed to be the most accurate method, the comparison has been done against that. However, it is interesting

TABLE (A): Summary of comparision of Evaporation calculated by different Methods
(Values are the percent of difference between evaporation calculated by given methods from that calculated by energy budget method)

Lake	Water Budget	Mass Transfer	Class-A Pan (uncorrected)	Class-A Pan (corrected)	Computed Class-A Pan (uncorrected)	Computed Class-A Pan (corrected)	GGI-3000 Pan	Period	Length of Study
Mead lake	-----	2.00-27.40	-----	0-22.20	----	-------	-------	4 Weeks	12-3-52 to 28-9-53
(Arizona-Nevada)	-----	10.00	-----	7.20	-----	------	-------	Mean of periods	
[Harbeck et al.1958]	-----	1.10	-----	4.70	-----	------	-------	Total	
Salton Sea(	0-36.70	0.90-46.40	several hundred	----	-----	------	-------	2 Weeks	9-1-61 to 8-1-63
California	10.95	13.13	-----	-----	-----	------	-------	1961 mean of periods	
[Hughes, 1967]	14.65	13.59	-----	-----	-----	------	-------	1962 mean of periods	
	5.00	3.80	-----	-----	-----	------	-------	1961 Total	
	1.20	0.60	-----	-----	-----	------	-------	1962 Total	
Salton Sea	1.40-40.40	0.20-24.20	____	______	_____	______	_______	Monthly	August 67-Dec. 68
(California)	13.39	8.23	____	______	_____	______	_______	Mean of Periods	
[Sturrock,1977]	2.90	0.30	____	______	_____	______	_______	Total	
Pretty (Indiana)	3.50-16.90	0.20-39.30	0-70.20	0.50-68.10	0.90-37.50	0.80-51.10	_______	2 weeks	April 63-Sept. 66
(Ficke, 1972)	16.22	14.89	15.77	18.07	14.75	13.10	_______	Mean of periods	
	9.30	9.40	25.80	18.90	4.50	2.80	_______	1964 Total	
	4.30	2.70	27.00	28.70	0.00	2.30	_______	1965 Total	
Veten (Sweden)	4.00	______	_______	2.00	_____	________	22	June and July	June 71-Sept., 1
(Rodhe, 1973)	8.00	______	_______	36.00	_____	_______	51	August	
	35.00	______	_______	54.00	_____	_______	32	September	
	8.00	______	_______	15.00	_____	_______	29	Total	

Source: NIH 1986-87, TR-14

to note that the estimated errors in selected terms of given equations, or in evaporation itself are generally judget against other methods of evaporation, which in themselves may contain errors. it is evident from the table (8) that less accurate results are obtained for shorter time periods e.g. weekly or daily as compared to longer periods of a month of more. It could also be inferred from the table that mass transfer method provides relatively better estimates of evaporation as compared to other methods used. Ficke (1972) reported that the energy budget estimates tend to be lower than other methods during spring and autumn low rate seasons and higher during the summer high rate season. Since these average out, so seasonal totals are the same. He stated that the spring time and short term energy budget data are perhaps less reliable as compared to mass transfer data. In an attempt of 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 co-axial graphical technique using climatologically derived estimates of radiation term also seems to be adequate.

5.0 ASSESSMENT OF EVAPORATION LOSSES IN INDIA:

As per available records, assessment of evaporation losses in the country was first made by D.A. Pamdas and presented in Symposium on Evaporation control in 1968. This assessment was based on the assumptions:(i)Area of arid, Semi arid and long dry spell regions of India as 2,000,000 sq. km; (ii) Estimated water area in this region (1%) as 20,000 sq. km.; (iii) Estimated area where film application may be feasible as 2,000 sq. km. The evaporation loss from the above area was about 6,000 M. cum.

The National Commission on Agriculture (1976) has estimated that the annual evaporation losses from reservoir surfaces in the order of about 50,000 M.Cum. Also the Water Management Forum (W.M.F.), a national body of the Institution of Engineers of (India) in their publication "Water Conservation by Evaporation Control, 1988" has indicated that in the Indian subcontinent the estimated total evaporation loss of water from large, medium and small storages will be to the tune of 60,000 M.cum, which according to WMF would be adequate to meet the entire municipal and rural water needs of India by 2000 A.D. The CWC has estimated (as per the review of 1990) the annual evaporation loss from the water bodies as 56,000 M.Cum. This figure is for the ultimate stage of development when the total surface area of large and small storages, lakes and tanks in the country is likely to be around 25000 sq. km.

It may , however, be realised that the evaporation from storages/water bodies may greatly influence the design requirement of any water storage system.

Based on the existing network of IMD Evaporimeter stations in India and the available evaporation data from 104 evaporimeter stations, Ramasastri (1987) studied the lake evaporation by using lake to pan coefficients. He concluded that evaporation is highest during the months of April and May and decreases during rainy season and winter months. Less evaporation values were observed in hill stations. This was due to low temperature at high altitudes. The annual evaporation is lowest 100 cm. over Assam. Parts of Uttar Pradesh and Bihar states have evaporation ranging from 150 cm to 200 cm.per annum. The 200 cm isoline covers a narrow strip of north south track from Punjab to Karnataka through Rajasthsn and Maharastra. Bellary and Raichur in interior Karnataka ,part of Maharastra, part of Tamilnadu, Saurashtra & Kutch region in Gujrat have higher evaporation values.

6.0 METHODOLOGY

6.1.0 BASIC APPROACHES FOR EVALUATION OF EVAPORATION

The basic theories of the process of evaporation were under stood much earlier. There are two fundamental approaches to the theoretical study of evaporation from a free-water surface. One involves formulation of the mass transfer process by which vapour is removed from the water surface and is called diffusion method. The other technique ignores momentary dynamics of the process to determine, by book keeping energy flux over some finite time interval, the quantify of energy used in the liquid vapour phase change. This is known as energy balance method. Past experience shows that the best evaporation estimates can be obtained by energy balance and mass transfer methods, widely used all over the world. The evaporation process was never really measured in detail until 1950s, when the U.S. Geological Survey (1954,1928) in cooperation with U.S. weather Service, Bureau of Reclamation and Navy Laboratories, conducted evaporation studies on Lake Hefner and Lake Mead. Most of the previous evaporation studies had used the less precised methods of water budget or pan evaporation (Anderson and Sobson 1982).

Evaporation can be determined by several methods. The following methods and their modifications are generally used:

a) Water budget or storage equation.

b) Mass transfer method or humidity and wind velocity gradients method.

c) Energy budget method or insolation method.

d) Measurement in an auxiliary pan and reduction of the pan evaporation to natural water surface evaporation

e) Empirical formulae.

6.1.1 Water Budget or Storage Equation Approach

This method involves the equation.

$$E = P + I - O \pm U \pm \Delta S \qquad (5.1)$$

Where P is the precipitation on water surface, I is the surface inflow, O is surface outflow, U is underground inflow or outflow, ΔS is change in storage and E is evaporation. ΔS is positive for any increase and negative for a decrease in storage. The quantities are usually expressed in terms of depth in mm over the water area for some convenient time interval. The main disadvantage of this approach is that the above quantities can be determined with only varying degrees of accuracy. All errors in measurements get accumulated and thrown into the resulting value of E. It is specially difficult to make accurate measurement or estimates of the under ground flow. In some cases, this quantity is negligible whereas in others it is an important factor. Springs may occur in the lake bed or if the bed and surrounding area are highly permeable the direct underground inflow may be large. On the other hand, large underground seepage losses may also occur from artificial reservoirs. Unless loss of waters due to seepage is correctly assessed, this equation does not give the correct figures of evaporation. Two research stations of India viz. (a) Irrigation Research Institute, Poondi, Madras and (b) Irrigation Research Institute, Roorkee have made attempts to develop methods for measuring seepage. Using the constant head seepage meter developed by IRI, Roorkee, seepage loss from the water bodies can be measured with fair degree of accuracy.

6.1.2 Mass Transfer Approach

As the name suggests two important factors (i) humidity and (ii)wind velocity form the basis of calculating the evaporation.

The basic assumptions involved in this method are:

i) If the moisture gradient exists in air, water vapours will move towards points of lower moisture contents.

ii) The rate of movement of water vapour is accentuated by the intensity of turbulence in the air.

The method is applicable to both land and water surfaces. However, relatively expensive and highly sensitive hygrometers and wind velocity meters are required to measure the corresponding factors simultaneously at two different elevations above the ground.

6.1.3 Energy Budget or Insolation Method:

This method was suggested by Angstorm in 1920 and is based on the conservation of heat within the body. For any given body of water, a balance must exist between heat gains and losses. Heat is normally gained by long and short-wave radiation, conduction and condensation. Heat losses result from direct land reflected radiation, conduction, convection and evaporation. Radiation conduction, convection and changes in the energy storage in water may be measured and the evaporation or condensation may be computed. In this type of calculation some factors, such as heating due to chemical and biological processes, conduction of heat through the lake bottom and transformation of kinetic energy into thermal energy are considered insignificant. Different equations relating each of the parameters mentioned have been developed by various research workers in the field. This method suffers from the main draw back of measuring various parameters accurately with the help of sensitive and costly equipped.

6.1.4 Measurement in an Auxiliary Pan

Kohler and others had calculated evaporation from lakes by converting measured evaporation from pans by applying a coefficient. Bleney had studied the effects of high altitude on evaporation from pans and determined suitable coefficient. 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 eight of that measured from an isolated pan placed outside the vapour blanket. Further studies by Rohwer, Kohler and Mansfield showed that the evaporation coefficient ranges anywhere between 0.2 to 1.5 and this factor is dependent upon 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 present practice is to estimate evaporation loss from land pan evaporimeter. In the studies being done at IRI, Poondi a floating evaporimeter is used for the experiments. A floating evaporimeter made of GI sheet was initially used. Later on it was found that the stored energy inside the waterbody has a significant effect on the evaporation loss. To have this effect truly reflected, IRI found it necessary to have a suitable material for manufacturing floating evaporimeters. An ideal materials to achieve this objective should perhaps be the one which will have a thermal conductivity equivalent to that of water, but at the same time nonleaky. With this in mind, a study of the thermal conductivity of some materials was made. Thermal conductivity of water is 0.556 W/m C. It is 0.75 for iron, 0.60 for brick, 0.78 for window glass, 0.1 for concrete and 0.02 for plastics. It shows that plastics and concrete have low values and the metals have high values. Ideally brick or glass should be made use of for making floating evaporimeter. But the brick is heavy and highly permissible and the glass is brittle. Hence a new material, perspex sheet, which is akin to glass but at the same time non-brittle and workable was chosen as an alternative material for the fabrication of floating evaporimeter installed at Poondi reservoir.

From the experiences so far gained in the installation of a floating evaporimeter, an arrangement that might perhaps sub-serve the objective of rational determination of evaporation loss and the seepage loss as a by product, as devised by IHH, Poondi. The arrangement consists of an evaporimeter (made up of perspex sheet) which is enclosed by a sliding type of wave arrester (again made up of perspex sheet). This sliding unit slides on the supporting legs of the stand which carries the evaporimeter with a wire drop and a pulley. Equipment like wind anemometer, thermometers etc. can be mounted on the outer sliding frame work. The main advantage of this system is that the sliding arrangement follows the water surface and could be fixed at the desired location. Further, the unit remains at a fixed location. A graduated gauge of requisite least count when fixed to the frame work shall enable the observation of water level fluctuations at the site of evaporation through the transparent perspex sheets.

Since the meteorological factors affecting hydrological processes including evaporation vary over the year, IRO plans to obtain data for a few years for deriving reliable results for possible use in reservoirs analysis problems.

6.1.5 Empirical Formulae

The rate of evaporation at a given location depends upon a number of parameters as explained earlier. Dalton was one of the first scientists to have impounded an empirical formulae for evaporation loss which states that:

$$E = C\,(P_w - P_a) \qquad (5.2)$$

where E = Rate of evaporation in inches per day of the exposed surface

P_w = vapour pressure in the film of air next to water surface

P_a = vapour pressure in the air above the film

C = coefficient dependent upon barometric pressure, wind velocity and other variables.

Many other scientists have proposed different modifications of this evaporation equation by taking into account various related factors. Fitzgerald modified the Dalton's equation by taking into account the effect of wind velocity on evaporation. Carpenter subsequently further modified the Fitzgerald equation by taking modified coefficient factor for wind velocity and his equation was found applicable to the conditions in western United States. Research scientists, Boelter, Hickox, Thomas and Fergusal have later significantly contributed in the development of evaporation equations and removal of doubts and confusion of terms adopted by different authors.

However, as can be seen from the equation, some parameters like temperature conditions, wind velocity etc. have not been separately considered but their effect is lumped in the form of coefficient C.

In India, S.P. Ghosh and S.R. Sarkar of River Research Institute, West Bengal had made attempts to develop equations, correlating evaporation with meteorological factors like temperature, degree of saturation of water vapour, wind velocity and atmospheric pressure. They have suggested the following equation for calculation of Pan evaporation from meteorological factors:

$$E = [1.3684 - 0.0189B\,(0.41 + 0.136W)\,(e_s - e_d)] \qquad (5.3)$$

where,

E = daily evaporation in inches

B = mean barometric pressure in inches of mercury

W = mean velocity of ground wind in miles per hour

e_s = Mean vapour pressure of saturated air at the temperature of water surface in inches of mercury

e_d = mean vapour pressure actually present in the air in inches of mercury.

The pan evaporation as calculated can be converted into reservoir evaporation by multiplying with standard pan coefficient. They suggested standard coefficient for 1.22m dia US Class A land pan as 0.70.

The above equation was developed based on the limited years of meteorological data of four stations having, evaporation ranges from 0.041 inch to 0.389 inch, (1.04 mm to 9.88 mm), barometric pressure ranges from 25.54 inches to 30.07 inches (648.72 mm to 763.78 mm) of mercury, ground wind velocity ranges from 0.30 to 5.78 miles per hour (0.48 to 9.30 km/hr) and temperature ranges from 51.75xF to 97.22xF (10.97xC to 36.23xC). In view of this, the equation suggested can be considered as a generalized equation for regions having meteorological values within the range indicated.

The choice of method used to determine evaporation depends on the required accuracy of the results and the type of information or data available. If a highly accurate study on an existing lake is desired and the resources are available, then an energy budget should be calibrate the mass transfer coefficient, after which the mass transfer method-which does not require such expensive instrumentation-can be used to provide fairly accurate results.

Both the combination and adjusted pan evaporation are reasonable methods for computing lake evaporation over a long time interval, such as a year. For annual evaporation, the combination method, using climatological observations, has not been shown to be any more accurate than pan evaporation. It seems reasonable, therefore, to use available pan evaporation data, particularly those compiled by Farnsworth et.al. (1982) and Farnsworth and Thompson (1982).

In reservoir management and operation, the monthly and weekly distribution of lake evaporation can be extremely important. For such cases, it is essential that the investigator accurately account in some manner for heat storage of the lake-something neither the pan evaporation method nor the combination equation does. Occasionally, enough information can be assembled with which to predict roughly the lake's surface temperature or the extent of heat storage in the lake. If the lake's surface temperature is estimated, the mass transfer equation can be applied to obtain shorter-interval estimates of evaporation. However, if they are not applied intelligently, these approximation methods can result in considerable error.

Average values of lake evaporation are generally not appropriate in designing reservoirs for drought years, because these years can be expected to have higher evaporation rates. The exception occurs when the evaporation is computed over a period of several years, in which case evaporation tends toward the average value because the persistence of the process is not great (Yu et.al 1980). The coefficients of variation for annual and monthly evaporation given by Farnsworth and Thompson (1982) should be used to provide an idea of the increase in evaporation that occurs in a dry year. For example, the coefficient of variation for May to October pan evaporation for most locations in the midwest United States is about 10-12%. Assuming that pan and lake evaporation show similar annual variation and that the distribution of the seasonal evaporation is approximately normal (Gaussian), then evaporation should be 10% above normal roughly one year out of six. In this manner, conservative estimates of a 40-year drought may increase the annual evaporation by as much as 25 percent over the average annual value.

6.2.0 DISCRIPTION OF MODELS USED FOR EVAPORATION ESTIMATION:

Water evaporation is one of the most obscure component of hydrologic cycle to measure accurately. There are two basic reasons for this obscurity. First, no instrumentation exist that can truly measure evaporation from a natural surface. Therefore, one must estimate evaporation (1) from a controlled surface (e.g. from evaporation pans); (2) indirectly, by estimating the evaporation as a residual amount in an equation involving many other natural processes; (3) using empirical equations. The acceptable/reliable estimates of evaporation from Lakes/reservoirs requires either detailed instrumentation of the reservoir or an intuitive application of climatic and physical data.

It is clear that there are several alternatives of estimating reservoir evaporation ranging from fairly accurate techniques requiring sophisticated instruments (like in energy budget method) to relatively less accurate methods using conventional instruments and existing evaporation pans. the energy budget technique supposed to be the most accurate method where in the errors in estimating the evaporation range about 10 percent and 15 percent for annual and monthly estimates respectively. But it requires extensive instrumentation and frequent surveys of water body making it a comparatively expensive deal. The mass transfer method is another alternative which provides relatively better estimates of evaporation using routinely observed meteorological and reservoirs water level fluctuation data. The estimation of mass transfer coefficient, N is the only limitation of this method. However this could also provide relatively compromising results even when, N is worked out from thy surface area of a water body as suggested by Harbeck (1962). The data of pan evaporation using suitable pan coefficient can be made with caution.

There are several well recognized methods available for evaporation estimation. These methods include various equations primarily based on solar radiation, humidity, temperature, wind and miscellaneous principles. The selection of method for a particular use may depend on the accuracy of available meteorological data, the training and experience of user and the general acceptance of previous estimates. In this study the three recommended methods have been selected for estimation and evaluation of evaporation from Navil Tirth reservoir.

These methods are (i) Kohler et.al. (1954), (ii) Penman (1963) and (iii) Van Bavel & Businger (1966,1956). A computer programme was developed for all the three models.It is presented in appindix-III.

(I) PENMAN (1963) MODEL:

The rate of evaporation is influenced by energy available, vapour pressure gradients and resistance to Pathway. All three interact continuously, but only solar radiation can be considered constant. Under natural evaporation conditions, the state of a given mass of air can be described by its temperature and vapour pressure. Penman in (1948) first derived the 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 potential evaporation, which is the original Penman formula.

$$\lambda E = \frac{\Delta\,(Rn + G) + \rho\,Cp\,(e_z^o - e_z)/\,ra}{\Delta + \gamma} \qquad (6.1)$$

$$Ep = \frac{\Delta}{\Delta + \gamma}(Rn + G) + \frac{\gamma}{\Delta + \gamma}\,15.36\,(1.0\text{-}0.0062\,u_2)\,(e_z^o - e_z) \qquad (6.2)$$

where, Ep = Evaporation from a free water surface.

ra = Diffusion resistance of air layer

This formula was recommended by penman for estimation of daily evaporation. Following the evaporation studies at Lake Hefner, Oklahoma, and Penman 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 for the study site at Navil tirth Dam.

$$Ep = \left[\frac{\Delta}{\Delta + \gamma}(Rn + G) + \frac{\gamma}{\Delta + \gamma}15.36(0.5\text{-}0.01\,u_2)(e_z^o - e_z)\right]/59 \qquad (6.3)$$

Where, Ep = Evaporation (mm day^{-1})

Rn = Net radiation (langley day^{-1})

G = soil heat flux (considered as zero for water surface)

γ = Psychrometric constant

Δ = slope of saturation vapour pressure - temperature curve (de/dT) (mb C^{-1})

$e_z^o - e_z$ = Vapour pressure deficit (mb.)

u_2 = Wind speed (mile day^{-1})

Procedure for estimation of the parameters in the above model have been discussed in section 7.0.

(II) KOHLER et.al. MODEL:

Kohler, Nordenson and Fox (1955) adopted the Penman equation to class A Pan evaporation by using γ_p = 0.00157P, mb C^{-1} , and for lake or open water evaporation by multiplying the solution by 0.7 with γ_{ℓ} = 0.000661 P, 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.

$$EK = 0.7 \left[\frac{Rn\ \Delta}{\Delta + \gamma_{\ell}} + \frac{\gamma_{\ell}}{\Delta + \gamma_{\ell}}\ Ea\right] \qquad (6.4)$$

Where, $$Ea = (e_z^{o} - e_z)^{0.88}\ (0.37 + 0.0041\ u_2) \qquad (6.5)$$

EK = Evaporation from lake/reservoir (inches day^{-1})

Rn = Net radiation (equivalent to inches of water)

Δ & γ_{ℓ} = Psychrometric constants (inches of Hg ^{o}F)

$e_z^{o} - e_z$ = Vapour pressure deficit (inches of Hg.)

u_2 = Wind speed (mile day^{-1})

Details of the model parameters and their estimation procedure is discussed in section 7.0.

(III) VAN BAVEL-BUSINGER MODEL:

A modification of the transfer coefficient proposed by Businger (1956) and derived from the Thornthwaite and Haltzman (1939) equation was presented by Van Bavel (1966). It assumes adiabatic conditions and transfer coefficient for heat equals to transfer coefficient for vapour ($h_h = h_v$).He suggested the following equation for estimation of potential evaporation.

$$Ev = \frac{\Delta}{\Delta + \gamma}(Rn + G) + \frac{\gamma}{\Delta + \gamma} \; \frac{0.622\lambda\rho k^2}{p} \; \frac{u_z}{[\ln z/z_o]^2}(e^o_z - e_z)]/59$$

......(6.6)

Where, Ev = Evaporation (mm day^{-1})

Rn = Net radiation (langley day^{-1})

G = soil heat flux (considered as zero for water surface)

γ = Psychrometric constant

Δ = slope of saturation vapour pressure - temperature curve (de/dT) (mb C^{-1})

$e^o_z - e_z$ = Vapour pressure deficit (mb.)

u_z = Wind speed (Km day^{-1})

since ρ and p decrease with increase in elevation with λ =585 cal g^{-1} and p = 1000 , the factor $0.622 \; \lambda \; \rho \; k^2/p$ is considered as constant.

Where, λ = latent heat of vaporization (cal $gm.^{-1}$)

ρ = air density (gm. cm^{-3})

p = atmospheric pressure (mb)

k = Von Karman's constant

6.3.0 ESTIMATION OF MODEL PARAMETERS:

This section discusses the controlling characteristics and variables of atmospheric system which governs the physical properties of evaporation process at water-air interface to emphasize the parameters that needs to be estimated to study the evaporation losses for a reservoir. The weather data collected at the bank of the reservoir have been utilized for this purpose.

6.3.1 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.

$$R_{bo} = \varepsilon'\sigma\ (T + 273)^4 \qquad (7.1)$$

$$R_{so} = \frac{R_s}{[0.35 + 0.6(\frac{SSH}{MSH})]} \qquad (7.2)$$

$$R_b = R_{bo}[\ \frac{1.2\ R_s}{R_{so}}) - 0.2\ ] \qquad (7.3)$$

$$R_s = 59\ [0.31 + 0.49\ (\frac{SSH}{MSH})]\ R_A \qquad (7.4)$$

$$R_n = (1.0 - \alpha)R_s - R_b \qquad (7.5)$$

Where,

R_n = Net Radiation (langley day^{-1})

α = Short wave reflectance (α =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})

ε' = Emissivity constant
= $(0.39 - 0.05 \sqrt{e_d})$

σ = 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)

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 tables shown in appendix - I and II respectively.

6.3.2 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.

$$e_z^o = 33.86\ [0.000738\ T + 0.8072)^8 - 0.000019|1.8\ T + 48 + 0.00136] \qquad (7.6)$$

$$e_z = e_z^o \times \frac{Rh}{100} \qquad (7.7)$$

where, e_z^o = Saturation vapour pressure (mb)

e_z = Actual vapour pressure at temperature (mb)

Rh = Relative humidity (%)

T = Temperature (^{o}C)

6.3.3 Common parameters:

a) Psychrometric constant (γ):

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

$$\gamma = \frac{C_p\ P}{0.622\ \lambda} \qquad (7.8)$$

(γ in mb $^{o}C^{-1}$)

$$\lambda = 595 - 0.51\ T \qquad (7.9)$$

where. λ = 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 (Δ):

Change in saturation vapour pressure (Δ) with temperature is evaluated using Bone's formula for saturation vapour pressure.

$$\Delta = \frac{de^{o}}{dT} = 33.8639\ [0.05904\ (0.00738\ T + 0.8072)^{7} - 0.0000342]$$

(Δ in mb $^{o}C^{-1}$)

.....(7.10)

6.3.4 Atmospheric pressure (P) and density (ρ):

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.

$$P = 1013 - 0.1055\ EL \qquad (7.11)$$

(P in mb)

$$\rho = 0.00123 - 0.000034\ EL/1000 \qquad (7.12)$$

(ρ in g cm^{-3})

where, EL = Elevation (m)

The elevation of Navil Tirth dam site about 650m has been considered in above calculation.

6.4.0 ADJUSTMENT OF PAN-TO-RESERVOIR EVAPORATION:

The pan evaporation values does not represent the lake evaporation due to phase difference between pans and lakes in the storage of heat due to solar radiation. The other factor is the difference in the behavior of pans and lakes to advective heat transfer due to their different aerial extent and exposure to wind. But reliable estimates of annual lake evaporation can be obtained by application of the appropriate pan to lake coefficient to observed pan evaporation (WMO, Note 126). The lake-pan coefficients show considerable variation both in space and time. In order to account for the variation of the lake-pan relationship under different climatic region, the observed pan evaporation is adjusted for heat gain or less through the bottom of the pan. It is assumed that for the conditions when the pan water temperature and air temperature is on the average equal, the pain coefficient is 0.7. In warm and arid areas, the class A pan water temperature is on the average less than the air temperature and, when compared with evaporation from lakes on 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).

ISI standard (IS:6939-1973) recommended that the coefficient for conversion of class A Pan being used in India may very between 1.10 to 0.9 for lake evaporation of the order of 4 to 5 m/day, between 0.75 to 0.65 for lakes evaporation of the order of 10 mm and about 0.8 for transition months.

Ramasastri (1987) considered 22° latitude as demarcating line for south and north parts of India and he suggested the following combination of coefficients with months of the year.

		Coefficient		
		0.6	0.7	0.8
I	North of 22° latitude	Nov-Feb	Mar-Apr Sep-Oct	May-Aug
II	South of 22° latitude	Dec-Jan	Feb-Mar Sep-Nov.	May-Aug

As the pan evaporation is measured from the mesh covered class A pan, the observed pan data are adjusted by the factor as 1.144 to obtain evaporation from open pan.

Using the above criteria for the coefficients, the mesh factor as 1.144 and combination of pan to lake coefficients for south of 22° lat. have been considered, and pan data have been adjusted for evaporation from Navil Tirth reservoir.

7.0 RESULTS AND DISCUSSION:

Evaporation losses in tropical countries like India are high because of large overall aridity and a large number of sunshine days. Review of various studies on evaporation in the country indicated that the annual evaporation losses from the reservoirs in arid and semi arid areas vary from 1.5m to 3.0m, which represent about 20 to 25% of their water budget. The

TABLE: 1. MONTHWISE AVERAGE EVAPORATION RETES (mm/day)

ADJUSTED PAN-TO-RESERVOIR EVAPORATION

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1983	4.49	5.73	7.21	7.17	7.01	5.02	3.53	3.22	2.97	4.20	.00	.00
1984	.00	6.55	6.25	6.67	8.38	4.50	2.92	3.86	3.68	3.55	5.25	3.83
1985	3.81	5.69	6.94	6.71	7.60	3.98	3.14	3.31	3.79	4.00	5.20	4.05
1986	4.17	4.97	7.20	6.91	6.41	.00	.00	.00	.00	4.47	1.92	3.61
1987	4.24	5.65	.00	.00	.00	.00	3.63	3.64	3.49	3.52	4.55	.00
1988	3.99	5.27	6.92	6.35	7.33	4.55	3.10	2.92	2.64	4.54	5.34	3.65
1989	3.94	6.65	5.64	6.23	9.15	.00	.00	.00	.00	.00	.00	.00
MEAN	4.11	5.79	6.69	6.67	7.65	4.51	3.26	3.39	3.32	4.05	4.45	3.79

PENMAN METHOD (PENMAN,1963)

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
1983	1.92	2.86	3.67	4.65	5.61	4.72	3.68	2.97	3.10	2.87	.00	.00
1984	.00	3.27	3.99	5.28	6.65	4.64	3.15	3.27	3.18	2.53	2.22	1.77
1985	2.13	2.98	4.52	5.56	6.04	4.17	3.18	3.07	3.51	2.62	2.23	1.73
1986	1.86	3.10	4.63	5.78	5.63	.00	.00	.00	.00	2.87	1.85	1.77
1987	2.08	2.70	.00	.00	.00	.00	3.80	3.47	3.41	2.47	1.95	.00
1988	1.89	3.46	4.55	4.94	6.02	4.37	3.23	2.79	2.53	2.89	2.14	1.68
1989	1.90	2.78	3.82	5.10	7.06	.00	.00	.00	.00	.00	.00	.00
MEAN	1.97	3.02	4.20	5.22	6.17	4.48	3.41	3.12	3.15	2.71	2.08	1.73

KOHLER METHOD (KOHLER,NORDENSON AND FOX,1954)

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
1983	3.78	4.79	6.05	7.24	7.77	6.15	4.73	3.65	4.22	4.25	.00	.00
1984	.00	5.07	5.66	7.29	8.79	5.74	3.98	4.17	4.55	3.78	3.96	3.46
1985	3.74	4.81	6.44	7.78	8.19	5.27	3.80	3.93	5.01	3.98	4.02	3.39
1986	3.56	6.22	6.66	7.88	7.89	.00	.00	.00	.00	4.44	2.64	3.44
1987	3.77	4.58	.00	.00	.00	.00	4.77	4.44	4.76	3.80	3.05	.00
1988	3.66	5.26	6.46	6.93	7.96	5.62	4.13	3.51	3.32	4.57	3.96	3.35
1989	3.73	4.81	5.78	7.30	9.39	.00	.00	.00	.00	.00	.00	.00
MEAN	3.71	5.07	6.18	7.40	8.33	5.69	4.28	3.94	4.37	4.14	3.53	3.41

VAN BAVEL-BUSINGER METHOD (VAN BAVEL,1966 AND BUSINGER,1956)

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
1983	1.85	3.26	3.54	4.71	6.72	5.95	4.48	3.57	3.72	3.32	.00	.00
1984	.00	3.82	4.50	6.39	8.57	6.07	3.73	4.03	3.71	2.73	2.18	1.67
1985	2.21	3.33	5.22	6.69	7.66	5.26	3.90	3.68	4.21	2.87	2.17	1.55
1986	1.79	3.61	5.32	7.05	6.95	.00	.00	.00	.00	3.10	1.86	1.74
1987	2.14	2.83	.00	.00	.00	.00	4.73	4.25	4.05	2.56	1.94	.00
1988	1.80	4.21	5.35	5.80	7.66	5.47	3.80	3.24	2.90	3.09	2.14	1.59
1989	1.81	2.83	4.16	5.88	9.51	.00	.00	.00	.00	.00	.00	.00
MEAN	1.93	3.41	4.68	6.09	7.84	5.69	4.13	3.75	3.72	2.95	2.06	1.64

literature shows or that no direct method of evaporation measurement exists at present but the best evaporation estimates can be obtained by energy balance and mass transfer methods, widely used in the world. In this case the climetological data and pan evaporation data collected in the observatory located at the bank of Navil Tirth dam, have been analysed using Penman, Kohler et.al. and Van Bavel Models. The Pan-evaporation has been adjusted to make account of reservoir evaporation using Pan to lake correction factors. The following discussions are based on monthwise means of daily evaporation of the here presented model's results in table 1.

The adjusted pan to lake evaporation and the estimated values from the three methods indicate that in general, The models gave quite similar trends of reservoir evaporation behaviour. In winter periods (Dec. & Jan.). The differece between adjusted Pan to lake evaporation and estimated evaporation values appear to be large, where as in springs and summer these differences are comparatively less and model results are compareable. The overall comparision of adjusted pan-to reservoir evaporation and estimated values indicate that the estimates obtained from Kohler et.al. model gave better results for all the months. The comparision which is given in figure 1 also leads to the same conclusions. Also on the annual basis comparision, the results of Kohler et.al. model are in good agreement and look much more opimistic than that of Penman and Van Bavel models.

The following discussions are based on statistical analysis of adjusted pan-to-reservoir evaporation and model's results.

General statistics which includes the sample size, average, variance, standaerd deviation, standered error, range, skewness,and kurtosis etc of the adjusted pan evaporation and the

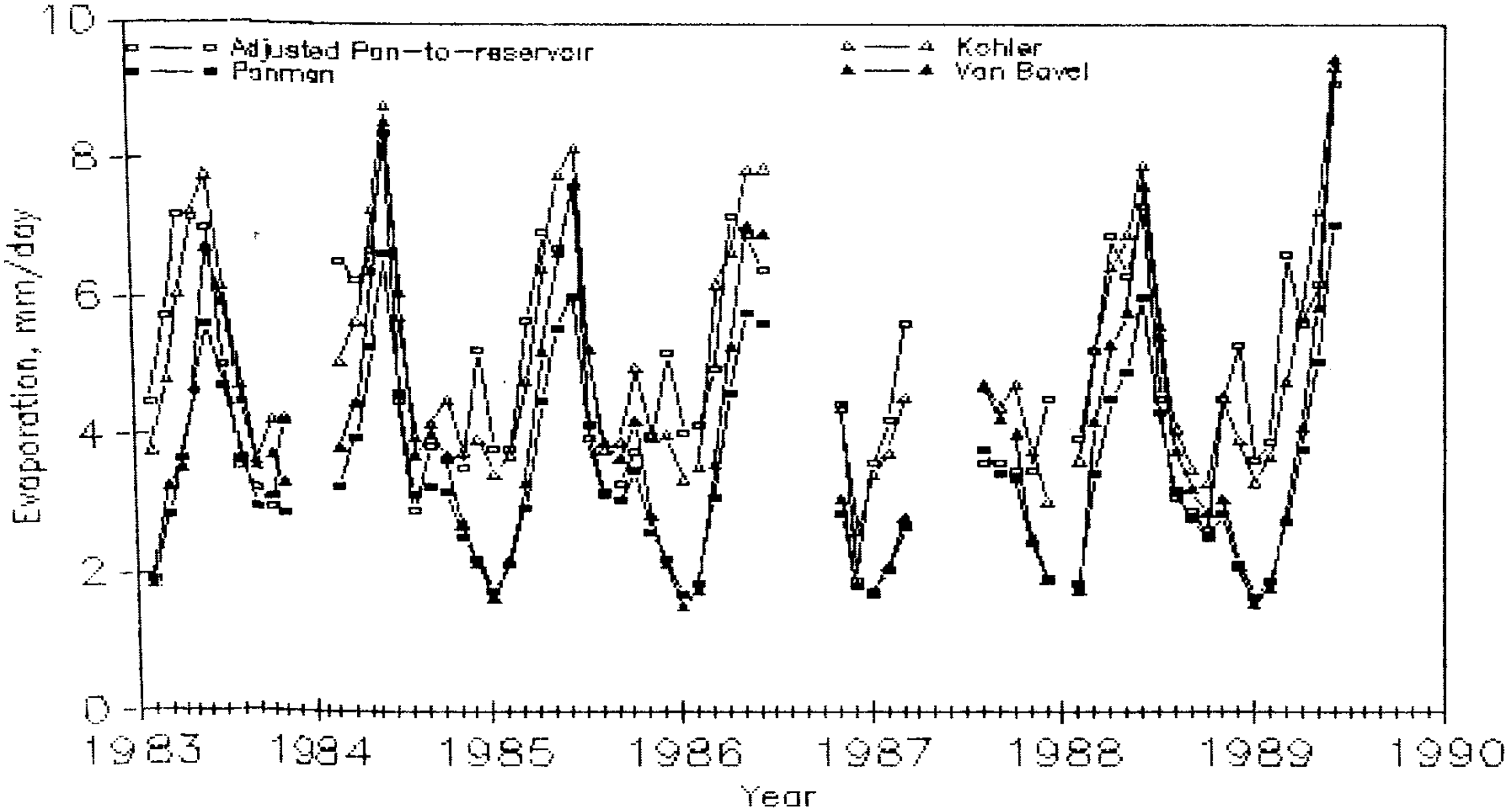

Fig: 1. Mean daily evaporation in different months.

estimates of Penman, Kohler, Van Bavel is repored in tables 2a, 2b, 2c, and 2d respectively. On viewing the sample size, we see that it is not constant in each month. The variation in sample size is only due to non-availability of either climatological or pan evaporation data. The statistical parameters such as Variance, standard deviation and range, which defines variability or spread of data/estimates, are observed to be relatively higher for adjusted pan data (table 2a) as compared to estimates of Penman, Kohler,and Van Bavel methods table 2b, 2c & 2d,respectively. This reveals that the measured pan data have greater dispersion.

The skewness of the distribution is departing from zero, it indicates that the data/estimates do not fallow a normal distribution, but is skewed to either right or left depending upon +ve and -ve values respectively. The Krutosis for a normal distribution should approach to 3.1 but the values reported in tables 2a, 2b, 2c,& 2c in the present analysis it has been transformed to zero. Therefore, for a normal distribution the Kurtosis may be considered as zero for results interpretation. Since the Kurtosis in any of the cases are not approaching zero, supports that the adjusted pan data and estimates both depart from a normal distribution.

The linear regressions have been developed in order to check one to one relationship between adjusted pan to reservoire evaporation and estimates obtained from three models. Statistical results of the regression are reported in table 3, and the plots of linear relationship are shown in Fig.2. The higher values of corelation coefficient, 'T'-ststistics & 'F' ratio and low standard error suggest that the corelation is better and vice versa, From table 3 it is observed that the relationship between adjusted pan to lake evaporation and estimates by Kohler model is

STATATISTICAL ABSTRACT OF MONTHLY EVAPORATION FOR NAVIL TIRTH DAM FOR THE PERIOD FROM 1983 TO 1989

TABLE: 2a, ADJUSTED PAN-TO-RESERVOIR EVAPORATION

	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
Sample size	6	7	6	6	6	4	5	5	5	6	5	4
Average	4.106	5.787	6.693	6.673	7.646	4.512	3.264	3.39	3.35	4.046	4.452	3.785
Variance	0.059	0.382	0.388	0.121	0.966	0.180	0.091	0.134	0.280	0.194	2.101	0.040
Standard deviation	0.244	0.618	0.623	0.347	0.983	0.425	0.302	0.367	0.529	0.440	1.449	0.200
Standard error	0.099	0.233	0.254	0.142	0.401	0.212	0.135	0.164	0.236	0.180	0.648	0.100
Minimum	3.81	4.97	5.64	6.23	6.41	3.98	2.92	2.92	2.64	3.52	1.92	3.61
Maximum	4.49	6.65	7.21	7.17	9.15	5.02	3.63	3.86	3.86	4.54	5.34	4.05
Range	0.68	1.68	1.57	0.94	2.74	1.04	0.71	0.94	1.22	1.02	3.42	0.44
Interquartile range	0.3	1.28	0.95	0.56	1.37	0.545	0.43	0.42	0.82	0.92	0.7	0.31
Skewness	0.548	0.393	-1.191	0.106	0.508	-0.175	0.314	0.085	-0.539	-0.241	-1.997	0.894
Standardized skewness	0.548	0.425	-1.191	0.106	0.508	-0.143	0.286	0.078	-0.492	-0.241	-1.823	0.730
Kurtosis	-0.219	-0.892	0.307	-0.823	-0.328	1.448	-2.318	-0.967	-1.953	-1.998	4.014	-0.805
Standardized kurtosis	-0.109	-0.482	0.153	-0.411	-0.164	0.591	-1.058	-0.441	-0.891	-0.999	1.832	-0.328

TABLE: 2b PENMAN MODEL (PENMAN,1963)

	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
Sample size	6	7	6	6	6	4	5	5	5	6	5	4
Average	1.963	3.008	4.211	5.143	6.168	4.475	3.408	3.114	3.146	2.708	2.078	1.737
Variance	0.012	0.077	0.158	0.253	0.333	0.063	0.094	0.069	0.146	0.036	0.028	1.825
Standard deviation	0.112	0.278	0.397	0.503	0.577	0.252	0.307	0.263	0.382	0.190	0.169	0.042
Standard error	0.045	0.105	0.162	0.205	0.235	0.126	0.137	0.118	0.171	0.077	0.075	0.021
Minimum	1.86	2.7	3.76	4.49	5.61	4.17	3.15	2.79	2.53	2.47	1.85	1.68
Maximum	2.13	3.46	4.63	5.78	7.06	4.72	3.8	3.47	3.51	2.89	2.23	1.77
Range	0.27	0.76	0.87	1.29	1.45	0.55	0.65	0.68	0.98	0.42	0.38	0.09
Interquartile range	0.19	0.49	0.73	0.91	1.02	0.41	0.5	0.3	0.31	0.34	0.27	0.065
Skewness	0.922	0.698	0.104	-0.154	0.756	-0.427	0.655	0.268	-1.245	-0.236	-0.623	-1.042
Standardized skewness	0.922	0.754	0.104	-0.154	0.756	-0.349	0.598	0.244	-1.137	-0.236	-0.568	-0.850
Kurtosis	-1.366	-0.817	-2.885	-1.514	-0.785	-2.745	-2.786	-0.763	1.727	-2.669	-2.112	-0.323
Standardized kurtosis	-0.683	-0.441	-1.442	-0.757	-0.392	-1.120	-1.271	-0.348	0.788	-1.334	-0.964	-0.132

STATATISTICAL ABSTRACT OF MONTHLY EVAPORATION FOR NAVIL TIRTH DAM FOR THE PERIOD FROM 1983 TO 1989

TABLE: 2c KOHLAR et al. MODEL

	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
Sample size	6	7	6	6	6	4	5	5	5	6	5	4
Average	3.706	5.115	6.175	7.403	8.331	5.695	4.282	3.94	4.372	4.136	3.526	3.41
Variance	6.9463	0.267	0.164	0.128	0.399	0.131	0.196	0.143	0.429	0.111	0.408	2.466
Standard deviation	0.083	0.517	0.405	0.358	0.632	0.362	0.443	0.378	0.655	0.333	0.638	0.049
Standard error	0.034	0.195	0.165	0.146	0.258	0.181	0.198	0.169	0.293	0.136	0.285	0.024
Minimum	3.56	4.79	5.66	6.93	7.77	5.27	3.8	3.51	3.32	3.78	2.64	3.35
Maximum	3.78	6.22	6.66	7.88	9.39	6.15	4.77	4.44	5.01	4.57	4.02	3.46
Range	0.22	1.43	1	0.95	1.62	0.88	0.97	0.93	1.69	0.79	1.38	0.11
Interquartile range	0.11	0.45	0.68	0.54	0.9	0.5	0.75	0.52	0.54	0.64	0.91	0.08
Skewness	-1.325	2.087	-0.198	0.317	1.144	0.238	0.302	0.256	-1.248	0.188	-0.830	-0.391
Standardized skewness	-1.325	2.255	-0.198	0.317	1.144	0.194	0.275	0.234	-1.139	0.188	-0.757	-0.319
Kurtosis	1.206	4.508	-2.075	-1.051	0.125	0.998	-2.819	-1.486	1.574	-2.113	-2.009	-2.444
Standardized kurtosis	0.603	2.435	-1.037	-0.525	0.062	0.407	-1.286	-0.678	0.718	-1.056	-0.917	-0.997

TABLE: 2d VAN BAVEL AND BUSSIGER MODEL

	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
Sample size	6	7	6	6	6	4	5	5	5	6	5	4
Average	1.933	3.412	4.666	6.086	7.845	5.687	4.128	3.754	3.718	2.945	2.058	1.637
Variance	0.035	0.258	0.592	0.680	1.086	0.148	0.201	0.156	0.255	0.077	0.021	7.158
Standard deviation	0.189	0.508	0.770	0.825	1.042	0.385	0.448	0.395	0.505	0.277	0.147	0.084
Standard error	0.077	0.192	0.314	0.336	0.425	0.192	0.200	0.176	0.225	0.113	0.066	0.042
Minimum	1.79	2.83	3.45	4.71	6.72	5.26	3.73	3.24	2.9	2.56	1.86	1.55
Maximum	2.21	4.21	5.35	7.05	9.51	6.07	4.73	4.25	4.21	3.32	2.18	1.74
Range	0.42	1.38	1.9	2.34	2.79	0.81	1	1.01	1.31	0.76	0.32	0.19
Interquartile range	0.34	0.99	1.16	0.89	1.62	0.645	0.68	0.46	0.34	0.37	0.23	0.135
Skewness	0.978	0.322	-0.767	-0.801	0.753	-0.167	0.700	4.155	-1.264	-0.110	-0.728	0.367
Standardized skewness	0.978	0.348	-0.767	-0.801	0.753	-0.136	0.639	3.793	-1.154	-0.110	-0.664	0.300
Kurtosis	-1.536	-0.754	-0.771	0.700	-0.198	-4.150	-2.247	-0.986	1.937	-0.965	-2.342	-2.102
Standardized kurtosis	-0.768	-0.407	-0.385	0.350	-0.099	-1.694						

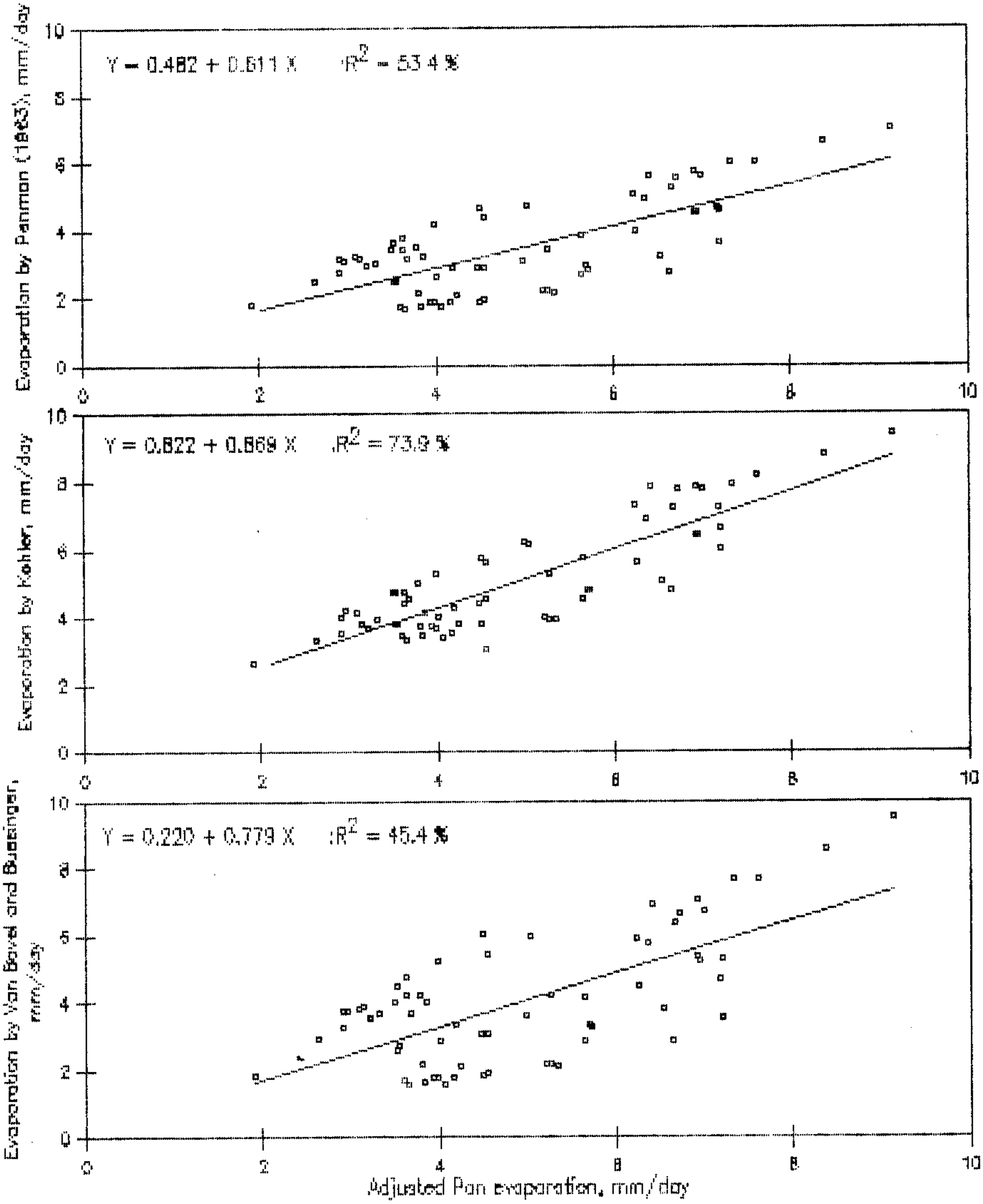

Fig : 2 Relationship between adjusted pan–to–reservoir evaporation and models' estimates of it

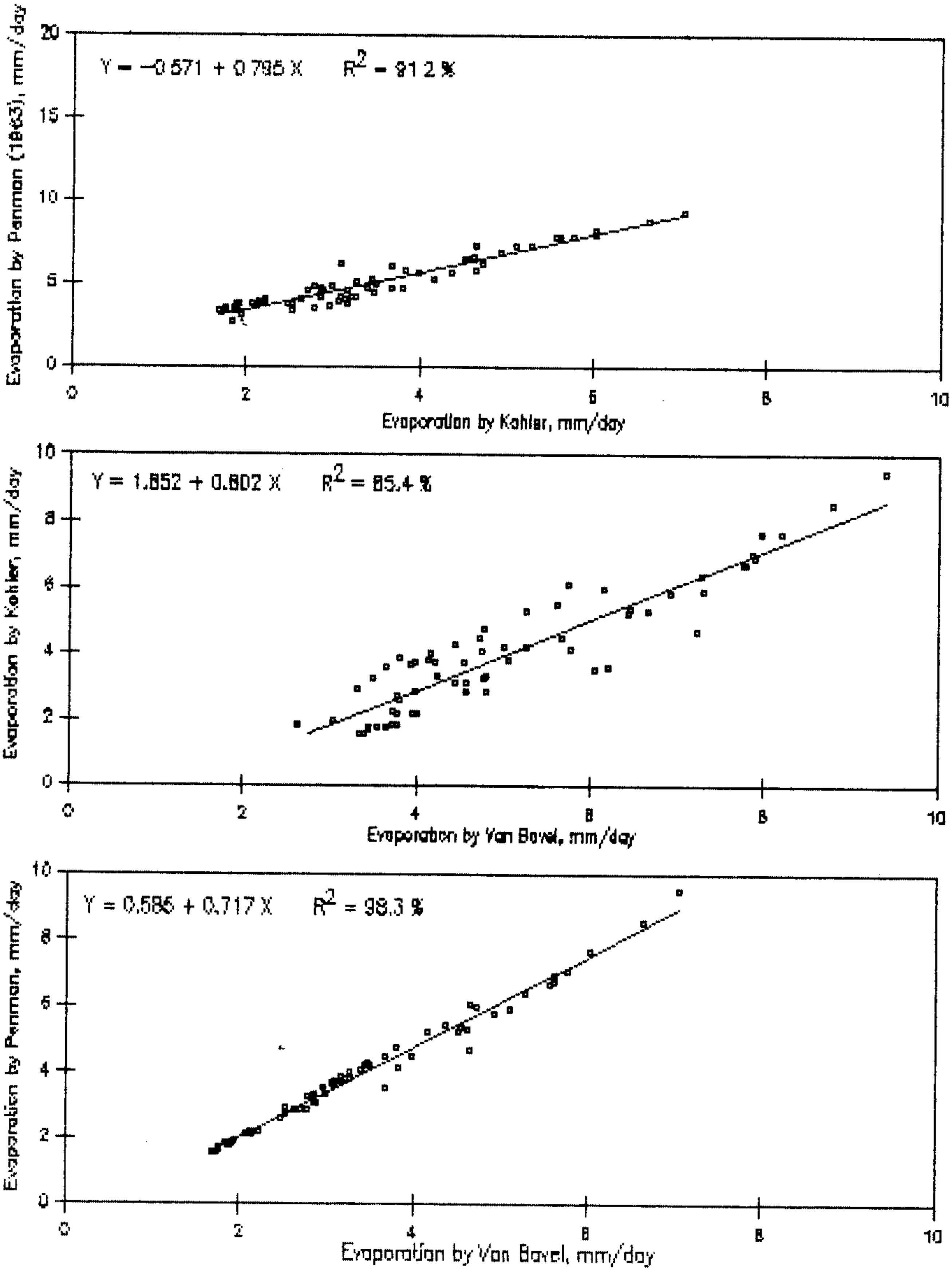

Fig. 3. Relationship between models' estimates of evaporation.

TABLE: 3 LINEAR RELATIONSHIP BETWEEN ADJUSTED PAN-TO-RESERVOIR EVAPORATION AND MODELS' ESTIMATES

SL NO.	Relationship between	Coefficient of correlation	Standard error of estimates	R-squared	F-ratio	T-value of		Probability level of	
						inter-cept	slope	inter-cept	slope
1.	Adjusted Pan-to-reservoir and estimates of Penman [Y = 0.482 + 0.611 X]	0.731	0.923	53.48%	71.266	1.281	8.442	0.204	6.791x10^{-2}
2.	Adjusted Pan-to-reservoir and estimates of Kohler [Y = 0.822 + 0.858 X]	0.859	0.834	73.94%	175.869	2.419	13.261	0.018	0
3.	Adjusted Pan-to-reservoir and estimates of Kohler [Y = 0.220 + 0.779 X]	0.674	1.382	45.46%	51.680	0.390	7.188	0.697	1.012x10^{-9}

TABLE: 4 LINEAR RELATIONSHIP BETWEEN MODELS' ESTIMATES

SL NO.	Relationship between	Coefficient of correlation	Standard error of estimates	R-squared	F-ratio	T-value of		Probability level of	
						inter-cept	slope	inter-cept	slope
1	Estimates of Penman model and Kohler model [Y = -0.571 + 0.795 X]	0.955	0.402	91.24%	656.112	-3.444	25.614	1.022	0
2	Estimates of Kohler model and Van Bavel model [Y = 1.852 + 0.802 X]	0.924	0.621	85.47%	370.526	1.221x10^{-14}	0	0	0
3	Estimates of Penman model and Van Bavel model [Y = 0.585 + 0.717 X]	0.991	0.174	98.35%	3744.557	11.251	61.192	0	0

better, and followed by estimates of Penmanand Van Bavel models respectively.

The linear regression between estimates of one model to other are also developed and shown in figure 3. The statistical summary of regression is presented in table 4. The relationship of Penman versus Van Bavel presents that the estimates obtain from Penman and Van Bavel methods are in better agreement to each other and followed by Kohler versus Penman and Van Bavel versus Kohler.

Thus it is concluded that the Kohler et.al. method may be considered as comparatively reliable approach for estimation of evaporation from reservoirs of lakes in the surrounding areas.

8.0 CONCLUSIONS:

The three methods used for estimation of reservoir evaporation give comparable estimates of evaporation from Navil Tirth reservoir. The estimates of the mean value for the reservoir evaporation in winter months are lower than those obtained from pan after adjustment for reservoir evaporation. The adjusted pan to lake evaporation and the estimated values from the three methods indicate that in general, the methods gave quite similar trends of reservoir evaporation behaviour for spring and summer months. In winter season (Dec. & Jan.) the differece between adjusted pan to lake evaporation and estimated evaporation values is large, where as in spring and sumer season these differences are comparatively less and model results are closer to adjusted pan-to-reservoir evaporation.

The overall comparision of adjusted pan-to lake evaporation and estimated values indicate that the estimates obtained from Kohler et.al. model gave better corelation for all the months. Also on the basis of comparision of annual values, the results of Kohler et.al. model are in good agreement and look much more opimistic than that of Penman and Van Bavel models. Thus it is concluded that the Kohler et.al. method may be considered as comparatively reliable approach for estimation of evaporation from reservoirs or lakes in the surrounding areas. However. The corfficients used for adjusting pan evaporation to lake are subjective and need further study.

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Extra Terrestrial Radiation (Ra) expressed in equivalent evaporation in mm/day

Northern Hemisphere													Southern Hemisphere											
Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Lat	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
3.8	6.1	9.4	12.7	15.8	17.1	16.4	14.1	10.[illegible]	7.4	4.5	3.2	50°	17.5	14.7	10.9	7.0	4.2	3.1	3.5	5.5	8.9	12.9	16.5	18.2
4.3	6.6	9.8	13.0	15.9	17.2	16.5	14.3	11.2	7.8	5.0	3.7	48	17.6	14.9	11.2	7.5	4.7	3.5	4.0	6.0	9.3	13.2	16.6	18.2
4.9	7.1	10.2	13.3	16.0	17.2	16.6	14.5	11.5	8.3	5.5	4.3	46	17.7	15.1	11.5	7.9	5.2	4.0	4.4	6.5	9.7	13.4	16.7	18.3
5.3	7.6	10.6	13.7	16.1	17.2	16.6	14.7	11.9	8.7	6.0	4.7	44	17.8	15.3	11.9	8.4	5.7	4.4	4.9	6.9	10.2	13.7	16.7	18.3
5.9	8.1	11.0	14.0	16.2	17.3	16.7	15.0	12.2	9.1	6.5	5.2	42	17.8	15.5	12.2	8.8	6.1	4.9	5.4	7.4	10.6	14.0	16.8	18.3
6.4	8.6	11.4	14.3	16.4	17.3	16.7	15.2	12.5	9.6	7.0	5.7	40	17.9	15.7	12.5	9.2	6.6	5.3	5.9	7.9	11.0	14.2	16.9	18.3
6.9	9.0	11.8	14.5	16.4	17.2	16.7	15.3	12.8	10.0	7.5	6.1	38	17.9	15.8	12.8	9.6	7.1	5.8	6.3	8.3	11.4	14.4	17.0	18.3
7.4	9.4	12.1	14.7	16.4	17.2	16.7	15.4	13.1	10.6	8.0	6.6	36	17.9	16.0	13.2	10.1	7.5	6.3	6.8	8.8	11.7	14.6	17.0	18.2
7.9	9.8	12.4	14.8	16.5	17.1	16.8	15.5	13.4	10.8	8.5	7.2	34	17.8	16.1	13.5	10.5	8.0	6.8	7.2	9.2	12.0	14.9	17.1	18.2
8.3	10.2	12.8	15.0	16.5	17.0	16.8	15.6	13.6	11.2	9.0	7.8	32	17.8	16.2	13.8	10.9	8.5	7.3	7.7	9.6	12.4	15.1	17.2	18.1
8.8	10.7	13.1	15.2	16.5	17.0	16.8*	15.7	13.9	11.6	9.5	8.3	30	17.8	16.4	14.0	11.3	8.9	7.8	8.1	10.1	12.7	15.3	17.3	18.1
9.3	11.1	13.4	15.3	16.5	16.8	16.7	15.7	14.1	12.0	9.9	8.8	28	17.7	16.4	14.3	11.6	9.3	8.2	8.6	10.4	13.0	15.4	17.2	17.9
9.8	11.5	13.7	15.3	16.4	16.7	16.6	15.7	14.3	12.3	10.3	9.3	26	17.6	16.4	14.4	12.0	9.7	8.7	9.1	10.9	13.2	15.5	17.2	17.8
10.2	11.9	13.9	15.4	16.4	16.6	16.5	15.8	14.5	12.6	10.7	9.7	24	17.5	16.5	14.6	12.3	10.2	9.1	9.5	11.2	13.4	15.6	17.1	17.7
10.7	12.3	14.2	15.5	16.3	16.4	16.4	15.8	14.6	13.0	11.1	10.2	22	17.4	16.5	14.8	12.6	10.6	9.6	10.0	11.6	13.7	15.7	17.0	17.5
11.2	12.7	14.4	15.6	16.3	16.4	16.3	15.9	14.8	13.3	11.6	10.7	20	17.3	16.5	15.0	13.0	11.0	10.0	10.4	12.0	13.9	15.8	17.0	17.4
11.6	13.0	14.6	15.6	16.1	16.1	16.1	15.8	14.9	13.6	12.0	11.1	18	17.1	16.5	15.1	13.2	11.4	10.4	10.8	12.3	14.1	15.8	16.8	17.1
12.0	13.3	14.7	15.6	16.0	15.9	15.9	15.7	15.0	13.9	12.4	11.6	16	16.9	16.4	15.2	13.5	11.7	10.8	11.2	12.6	14.3	15.8	16.7	16.8
12.4	13.6	14.9	15.7	15.8	15.7	15.7	15.7	15.1	14.1	12.8	12.0	14	16.7	16.4	15.3	13.7	12.1	11.2	11.6	12.9	14.5	15.8	16.5	16.6
12.8	13.9	15.1	15.7	15.7	15.5	15.5	15.6	15.2	14.4	13.3	12.5	12	16.6	16.3	15.4	14.0	12.5	11.6	12.0	13.2	14.7	15.8	16.4	16.5
13.2	14.2	15.3	15.7	15.5	15.3	15.3	15.5	15.3	14.7	13.6	12.9	10	16.4	16.3	15.5	14.2	12.8	12.0	12.4	13.5	14.8	15.9	16.2	16.2
13.6	14.5	15.3	15.6	15.3	15.0	15.1	15.4	15.3	14.8	13.9	13.3	8	16.1	16.1	15.5	14.4	13.1	12.4	12.7	13.7	14.9	15.8	16.0	16.0
13.9	14.8	15.4	15.4	15.1	14.7	14.9	15.2	15.3	15.0	14.2	13.7	6	15.8	16.0	15.6	14.7	13.4	12.8	13.1	14.0	15.0	15.7	15.8	15.7
14.3	15.0	15.5	15.5	14.9	14.4	14.6	15.1	15.3	15.1	14.5	14.1	4	15.5	15.8	15.6	14.9	13.8	13.2	13.4	14.3	15.1	15.6	15.5	15.4
14.7	15.3	15.6	15.3	14.6	14.2	14.3	14.9	15.3	15.3	14.8	14.4	2	15.3	15.7	15.7	15.1	14.1	13.5	13.7	14.5	15.2	15.5	15.3	15.1
15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8	0	15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8

APPENDIX-II

Mean Daily Duration of Maximum Possible Sunshine Hours (N) for Different Months and Latitudes

Northern Lats	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Southern Lats	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
50°	8.5	10.1	11.8	13.8	15.4	16.3	15.9	14.5	12.7	10.8	9.1	8.1
48	8.8	10.2	11.8	13.6	15.2	16.0	15.6	14.3	12.6	10.9	9.3	8.3
46	9.1	10.4	11.9	13.5	14.9	15.7	15.4	14.2	12.6	10.9	9.5	8.7
44	9.3	10.5	11.9	13.4	14.7	15.4	15.2	14.0	12.6	11.0	9.7	8.9
42	9.4	10.6	11.9	13.4	14.6	15.2	14.9	13.9	12.6	11.1	9.8	9.1
40	9.6	10.7	11.9	13.3	14.4	15.0	14.7	13.7	12.5	11.2	10.0	9.3
35	10.1	11.0	11.9	13.1	14.0	14.5	14.3	13.5	12.4	11.3	10.3	9.8
30	10.4	11.1	12.0	12.9	13.6	14.0	13.9	13.2	12.4	11.5	10.6	10.2
25	10.7	11.3	12.0	12.7	13.3	13.7	13.5	13.0	12.3	11.6	10.9	10.6
20	11.0	11.5	12.0	12.6	13.1	13.3	13.2	12.8	12.3	11.7	11.2	10.9
15	11.3	11.6	12.0	12.5	12.8	13.0	12.9	12.6	12.2	11.8	11.4	11.2
10	11.6	11.8	12.0	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5
5	11.8	11.9	12.0	12.2	12.3	12.4	12.3	12.3	12.1	12.0	11.9	11.8
0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0

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