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**An experience in estimating evapotranspiration using
Lysimeter in Hapugala, Sri Lanka**

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Efficient planning of water resources requires accurate evaluation of all components in the water budget. Evapotranspiration is an essential component of the water budget and the correct estimation of evapotranspiration is vital for improved water resources management. This study discusses about estimation of evapotranspiration using a simple technology which is economically viable for developing countries. In this study, daily reference evapotranspiration (ET_o) was estimated based on the measurements from a non-weighable drainage type lysimeter. ET_o estimations by Blaney Criddle, Radiation and Penman methods were compared with ET_o estimations by the lysimeter measurements. It is revealed that the lysimeter estimations were overestimating the ET_o during the months of February, March and April in year 2008 by 24%, 12% and 11% respectively compared to ET_o estimations by the Penman method. Reasons for the above overestimations were discussed and recommendations for reliable ET_o estimations by lysimeters were presented in relation to lysimeter design, installation, operation and maintenance.

Introduction

Hapugala area in Galle District of southern Sri Lanka belongs to the Wet Zone of the country. Different types of water demands in the area include water for agriculture, industrial needs, domestic needs, cultural practices and environmental needs. Water use for agriculture and forestry are at very high percentage compared to water usage in the other sectors such as domestic, industrial and tourism. Hence a good estimation of evapotranspiration is important in order to assess crop water requirements accurately and so forth to facilitate efficient water resources management in the area. The existing weather station in Hapugala records rainfall, wind speed, wind direction, air temperature and barometric pressure. But there are no provisions to measure evaporation, despite it being an important parameter in climatology. Hence this study aimed in estimating ET_o in Hapugala area based on the measurements from a non-weighable drainage type lysimeter. Above ET_o values were then compared with ET_o estimations by Blaney Criddle method, Radiation method and Penman method. Key climatic data required for the estimations were obtained from the near by weather station.

Materials and methods

Study area

Annual rainfall in the study area averages to 2300 mm, more than half of which normally falls from May to September. Mean annual temperature is about 27 °C. Relative humidity ranges from about 70% to 85%. The sunlight is possible about eight to nine hours a day on average, throughout the year. The area consists of medium textured type of soil. Figure 1 shows the location of Hapugala area.

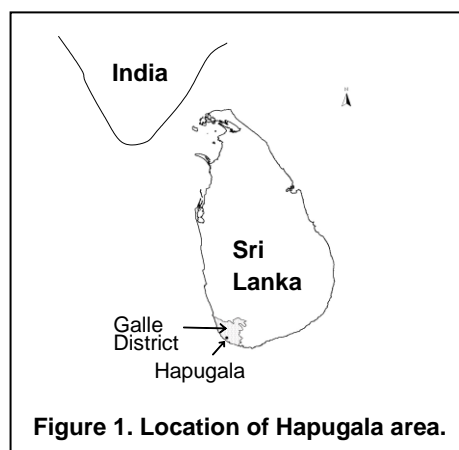


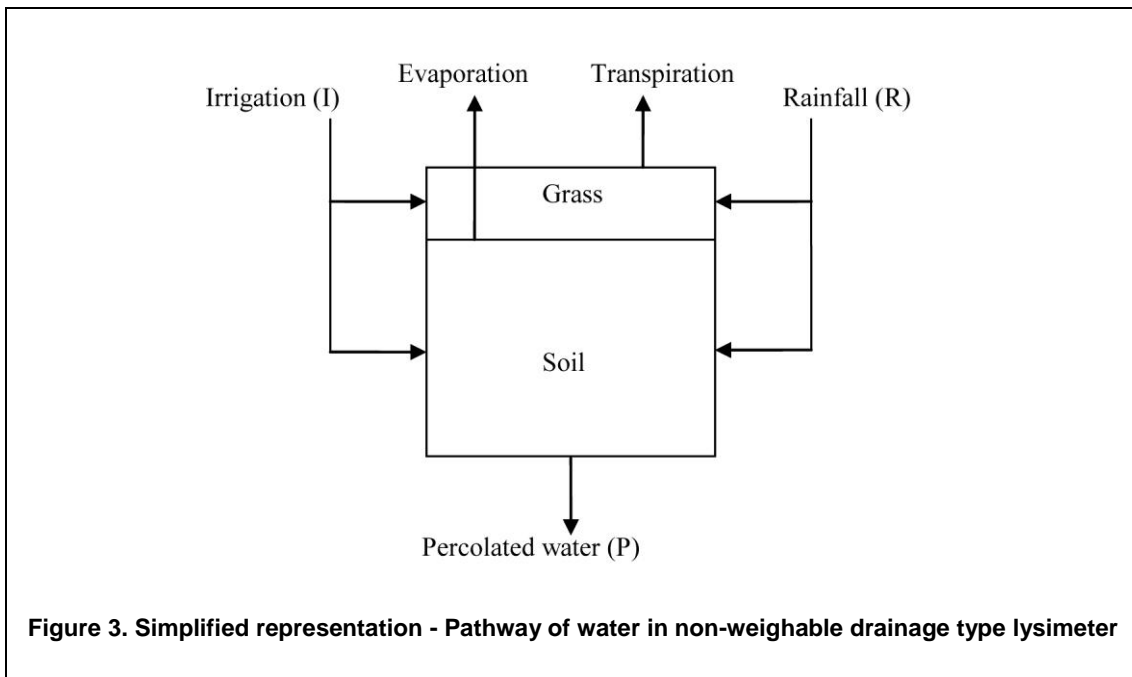
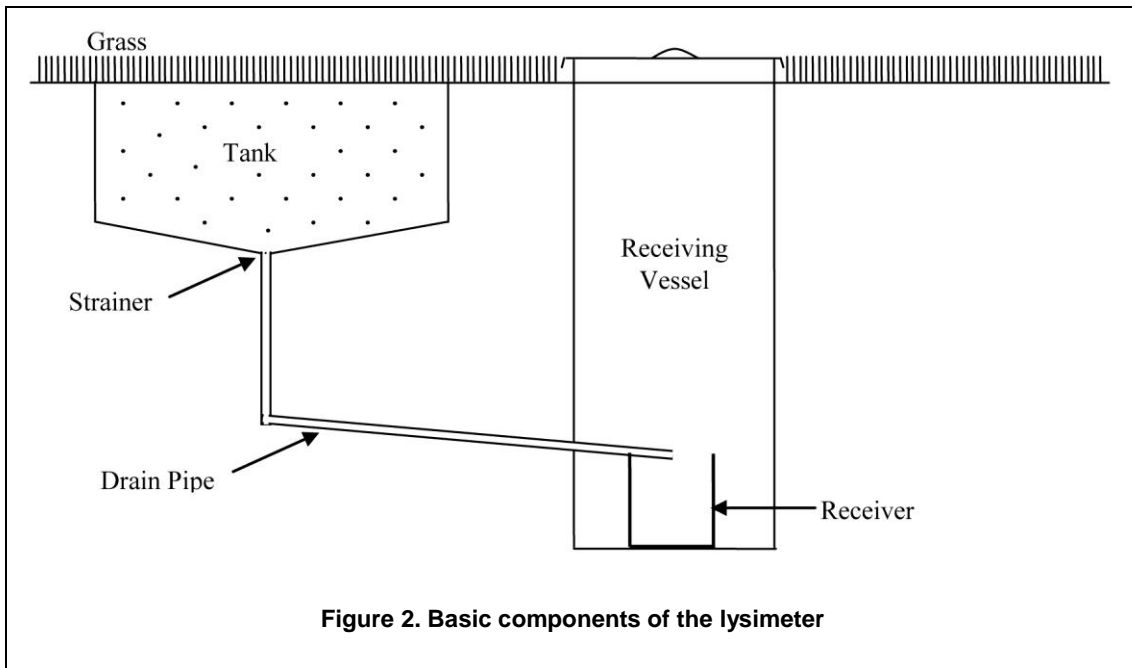
Figure 1. Location of Hapugala area.

Estimation of ETo based on the non-weighable lysimeter measurements

Lysimeters are widely used in laboratories and for field work, mainly for agronomic research. Lysimeter use in different fields of research includes hydrology, soil science, agriculture, forestry, ecology and environment protection. Lysimeters are defined as large containers filled with soil located in the field to represent the field environment, with bare or vegetated surfaces for determining the evapotranspiration of a growing crop or a reference vegetative cover, or for determining the evaporation from bare soils (FAO 39, 1982). Basically non-weighable lysimeters enable to determine evapotranspiration for a given period of time by deducting the drainage water collected from the total water input.

ETo is defined as the rate of evapotranspiration from an extensive surface of 8 cm to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water (FAO 24, 1977). In determining ETo in this study, a non-weighable drainage type lysimeter was installed inside the premises of the Faculty of Engineering, Hapugala, Sri Lanka [6°5'0" N, 80°12'0" E; 37 m elevation above Mean Sea Level] at the beginning of year 2008 and recording of measurements were started from February. Lysimeter installation was carried out in the middle of a 50 m x 50 m area covered by native grass but without having any trees. The location was selected considering the medium textured soil type in the area, almost flat terrain, type and size of the vegetation in the surrounding area, availability of water, accessibility and proximity to existing weather station.

Lysimeter consisted of a black plastic tank of 0.3 m diameter (0.07 m² surface area) and 0.5 m deep with tapered bottom to facilitate percolating water to drain into a receiver placed inside a receiving vessel. A drain pipe with a slight fall was used to carry percolated water from the tank to the receiver. At the drain hole, a strainer was provided to prevent the soil particles passing into the drain pipe. The receiving vessel was capable of holding the largest anticipated rainfall at the site. The tank was filled with the soil taken from the surrounding area, with minimum disturbances to the soil. A piece of turf covered with well grown buffalo grass taken from the immediate surrounding area was placed on the top of the tank. The immediate surrounding buffer area of 4 m x 4 m and the lysimeter surface were having similar plant with similar spacing. The plant height in the surrounding buffer area was maintained similar to that within the lysimeter (8 cm) by regular cutting. Figure 2 and Figure 3 show the basic components of the lysimeter and the simplified representation of pathway of water in non-weighable drainage lysimeter, respectively.



To determine E_{To} , incoming and outgoing water flux must be measured according to,
 $E_{To} = R + I - P \pm \Delta W$ ----- (1)

Where,

R – Rainfall

I – Irrigation

P – Percolated water

E_{To} – Evapotranspiration which includes soil evaporation and crop transpiration

ΔW – Change of water content of the isolated soil mass over a given time period

All the above parameters are expressed in mm per day.

The soil in the lysimeter was saturated at the beginning. Based on the results of the sand cone testing and specific gravity testing, the depth of water required for saturation was determined. For subsequent lysimeter

measurements, the soil in the lysimeter was maintained close to the field capacity by frequent water applications. The frequency of water application and the depth of water requirement at each application were determined according to FAO 24 (1977) and ID guideline (1984), considering the readily available soil water of 70 mm/m over the root zone and 90% application efficiency. It was found that 1.1 liter of water needed to be added to the lysimeter, daily. ETo for a given period was considered as the difference between water applied and that drained. FAO 39 (1982) revealed that in continuously draining lysimeters with daily irrigation, soil moisture content is more or less constant and hence the change in moisture storage is negligible. Using the non-weighable drainage lysimeter measurements, ETo was determined directly by, $ETo = R + I - P$ ----- (2)

Estimation of ETo by Blaney Criddle method, Radiation method and Penman method

According to FAO 24 (1977), ETo was estimated for Hapugala area for the same time period using Blaney Criddle method, Radiation method and Penman method. Mean daily values of the climatic data were used for these estimations. The key climatic and geometric data which were used for the ETo estimations are shown in Table 1.

Data	February - 2008	March - 2008	April - 2008
Latitude	6°5'0"N		
Altitude	37 m elevation above Mean Sea Level		
Mean temperature (°C)	25.9	26.9	26.9
Mean wind speed (m/s)	0.4	0.5	0.4
Mean relative humidity (%)	73	73	76
Mean actual sunshine (hours/day)	8	9	8

Results and discussion

The choice of Blaney Criddle method, Radiation method and Penman method out of the methods presented in FAO 24 (1977) were based on the type of climatic data available and on the accuracy required in determining the ETo. Buffalo grass was grown in the lysimeter so as to maintain similar vegetative condition as stated in the definition of ETo. Figure 4 shows the monthly average ETo values for the study area by different methods during February, March and April in year 2008.

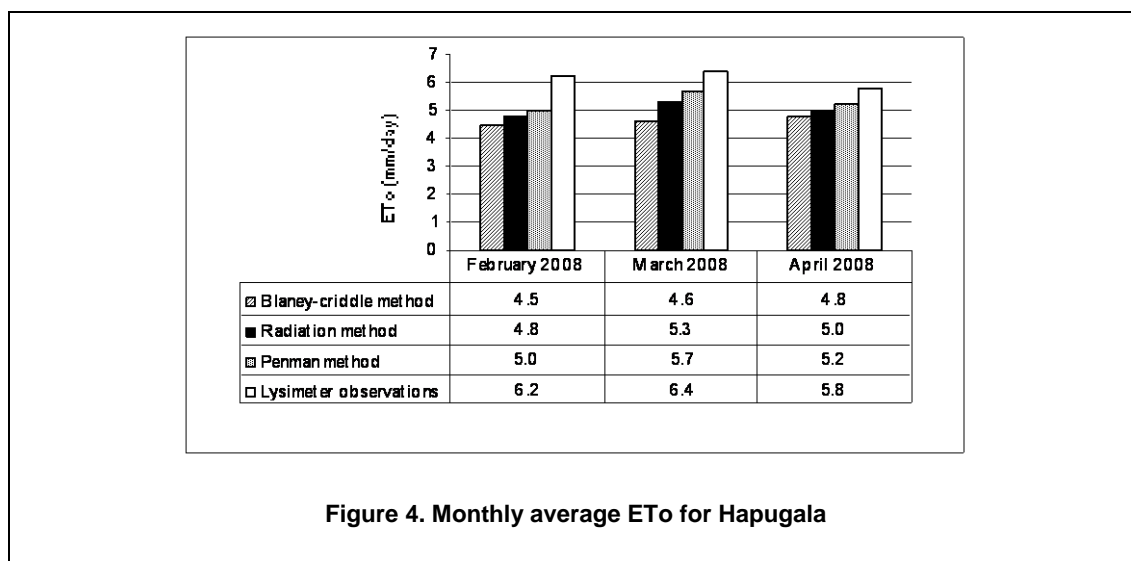


Figure 4. Monthly average ETo for Hapugala

The lysimeter observations estimated the highest ETo followed by the Penman method. The lowest estimates were by the Blaney Criddle method. FAO 24 (1977) stated that, among the ETo estimation methods presented there, the Penman method will offer the best results with minimum possible error of $\pm 10\%$ in summer conditions. The Radiation method involves a possible error of up to 20% in summer conditions. In the Blaney Criddle method, an over or under prediction of up to 25% is expected. Hence the ETo comparisons in this study were carried out by considering the Penman method as the baseline.

According to the Figure 4, estimates by the Penman method and the Radiation method did not significantly differ from each other. The Penman method estimations for February, March and April were 4%, 7% and 4% higher than that of the Radiation method estimations, respectively. This could be due to the aerodynamic term accommodated in the Penman method other than to the energy term used in both methods. The aerodynamic term considered wind and humidity data which differ from one month to another. The Blaney Criddle method which considered only temperature data, significantly under estimated ETo for all the months compared to the Penman method. It was recommended in FAO 24 (1977) to use the Blaney Criddle method for the situations where there are no any actual measured data other than the temperature.

Compared to the Penman method, lysimeter observations were over estimating ETo for all the months. The percentage of over estimation varied as 24%, 12% and 11% for the months of February, March and April, respectively. Since there is a decreasing trend in over estimations with time, there exists a potential to minimize such inaccuracies in the long run. However this needs to be further analyzed using the data obtain over a considerable period of time. In addition, FAO 39 (1982) stated that lysimeters require to be used at least for the first three years in conjunction with other methods of determining ETo, since soil disturbance and other sources of errors including managerial errors occurring during that time could be properly assessed and minimized.

According to Francaviglia et al (2000), soil in lysimeters must be representative of the horizons distribution of the original soil, and must be conditioned for several months prior to the use. Lanthaler (2004) stated that when soil is artificially backfilled into lysimeters, it has to be carefully compressed and should be investigated for longer periods. Measurements obtain by such lysimeters that have been in use for long periods of time are recommended for reliable ETo estimations. In addition WMO-No.8 (2006) recommended to use the non-weighable (percolation type) lysimeters only for long term measurements, unless the soil moisture content could be measured by some independent and reliable technique. Lysimeter and the buffer area should be planted, fertilized, watered and managed as much as possible in the same manner. Watering the buffer area weekly instead of every two to three days similar to the lysimeter, tends to give 25% to 35% overestimated values of ETo in semi arid conditions (FAO 39, 1982).

There is no universal international standard lysimeter for measuring evapotranspiration. The surface area of lysimeters in use varies from 0.05 m² to some 100 m² and their depth varies from 0.1 m to 5.0 m (WMO-No.8, 2006). FAO 39 (1982) recommended a lysimeter area of 4 m² for evapotranspiration measurements of grass and most other field crops. That is to reduce boundary effects and to avoid restricting root development. FAO 39 (1982) further stated that apart from the lysimeter area itself, it is necessary to give special care in relation to conditions and size of the buffer area. In semi-arid and arid regions the size of the buffer area becomes particularly critical and when crop height within the lysimeter is higher than in the surrounding buffer area, advection becomes a significant factor in lysimeter measurements. Mitchell (1966) showed strong advection effects of 50% to 85% higher values on evapotranspiration measurements with small lysimeters, and small buffer areas of 6 m diameter or less. In order to minimize the effects of advection, lysimeter plots need to be located at a sufficient distance from the upwind edge of the surrounding area, i.e. not less than 100 m to 150 m (WMO-No.8, 2006).

Lysimeter measurements are subjected to several sources of errors by disturbance of the natural conditions by the instrument itself. According to WMO-No.8 (2006), some of the major effects include: change of eddy diffusion by discontinuity between the canopy inside the lysimeter and in the surrounding area, insufficient thermal equivalence of the lysimeter to the surrounding area cause by thermal isolation from the subsoil, insufficient equivalence of the water budget to that of the surrounding area cause by disturbance of soil structure and restrictions to drainage. In addition to the careful design of lysimeter equipment, sufficient representativeness of the plant community and the soil type of the area under the study is of great importance. Moreover, the lysimeter conditions must be fully representative of the natural field conditions.

Conclusions

Non-weighable drainage lysimeter is the simplest and cheapest mean of estimating ETo and has to be properly designed, installed, operated and maintained, meeting the required standards in order to obtain valid ETo and crop water use data.

For an effective ETo estimation using lysimeter, only one years data would not be sufficient. Initially additional field investigations are needed in conjunction with lysimeter measurements but adequate knowledge and experience acquired subsequently on lysimetry could lead to obtain reliable ETo estimations over the long run. This technology could be best utilized for ETo estimations in areas with least developed hydro-meteorological measurement networks and in countries with limited access to the advanced technologies like geographic information systems and remote sensing applications due to many constraints.

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References

- FAO 24 (1977). Doorenbos J. and Pruitt W.O. *Guidelines for predicting crop water requirements*. Food and Agriculture Organization of the United Nations (FAO) Irrigation and Drainage Paper 24.
- FAO 39 (1982). Aboukhaled A., Alfaro A. and Smith A. *Lysimeters*. Food and Agriculture Organization of the United Nations (FAO) Irrigation and Drainage Paper 39.
- Francaviglia R., Capri E. and Trevisan M. (2000). *Experimental guidelines for lysimeter studies in the Mediterranean area*. Pesticide/Soil Interactions: Some current research methods, pp. 287 – 296.
- ID guideline (1984). Ponrajah A.J.P. *Design of irrigation head works for small catchments*. Irrigation Department, Colombo.
- Lanthaler C. (2004). *Lysimeter stations and soil hydrology measuring sites in Europe*. Diploma thesis, School of Natural Sciences, Karl-Franzens-University Graz.
- Mitchell P.K. (1966). *Field measurements of potential evapotranspiration in Malta*. Agricultural Meteorology, 3 (3-4), pp. 247-255.
- WMO-No.8 (2006). *World Meteorological Organization (WMO) guide to meteorological instruments and methods of observation, Chapter 10 – Measurement of evaporation*, Draft seventh edition, pp. 1–8.

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