

## Estimation of Evaporation Loss in Red hills Lake at Thiruvallur District, Tamil Nadu

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### ABSTRACT

Redhills lake, Chennai City's primary reservoir serves as the primary storage nearly about 40 years old. It receives water from Poondi and Cholavaram reservoir and is the last stop before water transmitted to Kalpak Water Works of Metro water. Generally water storage reservoirs are prone to losses through seepage and evaporation. Seepage generally occurs when the water escapes through the bottom of the reservoir and horizontal filtration through weirs and dykes. Owing to the heat energy of sun, water loss take place by evaporation from the surfaces of lakes, ponds, canals, rivers, reservoirs, etc. Water loss by evaporation is a very serious problem in semiarid and arid regions. Red Hills Lake is of no exception. In this thesis, the evaporation losses in Red hills lake is estimated by Bulk Aerodynamic method and Combined Penman Monteith Model using real time meteorological data for the past 10 years (2004 -2013) and compared between them. The relationship between water losses due to evaporation, water level in the lake, lake inflow and lake water storage were carried out. The evaporation values determined by Bulk Aerodynamic Method Which is the function of vapour pressure difference between the water surface and atmosphere, as well as horizontal wind speed varies between 0.20 mm and 39.98 mm with an average of 7.56mm. The evaporation values determined by Combined Penman Model which depends on solar radiation varies between 1.82 mm and 30.54 mm with an average of 9.56 mm..On comparison, Combined Penman Monteith Method showed the better evaporation values and it forms the favourable method as it depends on minimum factors of solar radiation and sunshine hours for finding evaporation loss in the study area.

**Keywords:** Seepage, Evaporation, Dykes, Filtration, weirs.

### INTRODUCTION

Evaporation is a process by which water from water bodies or land mass passes into vapour state and is diffused into the atmosphere. It is observed from oceans, lakes streams; land; vegetation; glaciers and ice and during rainfall. Water evaporation is one of the obscure components of hydrological cycle to measure accurately. There are two basic reasons namely, first, there is no instrumentation exists which can truly measure evaporation from a natural surface and the second, the indirect, none of the methods used for estimation of evaporation are universally accepted. Estimation of reliable or acceptable value of evaporation require either a

detailed instrumentation or a judicious application of climatic and physical data [1]. The factors affecting evaporation are (1) temperature (2) solar radiation (3) wind. (4) Barometric pressure and altitude, (5) dissolved solids, (6) turbidity, depth of water, (7) shape of surface, (8) extent, i.e, total area of water surface, (9) colour of water (10) velocity of water and (11) waves at water surface. The following methods are generally adopted to evaluate the rate of evaporation from a reservoir water budget method, Energy budget method, Mass transfer method, Actual observations, and evaporation formulae. Large amounts are spent in constructing a dam and creating a reservoir to store water. Canals are also constructed to carry water. Some water stored in these reservoirs and flowing in canals is lost due to evaporation. The amount of the loss of water due to evaporation can be substantial (about 30%). It is, therefore, necessary to estimate the loss due to evaporation to assess the water available for use in different seasons [2]. Bulk Aerodynamic method said to be widely used for estimating the water losses due to evaporation from large reservoirs and lakes by using Herbeck equation [3]. Combined Penman Monteith model, simply the combination equation of energy balance and aerodynamic method. It is represented as the function of solar radiation and sunshine hours. Redhills lake, Chennai city's primary reservoir serves as the primary storage to Chennai city water supply. It is one such lake where water is lost due to evaporation and this brings the necessity to carry out the estimation of evaporation loss by above mentioned two methods. In this thesis, the evaporation losses in Redhills lake is estimated by Bulk Aerodynamic method and Combined Penman Monteith Model using real time meteorological data for the past 10 years (2004 -2013) and compared between them.

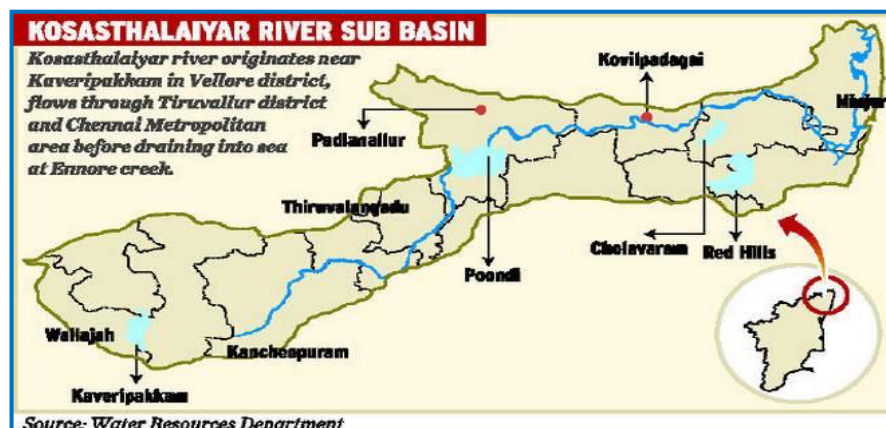
## 1.1 Objective

1. To estimate the evaporation loss in Red Hills lake by Bulk Aerodynamic Method and Combined Penman Monteith Model for the past 10 last years (2004-2013) using real meteorological data.
2. To find the relationship between water losses due to evaporation by Bulk Aerodynamic method and Combined Penman Montecito, water level in the lake, lake inflow and lake water storage.

## 2. Materials and Methods

### 2.1 Study Area

Puzhal aeri, or Puzhal lake, also known as the Red Hills Lake, is located in Red Hills, Chennai, India. It lies in Thiruvallur district of Tamil Nadu state.



*Fig .1 Study area map*

**Table 1. Red hills Lake**

<b>Puzhal Lake or Redhills Lake</b>	
<b>Location</b>	RedHills,Thiruvallur district, Tamil Nadu
<b>Coordinates</b>	13°10'00"N,80°10'17.5"E
<b>Type</b>	Reservoir
<b>Primary inflows</b>	9607 (cusecs) Highest
<b>Primary outflows</b>	5470 (cusecs) Highest
<b>Built</b>	1876
<b>Surface area</b>	4,500 acres (18 km <sup>2</sup> )
<b>Average depth</b>	50.20 feet (15.30 m)
<b>Water volume</b>	3,300 million cubic feet (93×10 <sup>6</sup> m <sup>3</sup> ;76,000 acre ft)

It is one of the two rain-fed reservoirs from where water is drawn for supply to Chennai City, the other one being the Chembarambakkam Lake and Porur Lake. The full capacity of the lake is 3,300 million ft<sup>3</sup> (93 million m<sup>3</sup>).

## 2.2. Materials

The study area “REDHILLS LAKE” selected and followed by field visit to the lake. The complete details about the study area gathered and problems faced by the lake currently are also completely sketched and accounted quantitatively and qualitatively. Since the lake located in the semi- arid region, subjected to great loss of water due to evaporation and seepage process. It is necessary to estimate the evaporation loss taking place in the lake. For estimation, the required data are collected. Then followed by the estimation stage by namely two methods, firstly BULK AERODYNAMIC METHOD and then COMBINED PENMAN MONTEITH MODEL, which perform well in better determination of evaporation rate as suggested in the journals during reviewing the literature study on evaporation loss estimation. The estimated values of evaporation rate are related to lake water level, water storage, rainfall, and inflow arriving the lake and the relationship between the above parameters are plotted. The discussions carried out on the plotted values. And finally the conclusion is made based on the findings and recommendations; suggestions are listed out for the minimization of loss taking place in the lake and maintain the lake water storage efficiently for various beneficial purposes. Thus how the methodology of the study of estimation of evaporation loss in the Red Hills lake, Thiruvallur District, Tamil Nadu.

### Data collected

- Meteorological data
- Red Hills lake live water level detailed data.
- For 10 years from 2004 - 2013.

### Source

- CMWSSB - Chennai Metropolitan Water Supply and Sewerage Board.
- SWAT -Soil and Water Assessment Tool, Global weather data tool.

## Methods of estimation

- Bulk Aerodynamic Method

Combined Penman Monteith model

### 3 Method of Estimation

#### 3.1 Bulk Aerodynamic Method

Bulk Aerodynamic used for finding water losses due to evaporation from large reservoirs and lakes. Herbeck Equation is as follows:

##### Step 1 - saturation vapour pressure (es )

$$es = 0.611 \exp[(17.27 \text{ wst })/( \text{ wst } + 237.3)]$$

Where es - saturated water vapor pressure at water surface (kpa), wst - water temperature (°C)

##### Step 2 - saturated vapour pressure of air (ESA)

$$ESA = 0.611 \exp [(17.27 AT)/(AT+23.3)]$$

Where ESA - Saturated vapor pressure of air (kpa), AT - air temperature (°C) at 2 m above water surface

##### Step 3 - Actual vapour pressure

$$ea = (\text{Relative Humidity } /100) * ESA$$

Where ea - actual vapour pressure of the air (kpa)

##### Step 4 - Estimation of evaporation from reservoir

By Her beck equation, the evaporation from Red Hills Lake found to be

$$E = NU2 (es - ea)$$

Where E - evaporation (mm/hour), U2 - wind speed (m/sec), ea - actual vapour pressure of the air (kpa) ,es -saturated water vapor pressure at water surface(kpa).

#### 3.2 Combined Penman Monteith Method

Combined Penman Monteith model simply the combination equation of energy balance and aerodynamic method. It depends on primarily on two factors namely solar radiation and sunshine hours.

##### Step 1 - Mean daily Temperature

The daily maximum and minimum air temperatures in degrees Celsius (°C) are needed.

Average temperature is given by:

$$T_{mean} = (T_{max} + T_{min})/2$$

Where Tmean - Mean daily temperature(°c) ,Tmax - Maximum daily air Temperature (°c),Tmin - Minimum daily air Temperature (° c)

##### Step 2 - Mean daily solar radiation (Rs)

The average daily net radiation (MJ m<sup>-2</sup> day<sup>-1</sup>) is needed. It is obtained from SWAT Weather data.

$$Rs \text{ (MJ m}^{-2}\text{day}^{-1}) = Rs \text{ (W m}^{-2}\text{day}^{-1}) * 0.0864$$

##### Step 3 - Wind speed (U2)

The wind speed is denoted by the following expression

$$U2 = Uh [4.87/\ln(67.8h-5.42)]$$

Where  $U_2$  - wind speed 2 m above the ground surface,  $ms^{-1}$ ,  $U_h$  - measured wind speed  $Z_m$  above ground surface,  $ms^{-1}$ ,  $h$  - Measurement height above ground surface, m. In case of wind speed is given in miles per hour (mi h<sup>-1</sup>) the conversion to  $ms^{-1}$  is required.

$$U_2 (ms^{-1}) = U_2(mi\ h^{-1}) \times 0.447$$

#### Step 4 - Saturation vapour pressure curve slope

The relationship between the saturation vapour pressure and temperature is given by

$$\Delta = 4098 \{0.6108 \exp [(17.27 \times T_{mean}) / (T_{mean} + 237.3)] / [(T_{mean} + 237.3)^2]\}$$

Where  $T_{mean}$  - mean daily air temperature, °C,  $\exp$  - 2.7183 (base of natural algorithm)

#### Step 5 - Atmospheric pressure (p)

The atmospheric pressure,  $P$  also affects evaporation. It is given by

$$P = 101.3 \{ [(293 - 0.0065 Z) / (293)] \}^{5.26}$$

Where  $P$  - Atmospheric pressure,  $Z$  - elevation (m)

#### Step 6 - psychrometric constant ( $\gamma$ )

It tells the relationship between the partial pressure of water in air and the air temperature. Under average atmospheric conditions,  $c_p = 1.013 \times 10^{-3} \text{ MJ kg}^{-1} \text{ }^\circ\text{C}^{-1}$  will be used. This term is kept constant for each location depending of the altitude as an average atmospheric pressure is used for each location,

$$\gamma = (C_p P / \epsilon \lambda) = 0.000665 P$$

Where  $\gamma$  - psychrometric constant,  $kpa \text{ }^\circ\text{C}^{-1}$ ,  $P$  - Atmospheric pressure,  $kpa$ ,  $C_p$  - specific heat at constant pressure,  $1.103 \times 10^{-3} \text{ MJ Kg}^{-1}$

#### Step 7 - Delta term (DT) (auxiliary calculation for radiation term)

In order to simplify the ETO Calculation, several terms are calculated separated. The delta term is used to calculate the “radiation term” of the overall ETO equation

$$DT = (\Delta) / (\Delta + \gamma(1 + 0.34 U_2))$$

Where  $\Delta$  - Slope of saturation vapour pressure curve,  $\gamma$  - psychrometric constant,  $U_2$  - wind speed

#### Step 8 - Psi term (PT) (auxiliary calculation for wind term)

The psi term is used to calculate the wind term of the overall ETO,

$$PT = (\gamma) / [(\Delta) + (\gamma(1 + 0.34 U_2))]$$

Where  $PT$  - Psi term,  $\gamma$  - psychrometric constant,  $U_2$  - wind speed,  $\Delta$  - Slope of saturation vapour pressure curve

#### Step 9 - Temperature term (TT) (auxiliary calculation for wind term)

The temperature term is used to calculate the “wind term” of the overall ETO equation.

$$TT = [(900) / (T_{mean} + 273)] \times U_2$$

Where  $T_{mean}$  - mean daily air temperature, °C

#### Step 10- Mean saturation vapor pressure derived from air temperature (es)

It is given by the following expression,

$$e(T) = 0.6108 \exp [(17.27 T) / (T + 237.3)]$$

Where  $e(T)$  - Saturation vapour pressure at the air temperature  $T$ ,  $T$  - air temperature, °C

#### Step 11- Actual vapor pressure (es) from relative humidity

The actual vapor pressure can also be calculated from the relative humidity. Depending on the availability of the humidity data, it is as follows:

$$ea = \{e(T_{min}) [RH_{max} / 100] + e(T_{max}) [RH_{min} / 100]\} / 2$$

Where  $e_a$  - actual vapour pressure, kpa,  $e(T_{min})$  - saturation vapour pressure at daily minimum temperature, kpa,  $e(T_{max})$  - saturation vapour pressure at daily maximum temperature, kpa

### **Step 12 - The inverse relative distance Earth - sun and solar radiation ( $\delta$ )**

It is given by :

$$dr = 1 + 0.033 \cos (2\pi j / 365)$$

$$\delta = 0.409 \sin [(2\pi j / 365) - (1.39)]$$

### **Step 13 - Conversion of latitude in degrees to radians**

The conversion is given by:

$$\phi [Radians] = (\pi / 180) \phi (decimal\ degrees)$$

### **Step 14 - sunset hour angle**

The sunset hour angle ( $\omega_s$ ) is given by:

$$\omega_s = \arccos [-\tan(\phi) \tan(\delta)]$$

### **Step 15 - Clear sky solar radiation**

$$R_{so} = (0.75 + 2E10^{-5}z)R_a$$

Where,  $z$  = elevation above sea level, m;  $R_a$  = extraterrestrial radiation, MJ m<sup>-2</sup> day<sup>-1</sup>,  $R_{so}$  = clear sky solar radiation, MJ m<sup>-2</sup> day<sup>-1</sup>.

### **Step 16 - Net solar or net shortwave radiation**

The net shortwave radiation is given by:

$$R_{ns} = (1 - a)R_s$$

Where  $R_{ns}$  = net solar or shortwave radiation, MJ m<sup>-2</sup> day<sup>-1</sup>;

### **Step 17 - Net outgoing long wave solar radiation**

The Net outgoing long wave solar radiation is quantitatively by the Stefan-Boltzmann law.

$$R_{nl} = \{ [T_{max} + 273.16]^4 + (T_{min} + 273.16)^4 / 2 \} \times (0.34 - 0.14(e_a / e_s))^{1/2} \times [1.35 (R_s / R_{so}) - 0.35]$$

Where  $R_{nl}$  = net outgoing long wave radiation, MJ m<sup>-2</sup> day<sup>-1</sup>,  $T_{max}$  = K maximum absolute temperature during the 24-hour period [ $K = ^\circ C + 273.16$ ],

$T_{min}$  = K minimum absolute temperature during the 24-hour period [ $K = ^\circ C + 273.16$ ],  $e_a$  = actual vapor pressure, kPa,  $R_s$  = the incoming solar radiation, MJ m<sup>-2</sup> day<sup>-1</sup>,  $R_{so}$  = clear sky solar radiation, MJ m<sup>-2</sup> day<sup>-1</sup>.

### **Step 18 - Net radiation**

It is the difference between the incoming net shortwave radiation ( $R_{ns}$ ) and the outgoing net long wave radiation ( $R_{nl}$ ):

$$R_n = R_{ns} - R_{nl}$$

$$R_{ng} = 0.408 \times R_n$$

Where,  $R_{ns}$  = net solar or shortwave radiation, MJ m<sup>-2</sup> day<sup>-1</sup>,  $R_{nl}$  = net outgoing long wave radiation, MJ m<sup>-2</sup> day<sup>-1</sup>,

To express the net radiation ( $R_n$ ) in equivalent of evaporation (mm) ( $R_{ng}$ )

### **Step 19 - over all equation**

$$E_{Trad} = DT R_{ng}$$

Where  $E_{Trad}$  radiation term,  $DT$  - delta term,  $R_{ng}$  - net radiation, mm



## **Step 20- Final evapotranspiration value**

$$ET_{wind} = PT \times TT (e_s - e_a)$$

Where TT = Temperature term,  $e_a$  = actual vapor pressure, kPa,  $e_s$  = mean saturation vapor pressure derived from air temperature, kPa.

Final Reference Evapotranspiration Value ( $ET_o$ )

$ET_o = ET_{wind} + ET_{rad}$  Where  $ET_o$  - final reference evapotranspiration,  $mm\ d^{-1}$ ,  $ET_{wind}$  - wind term,  $mm\ d^{-1}$   $ET_{rad}$  - radiation term,  $mm\ d^{-1}$

## **4. Result and Discussions**

### **4.1 Bulk aerodynamic method of estimation**

#### **A) Monthly variation of evaporation loss from 2004-2013**

The monthly variation of evaporation loss by bulk aerodynamic estimation method from 2004-2013 was plotted. It showed the variations from minimum of 1.95 mm of evaporation in the month of Nov 2006 to maximum of 22.82 mm in the month of July 2006. The average evaporation on monthly basis is found to be 6.97 mm. The year 2013 showed constant 4.61 mm of evaporation loss of water. Similarly the year 2012 and 2011 showed constant evaporation loss of water of 4.58mm and 4.65 mm respectively.

#### **B) Relationship between Bulk Aerodynamic Evaporation loss and Water level of Lake**

The monthly variation of evaporation loss by bulk aerodynamic estimation method relative to Lake water level from 2004-2013 was plotted. It showed the variations from minimum of 1.95 mm of evaporation in the month of Nov 2006 with water level of 13.83 m to maximum of 22.82 mm in the month of July 2006 with water level of 13.12 m. The average evaporation on monthly basis is found to be 6.97 mm. The year 2013 showed constant 4.61 mm of evaporation loss of water with constant water level of 13.71 m.

#### **C) Relationship between Bulk Aerodynamic Evaporation loss and inflow of Lake**

The monthly variation of evaporation loss by bulk aerodynamic estimation method relative to Lake inflow water from 2004-2013 was plotted. It showed the variations from minimum of 1.95 mm of evaporation in the month of Nov 2006 with inflow of 556026m<sup>3</sup> to maximum of 22.82 mm in the month of July 2006 with inflow of 227531 m<sup>3</sup>. The average evaporation on monthly basis is found to be 6.97 mm. The year 2013 showed constant 4.61 mm of evaporation loss of water with constant inflow of 1411742m<sup>3</sup>.

#### **D) Relationship between Bulk Aerodynamic Evaporation loss and Lake water storage**

The monthly variation of evaporation loss by bulk aerodynamic estimation method relative to Lake water storage from 2004-2013 was plotted. It showed the variations from minimum of 1.95 mm of evaporation in the month of Nov 2006 with water storage of 64 \*10<sup>6</sup>m<sup>3</sup> to maximum of 22.82 mm in the month of July 2006 with water storage of 53\*10<sup>6</sup> m<sup>3</sup>. The average evaporation on monthly basis is found to be 6.97 mm. The year 2013 showed constant 4.61 mm of evaporation loss of water with constant water storage of 63 \*10<sup>6</sup>m<sup>3</sup>.

### **4.2 Combined penman monteith method of estimation**

#### **A) Monthly variation of evaporation loss from 2004-2013**

The monthly variation of evaporation loss by Combined Penman Montecito estimation method from 2004-2013 was plotted. It showed the variations from minimum of 3.33 mm of evaporation in the month of Nov 2011 to maximum of 21.14 mm in the month of May 2008. The average evaporation on monthly basis is found to be 9.62 mm.

## B) Relationship between Combined Penman Monteith Evaporation loss and Water level of Lake

The monthly variation of evaporation loss by Combined Penman Monteith estimation method from 2004-2013 relative to water level of the lake was plotted. It showed the variations from minimum of 3.33 mm of evaporation in the month of Nov 2011 relative to water level of 4.58 m to maximum of 21.14 mm in the month of May 2008 relative to 22.59 m. The average evaporation on monthly basis is found to be 9.62 mm.

## C) Relationship between Combined Penman Monteith Evaporation loss and inflow to the lake

The monthly variation of evaporation loss by Combined Penman Monteith estimation method from 2004-2013 relative to water inflow to the lake was plotted. It showed the variations from minimum of 3.33 mm of evaporation in the month of Nov 2011 relative to  $1.4 \times 10^6 \text{ m}^3$  to maximum of 21.14 mm in the month of May 2008 relative to  $0.79 \times 10^6 \text{ m}^3$ . The average evaporation on monthly basis is found to be 9.62 mm.

## E) Relationship between Combined Penman Monteith Evaporation loss and lake water storage

The monthly variation of evaporation loss by Combined Penman Monteith estimation method from 2004-2013 relative to lake water storage was plotted. It showed the variations from minimum of 3.33 mm of evaporation in the month of Nov 2011 relative to  $63 \times 10^6 \text{ m}^3$  to maximum of 21.14 mm in the month of May 2008 relative to  $75 \times 10^6 \text{ m}^3$ . The average evaporation on monthly basis is found to be 9.62 mm.

## 4.3 Comparison between bulk aerodynamic method and combined penman monteith method

The monthly variation of evaporation loss by bulk aerodynamic estimation method from 2004-2013 was plotted. It showed the variations from minimum of 1.95 mm of evaporation in the month of Nov 2006 to maximum of 22.82 mm in the month of July 2006. The average evaporation on monthly basis is found to be 6.97 mm. The year 2013 showed constant 4.61 mm of evaporation loss of water. Similarly the year 2012 and 2011 showed

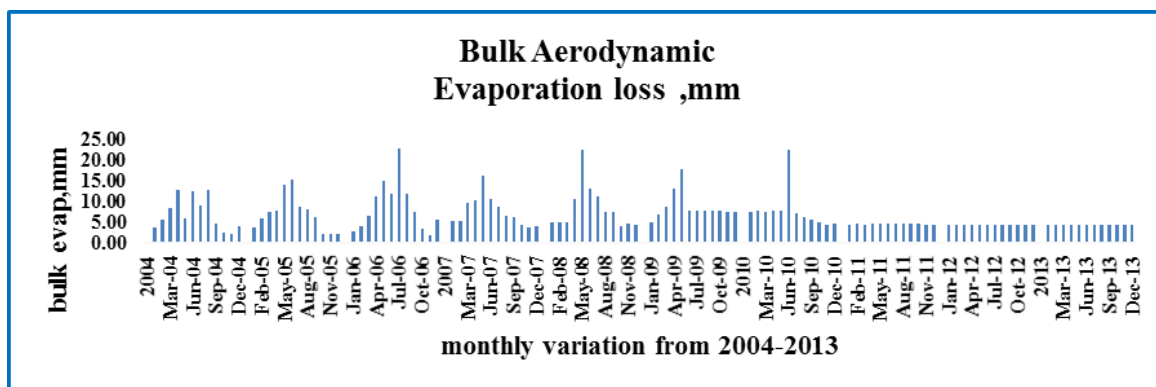


Fig.2 Monthly variation of evaporation loss from 2004-2013 by Bulk Aerodynamic Method



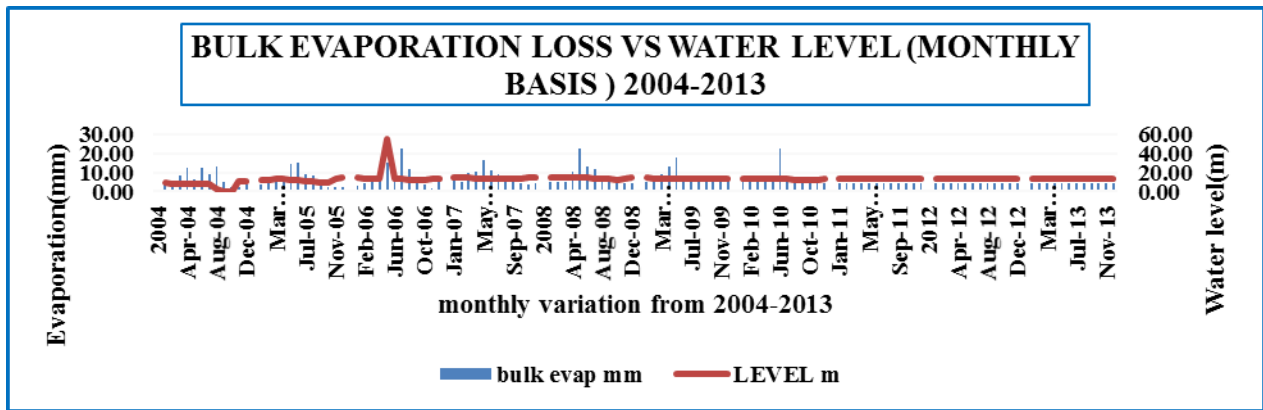


Fig.3 Monthly variation between Bulk Evaporation loss and Water level

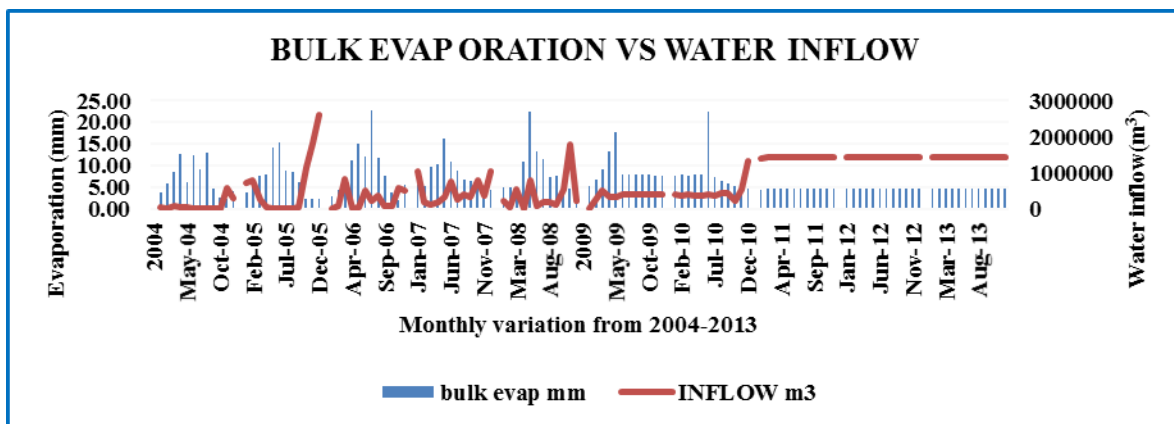


Fig.6 Monthly variation of Combined Penman Monteith Method

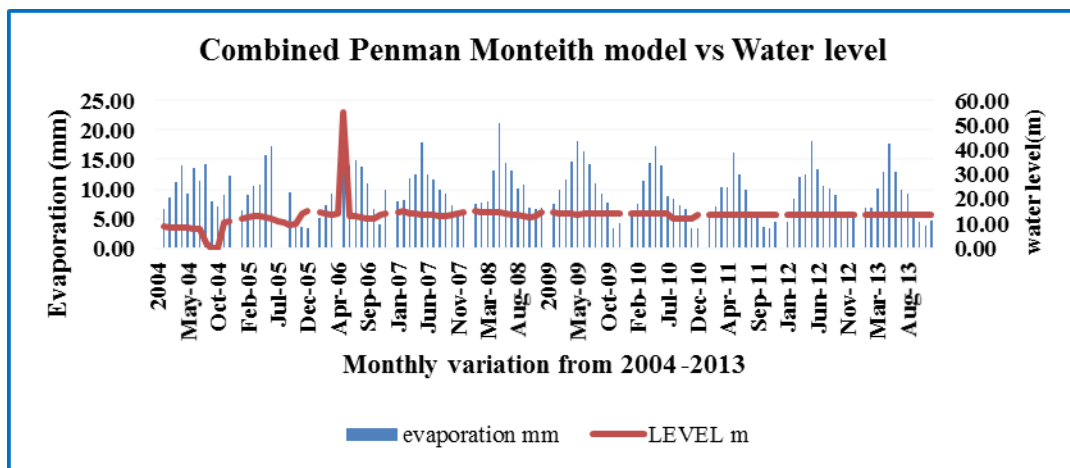


Fig.7 Monthly variation of Combined Penman Monteith Method relation with water level

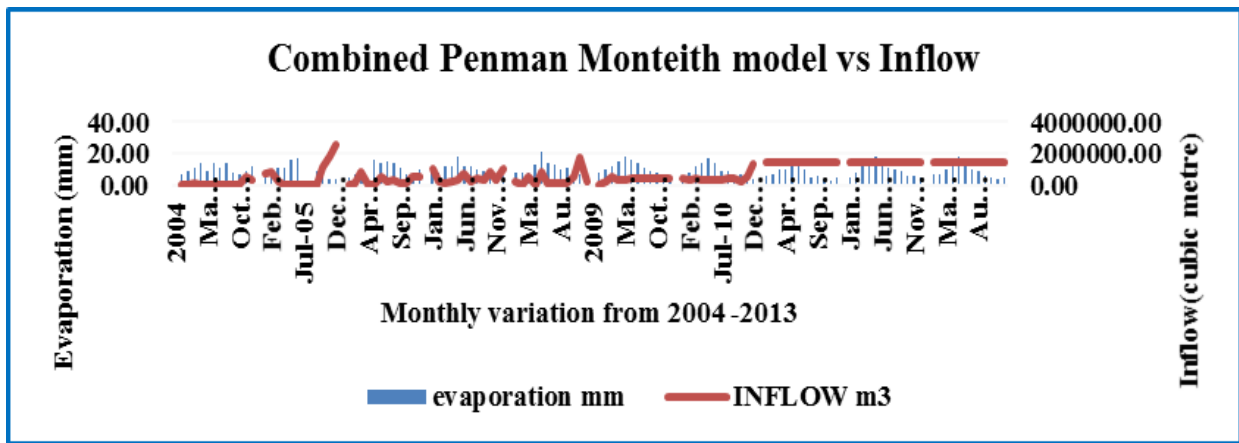


Fig.8 Monthly variation of Combined Penman Monteith Method in relation with water inflow

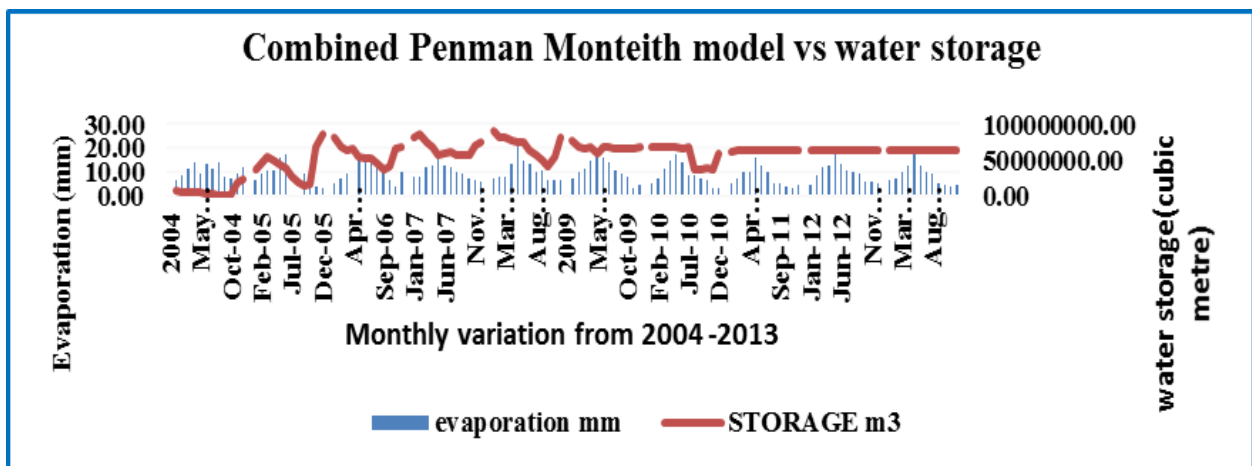


Fig.9 Monthly variation of Combined Penman Monteith Method in relation with lake water storage

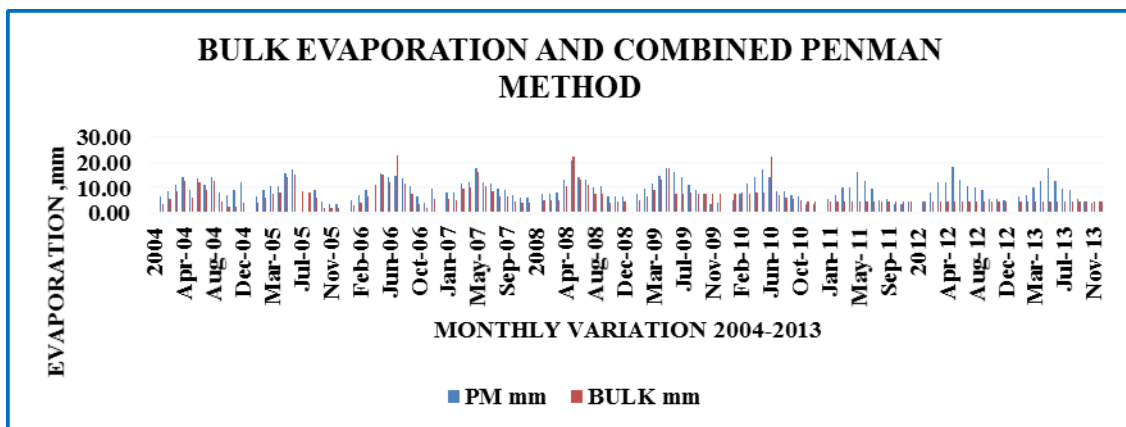


Fig.10 Combined Penman Monteith Method and Bulk Aerodynamic method

## **5. CONCLUSIONS**

The estimation of evaporation loss in Redhills lake, Thiruvallur District done by applying two methods namely Bulk Aerodynamic method and Combined Penman Montecito model, used to estimate evaporation losses for the last 10 years(2004-2013) by collecting meteorological data and Red hills lake details data. The relationship between water losses due to evaporation, water level in the lake, lake inflow and lake water storage were carried out. The evaporation value determined by Bulk Aerodynamic Method which is the function of vapour pressure difference between the water surface and atmosphere, as well as horizontal wind speed varies between 0.20 mm and 39.98 mm with an average of 7.56mm. The evaporation values determined by Combined Penman Model which depends on solar radiation varies between 1.82 mm and 30.54 mm with an average of 9.56 mm. On comparison, Combined Penman Montecito Method showed the better evaporation values and it forms the favorable method as it depends on minimum factors of solar radiation and sunshine hours for finding evaporation loss in the study area.

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### **Conflict of Interest**

None of the authors have any conflicts of interest to declare.

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