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Exploring Estimation of Evaporation in Dry Climates Using a Class 'A' Evaporation Pan

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Abstract

The rate of evaporation in dry climates is a concern and needs to be assessed and quantified for planning in water management activities. The main objective of the study was to investigate evaporation rate of a bare ground in Masvingo district in Zimbabwe using a class 'A' evaporation pan. Specific objectives include calibrating the pan using the FAO-Penman Monteith (P-M) method and obtaining typical evaporation rates for the area which could be extended to represent areas of relatively similar climates. To achieve these objectives an evaporation pan was installed on a wooden grid platform near a weather station that recorded wind speed, air temperature, humidity, maximum and minimum temperatures. Considering fetch dimensions the pan results were correlated against P-M method results to give pan calibration coefficient and the slope of the curve gave a Kpan of 0.91 and changes in water depths with respect to pan dimensions gave average evaporation rates of 5.1 mm/day at mean maximum temperature of 24.9°C. The evaporation rates obtained were not sustainable in the long term if water harnessing and conservation strategies are not employed.

Keywords: Evaporation; Water; Pan; Dry climate; Penman-monteith; Zimbabwe

Introduction

Water is a finite and important resource for agricultural production. In Sub-Saharan region there has been water scarcity due to climate change and an increasing demand by different competing various socio – economic users making water conservation practices important [1]. One critical way in which water is lost is through evaporation into the atmosphere due to high ambient temperatures associated with Global Warming. Evaporation is a parameter that is not easily estimated accurately yet it is of vital importance in the crop farming, water conservation, and in water inventory issues for surface and ground water sources. In this study the proposed evaporimeter, which is a Class 'A' pan will need calibration to give accurate readings, hence the need for the calibration exercise and ensuing evaporation measurements. These measurements will open future research doors in water related research at the Great Zimbabwe University and can be extrapolated to surrounding areas. A relationship established by Allen et al. relates that pan evaporation to evapotranspiration made is employed to achieve the calibration of the evaporimeter and ensuing evaporation measurements [2]. Evapotranspiration (ETo) estimated by the FAO-Penman-Monteith method is compared against the pan evaporation (Epan) method at Great Zimbabwe University in order to validate the use of the pan locally.

Energy enables water to change from liquid to gas (vapour). Direct solar radiation and to a reduced extent, the ambient temperature provide this energy. The driving force to remove water vapour from an evaporating surface is the difference between the vapour pressure at the evaporating surface and that of surrounding atmosphere. Increased saturation of air surrounding the evaporating surface slow down evaporation and may stop it if wet air is not transferred to the atmosphere. Therefore, solar radiation, air temperature, humidity, rainfall and wind speed are climatological parameters to consider when assessing the evaporation process. The rate of evaporation depends on these climatological parameters as well as soil water availability [3,4].

Many methods have been developed to derive reference evapotranspiration (ETo) and water evaporation (E) estimates [5]. Among these methods are FAO-Penman, FAO-corrected Penman, Blaney-Criddle, Hargreaves and FAO-Ration [2,6-10]. Many of these methods are subject to local calibration; thereby require local characterisation of topography, altitude and type of soils of the area under study to improve accuracy [11]. However, the high performance of the Penman Monteith method in estimating evapotranspiration in different parts of the world when compared with other methods has made it accepted as the sole method for computing evapotranspiration from meteorological data (temperature, relative humidity, solar radiation and wind speed) [12]. Roderick et al. observed that the universal application of the Penman Monteith approach enables it to be used as a standard to verify or calibrate other methods [13]. The pan evaporation method is also widely used because it is simple to use for estimating evapotranspiration. Before an evaporation pan can be used, it must be locally calibrated because its performance is site specific or depends on geographical location.

Water demand is controlled by the atmosphere depending on the vapour pressure deficit conditions and water supply is governed by the existing soil moisture and water bodies available. Some water is drained out of the soil due to gravitational forces exerted on the water in the soil. The water that remains in the soil via molecules and matric forces is known as the field capacity. Matric forces are generated by the soil particles adhesive and absorptive molecules attraction to water and cohesive attraction exerted by water molecules on other water molecules [14]. Capillary action enables water to move through the soil and plant, in the presence of potential difference .Water moves in the direction of decreasing energy that from areas of low to high matric potential. In the soil and plant system, this implies water moves from wet soil to dry and from soil to stomata [14]. This process continues until the soil reaches its maximum moisture deficit. Up to this point

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soil water extraction by the plant is not operating under stressed condition, thus water supply is virtually unlimited. Once the soil water content falls below the maximum soil moisture deficit, it becomes increasingly more difficult for the plant to extract water from the soil [15]. Therefore, it is vital that irrigation scheduling is efficiently done to meet plant water requirements.

Objectives of the study

The main objective of the study was to investigate evaporation rate of a bare ground in Masvingo district in Zimbabwe using a class 'A' evaporation pan. Specific objectives include calibrating the pan using the FAO-Penman Monteith (P-M) method and obtaining typical evaporation rates for the area which could be extended to represent areas of relatively similar climates.

Pan evaporation

An evaporation pan is used to hold water during observations for the determination of the quantity of evaporation at a given location. Such pans are of varying sizes and shapes, the most commonly used being circular or square [16,17]. The best known of the pans are the "Class 'A'" evaporation pan and the "Sunken Colorado Pan [18]. In Europe, India and South Africa, a Symon's Pan (or sometimes Symon's Tank) is used. Often the evaporation pans are automated with water level sensors and a small weather station is located nearby.

Penman-Monteith equation

The equation is stated as:

$$ETo=\frac{0.408\Delta(Rn-G)+\frac{Y900}{T}+273U_2(e_s-e_a)}{\Delta+Y(1+0.34U_2)} \quad \text{.......................(1)}$$

Where:

ETo=Reference evapotranspiration (mm/day)

Rn=Net radiation at crop surface (MJ/m^2 per day)

G=Soil heat flux density (MJ/m^2 per day)

T=Mean daily air temperature at 2 m height (°C)

$U_{2=}$Wind speed at 2m height (m/sec)

e_s=Saturated vapour pressure (kPa)

(e_s- e_a)=Saturation vapour pressure deficit (kPa)

Δ=Slope of saturation vapour pressure curve at temperature T (kPa/°C)

Y=Psychrometric constant (kPa/°C)

Penman Monteith uses standard climatological records of solar radiation (sunshine), air temperature, humidity and wind speed for daily, weekly, ten-day or monthly calculations [10]. The selection of the time step with which ETo is calculated depends on the purpose of the calculation required and the climate data available. Some data are measured directly in weather stations Parameters related to commonly measured data are derived using direct or indirect empirical equations. Integrity of computation is assured by making weather measurements at 2 m (or converted to that height) above an extensive surface of green grass shading the ground that is not short of water. Common units should be converted to standard units.

Parameters used in the Penman-Monteith equation are calculated using equations (2) to (8) given below.

$$Y=\frac{C_pP}{\varepsilon\lambda}=0.665\times10^{-3}P \quad \text{..................(2)}$$

Where:

C_p=Specific heat at constant pressure=1.013 × 10^{-3} MJ/kg/°C

P=Atmospheric pressure (kPa)

ε=Ratio molecular weight of water vapour/dry air=0.622

λ=Latent heat vaporization=2.45 MJ/kg (at 20°C)

$$T_{mean}=\frac{T_{\max}+T_{\min}}{2} \quad \text{.................(3)}$$

Where:

$T_{mean=}$mean daily temperature (°C)

$T_{max=}$mean daily maximum temperature (°C)

$T_{min=}$mean daily minimum temperature (°C)

$$e_s=\frac{e^0(T_{\max})+e^0(T_{\min})}{2} \quad \text{.......................(4)}$$

Where:

$e_{s=}$mean saturation vapour pressure (kPa)

e^0 (T_{max})=saturation vapour pressure at maximum air temperature (kPa)

e^0 (T_{min})=saturation vapour pressure at minimum air temperature (kPa)

$$e^0(T)=0.6108\exp\frac{(17.27T)}{(T+237.3)} \quad \text{.....................(5)}$$

Where:

T=Mean air temperature (°C)

exp[...]=2.7183 (base of natural logarithm) raised to the power [...]

$$\Delta=\frac{4.098\left[0.6108\exp\left\{\frac{17.27T}{T+237.3}\right\}\right]}{(T+237.3)^2} \quad \text{.................... (6)}$$

Where: $0.6108\exp\frac{17.27T}{T+237.3}=e^0$

Where:

T=mean daily temperature (Equation 5)

$$e_a=\frac{\left[e^0(T_{\min})\times\frac{RH_{\max}}{100}\right]+\left[e^0(T_{\max})\times\frac{RH_{\min}}{100}\right]}{2} \quad \text{.............. (7)}$$

Where:

$e_{a=}$Actual vapour pressure (kPa)

e^0 (T_{min})=Saturation vapour pressure at daily minimum temperature (kPa)

e^0 (T_{max})=Saturation vapour pressure at daily maximum temperature (kPa)

Net radiation estimation

The calculation of clear sky radiation (R_{so}), when n=N, is required to compute net longwave radiation. R_{so} is given by the following simplified expression:

$$R_{so} = \left[0.75 + \frac{2z}{100000}\right] \times R_a \quad \text{..................(8)}$$

Where:

R_{so}=clear sky solar radiation (MJ/m^2 per day)

Z=station elevation above sea level (m)

Net longwave radiation (Rnl): The rate of longwave radiation emission is proportional to the absolute temperature (Kelvin) of the surface raised to the fourth power. Rnl is calculated using the following expression:

$$R_{nl} = \left(\frac{\sigma(T_{\max,K})^4 + \sigma(T_{\min,K})^4}{2}\right) \times (0.34 - 0.14\sqrt{e_a}) \times \left(1.35\frac{R_s}{R_{so}} - 0.35\right) \quad \text{...........................(9)}$$

Where:

Rnl=net outgoing longwave radiation (MJ/m^2 per day)

σ is the Stefan Boltzmann constant (4.903 x 10^{-9} MJ/K^4 per m^2 per day)

$T_{max,k}$ =Maximum absolute temperature during the 24 hr period(K)

$T_{min,k}$=Minimum absolute temperature during the 24 hr period (K)

$e_{a=}$actual vapour pressure (kpa)

R_s/R_{so}= Relative shortwave radiation (limited ≤ 1)

$R_{s=}$Measured or calculated solar radiation (MJ/m^2 per day)

R_{so}=calculated clear sky radiation (MJ/m^2 per day)

Calibration equation

$$ETo = kp \times Epan \quad \text{..(10)}$$

Where:

ETo is the evapotranspiration estimated by the FAO-Penman Monteith equation

kp is the pan coeffient

Epan is the pan evaporation

Pan siting

The accuracy of evaporation pans depend on the pan coefficient. Savva et al. defines pan coefficient as the ratio of the water body to pan evaporation [10]. Pan coefficients are pan specific and they depend on the colour, size, and position/site of the pan. Therefore when using a pan, consideration should be given to the pan type, the ground cover in the station where the pan is sited, its surrounding and the general wind and humidity conditions. This is particularly true if the pan is placed in fallow rather than cropped fields. Allen et al. identify two cases A and B of evaporation pan citing and their environments [2]. Case A is where the pan is sited on a fallow soil, and case B is where the pan is sited on fallow soil and surrounded by green crop as illustrated below in Figure 1.

Despite the apparent simplicity in use, evaporation pans need careful maintenance to provide accurate measurements. The water level must be kept to the prescribed level. Regular cleaning and periodic repainting are necessary, painting affects heat loss or absorption by the pan. The siting of the pan can have a major impact on the measurements. For instance, a pan sited on bare soil may record higher evaporation rates than one sited on the grass because the air moving over the pan tend to be drier. Heat storage in the pan can be appreciable and may cause significant evaporation during the night while plants transpire during the daytime. Differences also exist in the turbulence, temperature and humidity of air immediately above the respective surfaces. However, the evaporation pan has proved its practical value hence widely used to estimate ETo. Therefore, application of empirical coefficients to relate pan evaporation to ETo for periods of 10days or longer may be warranted [2].

Global warming and evaporation rates

Over the last 50 or so years, pan evaporation has been carefully monitored. For decades, nobody took much notice of the pan evaporation measurements. But in the 1990s scientists spotted something that at the time was considered very strange; the rate of evaporation was falling. This trend has been observed all over the world except in a few places where it has increased. As the global climate warms, all other things being equal, evaporation will increase and as a result, the hydrological cycle will accelerate. The downward trend of pan evaporation has been linked to a phenomenon called global dimming. In 2002 Roderick and Graham found that the "dimming" trend had reversed since about 1990 [19].

Location of the study site

The experiment was carried out at the Great Zimbabwe University (GZU) in Masvingo town in Zimbabwe. The location of the GZU is approximately on latitude 20, 10^0 S and longitude 30, 86^0 E (Figure 2). Like other places in Zimbabwe, the GZU experiences four seasons. The hot season starts in August up November. Temperatures rise up to 35°C. The rainy season begins in mid November up to March, with maximum temperatures up to 29°C. The post–rainy season from March to mid May is the transitional period to the cool season. The cool season called winter is from mid May to August. This study was at the end of April 2013 when temperatures had started failing.

Materials and Methodology

Instruments used

- Automatic weather station (AWS) called the RainWise MKIII Weather Transmitter and data logger

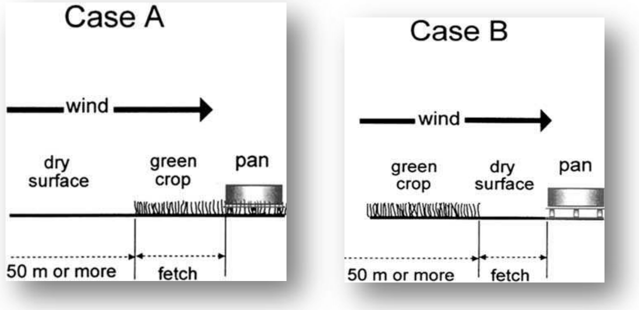

Figure 1: Siting of an evaporation pan [12].

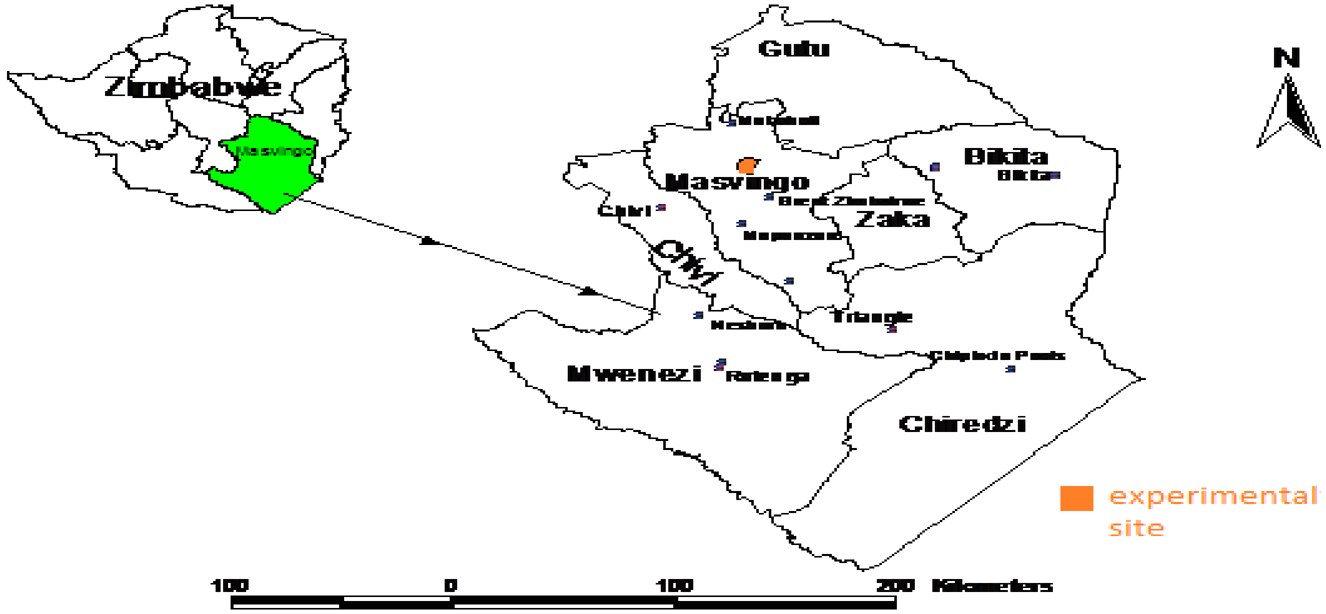

Figure 2: Map of Masvingo Province [19].

- Class ‘A’ pan
- Stevenson Screen (SS)
- Global Positioning System (GPS) 60 receiver
- Computer

Experimental setup

The experiment site comprised an automatic weather station, Class ‘A’ evaporation pan and a Stevenson screen with a hygrometer as illustrated in Figure 3. The experiment site was fenced to avoid unnecessary interference by animals and people.

Installation of instruments

All the instruments were levelled using the spirit level. Levelling is a pre-requirement for recording accurate readings. The automated weather station, pan and the Stevenson screen were all placed at least 1.5 m away from each other to avoid obstruction of measurements. The fetch of the study site was also of interest so the closest building was 15m away as this enabled correct measurements to be made.

RainWise MKIII Weather Transmitter: The MKIII automatic weather station was mounted at a height a standard height of 2 m as shown in Figure 3. The necked down end was placed into the MKIII assembly, until it bottomed the retaining screw in the slot and the screw was tightened. The solar panel was faced true north. The angle for optimum performance 60^0 on latitude $20^0\ 6'$ was obtained from the MKIII user’s manual.

RainWise MKIII Weather Transmitter mounted at experiment site: The RainWise MKIII Weather Transmitter shown in Figure 3 is designed to measure wind speed, wind direction, air temperature, humidity and rainfall. It is powered by a solar panel connected to rechargeable batteries. The station transmitted all the data via a wireless transmitter to a data logger. The received data was then downloaded to a computer, and analysed using MS Excel software.

Data logger: The RainWise CC-3000 MK-III Computer Interface is a device that will record and store weather data received from MK-III sensor. The CC-3000 MK-III Computer Interface has a 2 MB flash memory which allows the device to log data independently of a computer. It provides both current and historical information.

Signal transmission: The RainWise MKIII Weather Transmitter generates and uses radio frequency waves in the frequency band 2.4 GHz for signal transmission. The transmitter was set to transmit the signal at 1 second interval. The data collect was later converted to daily averages. Transmission range is around 100m along the line of sight. However, obstruction between the sensor transmitter and the receiver may affect overall range.

Class ‘A’ pan installed at the experimental site: The United States Class ‘A’ pan (obtained from South Africa) which is cylindrical and is made of 0.8 mm thick galvanized iron. It is 25, 4 cm deep and 120, 7 cm in diameter. The pan was installed on bricks and levelled using a spirit level. Ideally a wooden grid platform could have been used but was not available. The bricks however allowed for the air circulation and detachment of the pan from the ground. The pan shown in Figure 3 was placed on a piece of bare land measuring 10 m by 10 m, fenced permitted free air circulation and prevent animals from drinking water from the pan . Water was filled to 5 cm below the rim. The level of the water was not allowed to drop to more than 7, 5 cm below the rim.

The Stevenson screen 100050 is a louvered cabinet with a hinged and chain – supported door, with door catch. It is constructed from hard wood and finished with white enamel paint. All the SS 100050 Stevenson screen was mounted on a stand 1.5 metres above the ground surface and it carried with it the wet and dry bulb thermometers.

Measurement of Weather Variables

Automatic weather station

The AWS sampled after every 30 minutes data on air temperature, humidity, pressure, rainfall, wind direction, and wind speed. Through wireless transmission the data logger received data from the automatic weather station and stored it. Daily averages were used in this study.

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Figure 3: Meteorological instruments installed at experimental site.

Data was off loaded onto a computer via a USB cable and processed in Microsoft Excel spread sheets.

Measurement of evaporation

Decrease in height of water level was recorded at 30 minute intervals. Three readings were taken every 30minutes to minimise error and daily averages were computed. Microsoft Excel spreadsheets were used to process data.

Estimation of T_{max}, T_{min} and relative humidity

Readings were taken manually from the dry and wet bulb thermometers respectively, after every 30 minutes. The wet bulb thermometer gave minimum temperatures and the dry bulb thermometer gave maximum temperatures. The two temperatures were also used to estimate relative humidity using the tables in the manual. Daily averages were found and these were used during data processing with Excel spreadsheets

Estimation of net radiation

In the absence of a radiation sensor net radiation (R_n) was computed from solar and longwave radiation using equations (8) and (9). The computation is based mainly on T_{min} and T_{max} temperatures recorded by the Stevenson Screen. The magnitude of daily soil heat flux (G) beneath the reference grass surface relatively small, so it was ignored for 24 hour time steps used in this study.

Determination ETo by Penman–Monteith (P–M) method

Calculation of ETo with the Penman-Monteith equation on 24 hour time scales was done using equation 1. This generally provides accurate results. The daily ETo was computed from meteorological data consisted of the following parameters:

- Air temperature: maximum (T_{max}) and minimum (T_{min}) daily air temperatures.
- Air humidity: mean daily actual vapour pressure (e_a) derived from relative humidity data
- Wind speed: daily average for 24 hours of wind speed (u_2), measured at a standard height of 2 m.
- Net radiation was estimated using equations (8) and (9)
- Other parameters required for calculation of ETo by the Penman – Monteith method were calculated using equations (1) to (7).

Determination of Kp-the pan calibration constant

ETo values generated from the P–M method were plotted against E_p values to establish the correlation according to equation 10. A linear equation for correlation graph was generated using Microsoft Excel. The gradient of the curve gave the Kp value. The regression coefficient, R^2 indicated the strength of the relationship between variables calculated.

Corrective measures for evaporation measurements

Pan evaporation is used to estimate the evaporation from lakes [16]. There is a correlation between lake evaporation and pan evaporation. Evaporation from a natural body of water is usually at a lower rate because the body of water does not have metal sides that get hot with the sun, and while light penetration in a pan is essentially uniform, light penetration in natural bodies of water will decrease as depth increases. Most literature suggests multiplying the pan evaporation by 0.75 to correct for this [18]. Therefore in this study there are two sets of results, one for experimental pan measurements and for practical applications for dams and lakes which are multiplied by 0.75.

Class 'A' pan limitations

If precipitation occurs in the 24 hour period, it is taken into account in calculating the evaporation. Sometimes precipitation is greater than evaporation, and measured increments of water must be dipped from the pan. Evaporation cannot be measured in a Class 'A' pan when the pan's water surface is frozen [19].

The Class 'A' Evaporation Pan is of limited use on days with rainfall events of >30 mm (203 mm rain gauge) unless it is emptied more than once per 24 hours. Analysis of the daily rainfall and evaporation readings in areas with regular heavy rainfall events shows that almost without fail, on days with rainfall in excess of 30mm (203 mm Rain Gauge) the daily evaporation is spuriously higher than other days in the same month where conditions more receptive to evaporation prevailed. The most common and obvious error is in daily rainfall events of >55 mm (203 mm rain gauge) where the Class 'A' Evaporation pan will likely overflow.

Measurement of bare ground evaporation

Readings of water depth change in the Class 'A' pan were used to measure evaporation in units of mm day^{-1}. Graphs were plotted to show diurnal variation of evaporation with wind speed, net radiation.

The FAO-Penman-Monteith determined ETo, Class 'A' pan evaporation data and measured climatic data are presented. Data on variation of evaporation with relative humidity, air temperature, net radiation and wind speed various is analyzed and discussed.

Field measurements

Table 2 gives a summary of Ep values as determined by the Class 'A' pan ETo values estimated by the FAO Penman-Monteith method. The Penman-Monteith estimated values are higher than the Ep values because by definition ETo includes water lost both by evaporation from the soil and by transpiration. The average ETo is 5.6 mm per day, while the average Ep is 5.1 mm per day.

Table 1 and Table 2 shows that Ep has increased from 4.0 mm to 8.02 mm from day 1 to day 6. From day 6 to day 9, Ep decreased to 5.0 mm per day and then increased to 4.72 mm per day on day 10. The International Panel of Climate Change, IPCC (2007), Third Assessment Report [19], which assesses climate change research up to 2001, concludes that global average surface temperature has increased

Time (days)	Daily total net radiation ($MJm^{-2}day^{-1}$)	Air temperature (°C)			Relative humidity (%)	Wind speed (m/s)	Pressure (kPa)	Class A pan evaporation Ep (mm/day)
		Max	Min	Mean				
1	23.59	26.3	18.9	22.6	50.0	8.4	89.9	3.59
2	17.48	28.9	17.9	18.9	71.3	13.1	90.5	3.80
3	20.21	26.6	18.4	18.5	65.2	9.6	90.6	4.91
4	20.60	24.3	19.9	20.1	52,4	12.1	90.4	5.33
5	21.71	25.5	18.1	19.8	54.7	13.9	90.6	7.12
6	17.91	24.3	13.7	19.0	50.2	15.7	90.7	8.02
7	23.77	25.7	18.5	20.1	40.8	10.7	90.3	5.65
8	21.37	23.5	19.1	19.3	38.4	8.4	90.4	5.02
9	22.22	21.1	13.5	17.3	50.3	10.7	90.7	2.90
10	19.51	23.0	14.4	17.8	53.6	11.4	90.6	5.72

Table 1: A summary of daytime climatic variables.

Time (days)	FAO Penman-Monteith Daily total evapotranspiration ETo (mm/day)	Class A pan evaporation Ep (mm/day)	Adjusted Ep (Lake Evaporation) (Ep x 0.75) (mm/day)
1	4.0	3.59	2.70
2	4.5	3.80	2.85
3	4.7	4.91	3.68
4	6.0	5.33	4.00
5	7.8	7.12	5.34
6	8.6	8.02	6.02
7	6.2	5.65	4.24
8	5.5	5.02	3.77
9	3.1	2.90	2.18
10	5.0	4.72	3.54
Average	5.6	5.1	3.83

Table 2: Evaporation rates.

by 0.6°C (±0.2°C) over the 20th century, and is predicted to increase by 1.4°C to 5.8°C between 1990 and 2100; average precipitation has increased over tropical latitudes by about 2% to 3% throughout the 20th century, and on average has decreased by about 3% in the sub-tropics . If water harnessing mechanisms are not put in place there will be water scarcity in Masvingo town due to evaporation.

Air temperature does not show a consistent pattern. For instance, when Ep increased from 4.0 mm to 4.91 mm per day, maximum temperature was almost constant from day1 to day 3 from 26.3°C to 26.6°C, then decreased to 23.0°C on another day to other day 10°C showing that Ep does not depend on air temperature alone.

Figure 4 shows the regression of the Class 'A' pan evaporation and evapotranspiration, ETo estimated by the Penman-Monteith method for a period of ten days. The linear regression coefficient R^2 with a value of 0.97 indicated a very strong correlation. Considering the equation (10) the pan coefficient Kp=0.91. The pan coefficient on an annual basis has an average value of 0.8 [20].

The experimentally obtained pan coefficient is within ± 1.5 of error which makes the reading acceptable.

Effects of weather variables on evaporation

Figure 5 shows that from day 1 to 2, RH increased from 50% to a peak value of 71%. In the same period Ep increased from 3.59 mm to 3.80 mm per day. After day 2 up to day 4, RH decreased to 52.4% while Ep continued increasing until it reached a peak value of 8.0 mm per day on day 6. RH increased from day 4 to 5 to 54.7% and up to day 8 to 38.4%. After day 8 RH increased up to day 10 to 53.6%. From day 6 to 9, Ep decreased to from 8.0 to 2.9 mm per day and then increased to 4.7 on day 10. It is clear that Ep does not always vary proportionally directly with relative humidity. This shows that some whether variables other than relative humidity are also responsible for influencing the rate of evaporation, otherwise the rate of evaporation should have decrease whenever relative humidity increased.

Figure 6 shows that generally Ep increased when net radiation increased and decreased when net radiation decreased. This consistent with theory which identifies the main driver of evaporation is net radiation.

Figure 7 shows that Ep generally increases with wind speed. This because area around the pan remained unsaturated since water vapour was continuously swept away by wind. From day 2 to day 3 Ep increased although wind speed was decreasing. This clearly shows that Ep is dependent on other weather variables as well other than wind speed.

Conclusions

Evaporation rates seemed to be driven by net radiation and wind speed, and less by relative humidity and air temperature as shown by graphs. In most cases for the ten day period of the study, the rate of evaporation increased when net radiation and wind speed increased. This is because direct solar radiation, provided energy to change the state of water molecules from liquid to vapour. Net radiation also induced air motion which kept the vapour pressure deficit around the Class 'A' pan high hence increasing the rate of evaporation.

Generally the experiments gave close to literature readings for pan coefficient which in turn mean that the results from the pan can be accepted and used to estimate evaporation rates in the vicinity.

Typical evaporation rates estimated by the Class 'A' pan method

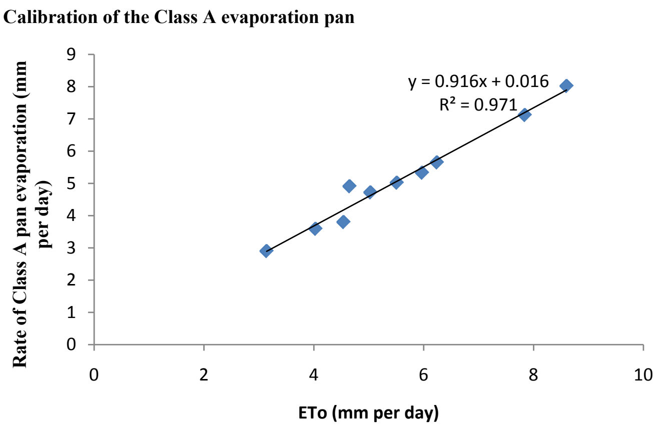

Figure 4: Correlation between Class A pan Evaporation and ETo.

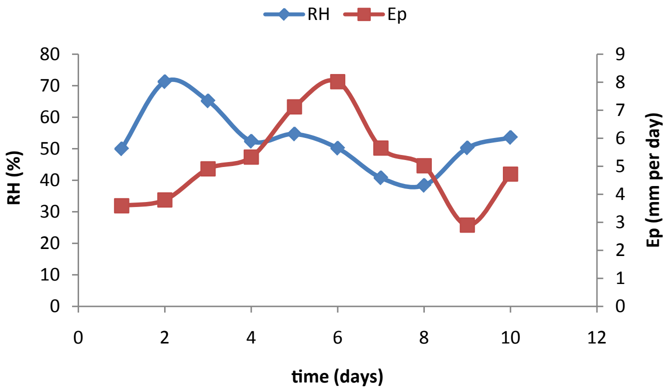

Figure 5: Variation of Ep with relative humidity.

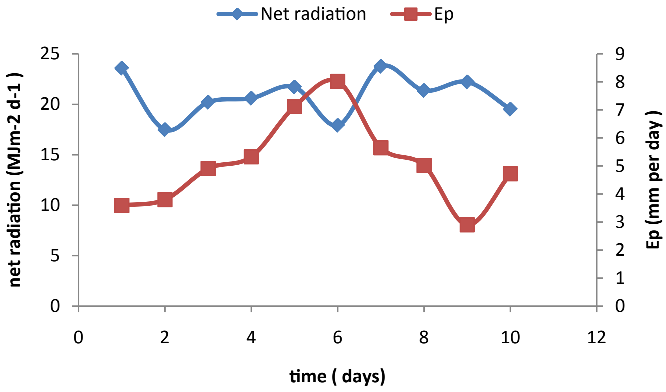

Figure 6: Variation of Ep with net radiation.

ranged from 2.9 to 8.0 mm/day, while for the Penman-Monteith method they ranged from 3.1 to 8.6 mm/day. The average for the former method was less than that and for the latter. This is consistent with what was expected because the Penman – Monteith method estimated evaporation rates included water lost by evaporation and transpiration, while the Class 'A' pan method estimates involved only water lost by evaporation. The evaporation rates obtained were not sustainable in the long term if water harnessing strategies are not employed.

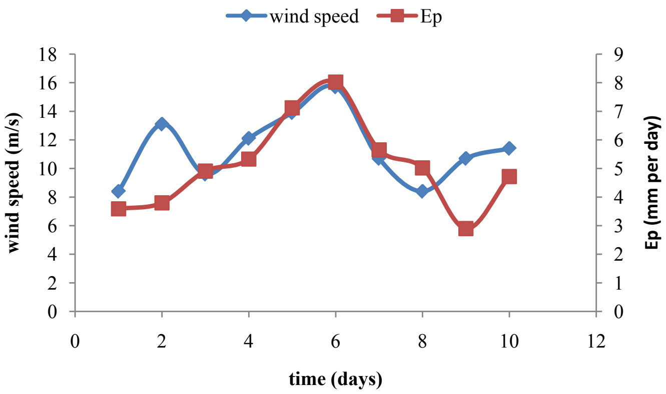

Figure 7: Variation of Ep with wind speed.

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