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Original Research Paper

Variability And Interrelationship Between Evaporation And Potential Evapotranspiration

Biological Science

KEYWORDS : Evaporation, Potential evapotranspiration, Microwatershed, Meghalaya

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ABSTRACT

Evaporation and evapotranspiration are key parameters for understanding the hydrology of any ecosystem. In this study, the rates of pan evaporation and potential evapotranspiration (PET) have been measured and estimated respectively on a daily basis averaged to an annual rate. The annual pan evaporation was measured using a US Class A pan evaporimeter. The potential evapotranspiration was estimated using Thornwaite's method. Significant monthly variations were recorded in both processes. The analysis of interrelationship between the two processes showed that both followed a dissimilar distribution pattern in the microwatershed. The PET was found to be related to rainfall while the pan evaporation did not show any correlation with rainfall.The value of empirical data on evaporation and PET in management of water resources has been underlined.

INTRODUCTION

In hydrology and irrigation practices, the terms evaporation and transpiration are used synonymously as evapotranspiration. Evaporation is one of the most important components of the hydrological cycle responsible for major portion of water loss from water bodies, such as rivers, lakes, and reservoirs (Fu et al. 2004). It is considered as an important factor for decision making in agriculture, forestry and fisheries. Evaporation is either measured directly in the field or it is estimated from meteorological parameters. Two terms that are important to be understood are: free surface evaporation (Ep) and potential evapotranspiration (PET). Free surface evaporation is the quantity of water evaporated from an idealised, extensive open water surface per unit area under existing atmospheric conditions (Penman, 1948). Measurement of water from a pan is the simplest technique commonly used for measuring evaporation from natural surfaces. The US class A pan evaporimeter is the official network instrument developed by the U.S. Weather Bureau which is extensively used by hydrologists (Kadel and Abbe, 1916). The basic idea in the deployment of evaporation pans was that these measurements can be assumed to be proportional to actual evaporation from moist surfaces, such as lakes or irrigated fields. Potential evapotranspiration is a calculated quantity and is used to refer to the maximum quantity of water capable of being lost as water vapour, under a given climate, by a continuous, extensive stretch of vegetation covering the ground when there is no shortage of water (Gangopadhyay et al., 1966). Evapotranspiration thus involves two basic processes: evaporation from the soil and transpiration from the leaf surfaces. Potential evapotranspiration can be characterised as a process of mass transport, whereas evaporation is treated as a diffusive process driven by the vapour pressure gradient (McKenney and Rosenberg, 1991).

Natural evaporation is the process whereby water at the Earth's surface, either in liquid or solid form, is converted to vapour or transferred to the atmosphere. It is therefore the reverse component to precipitation in the global water cycle and, in total over the whole surface of the Earth, the two must balance on the average. Evaporation is dependent on a number of meteorological factors. The rate of evaporation is defined as the amount of water evaporated from a unit surface area per unit of time. It can be expressed as the mass or volume of liquid water evaporated per unit area in unit time, usually as the equivalent depth of liquid water evaporated per unit of time from the whole area. The unit of time is normally a day and the amount of evaporation is considered in millimetres (WMO, 2003). The potential evapotranspiration is largely independent of soil and plant factors but is hugely dependent on climatic factors. According to Liang et al. (2010), temporal variations of PET and quantification of its trend can serve as a valuable reference data for the regional studies of hydrological modelling, agricultural water management, irrigation planning and water resource management. A number of empirical formulae/approaches have been used for the determination of PET from meteorological data. Thornwaite (1948) introduced a method to estimate PET based on air temperature. The method has been developed on the basis of an empirical study, between mean air temperature and evapotranspiration. Kumar et. al (1987) opined that Thornwaite's method (1948) is more preferable than Penman's method especially in India (Penman, 1948). They conducted a comparative study between the two methods for 26 years of data at 15 stations spread over the country and found that Thornwaite's waite's method gave considerably higher estimates of PET and showed lower inter-annual variability than Penman's method during the southwest monsoon season. Potential evapotranspiration and its measurement in regions of India has been studied and reviewed by Rao et. al., (2012). Chattopadhyay and Hulme (1997) studied short term and long term scenarios for evaporation and potential evaporation in India and suggested that both pan evaporation and potential evapotranspiration have decreased during recent years in India. In 1963, Bouchet hypothesised that, for large homogeneous areas, under conditions of little advective heat and moisture, potential and actual evapotranspiration depend on each other in a complementary way via feedbacks between the land and the atmosphere. In addition, Morton (1983), proposed that wet-environment evapotranspiration (ET_{Wet}) is equivalent to the conventional definition of potential evapotranspiration. He also conducted a study on complementary relationship (CR) between potential evaporation and actual evaporation and argued that the CR can be verified indirectly through a water balance study. The present paper attempts to study the variability and interrelation between evaporation and evapotranspiration rates in a microwatershed located in hilly area receiving moderately high rainfall.

MATERIALS AND METHODS

STUDY AREA

The study was conducted in Pahamsyiem microwatershed, Ri-Bhoi district of Meghalaya, India (Fig.1). It lies within 25.892°-25.917° N latitudes and 91.842°-91.885° E longitudes. The microwatershed is situated on the northern slope of Meghalaya plateau. It is part of a larger system of Umran river catchment (Singh, 2007). It is an undulating hilly region and is surrounded by hills on three sides. The altitude ranges from 350-850 m a.s.l. The hills lower down to flat valley lands which are fertile and favourable for cultivation. The microwatershed is 771 ha in area. The natural vegetation of the study area can be broadly classified as subtropical evergreen forest (Champion and Seth, 1968). Pahamsyiem microwatershed has a warm sunny weather and enjoys sub-tropical climate throughout the year. The area receives moderate rain with hyperthermic rainy season. The maximum and minimum temperatures recorded during the study period were 30.8°C°C and 5.6°C respectively. The maximum relative humidity during the study year was 88.9% and minimum relative humidity was 47.1% (Fig. 2.).

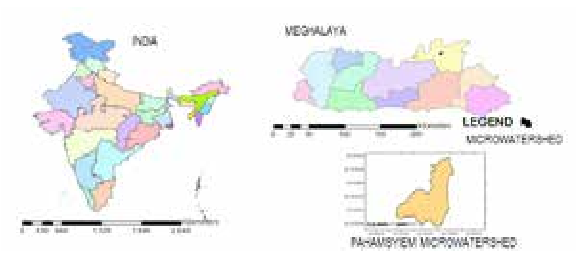

Fig.1. Location map of the study area

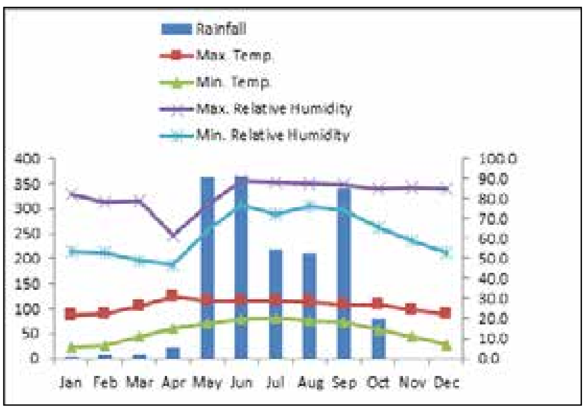

Fig. 2. Monthly rainfall, temperature and humidity in Pahamsyiem microwatershed

INSTRUMENTATION AND DATA COLLECTION

Evaporation: Evaporation was measured using a US Class A pan evaporimeter. A Stevenson box was placed near it with maximum and minimum thermometers. A non-recording raingauge was also installed near it to measure the daily rainfall. Free surface evaporation (E_p) was observed under two conditions, (i). When water level was below the tip of the gauge and (ii) when water level was above the tip of the gauge. In the former, the measuring cylinder was filled with water upto the zero mark and a measured amount of water was added slowly to the pan to bring the water level in the stilling well to the tip of the gauge. In such a case, E=R+(A/100) where A is the amount of water added to the pan in mm, R is the amount of rainfall in mm since the last observation and E is the amount of water lost by evaporation in mm since the last observation. Alternatively, an amount of water was removed from the pan whenever the level of water in the stilling well was above the fixed point gauge. The amount of water removed was measured using a measuring cylinder. In such a case, E= R-(A/100).

Evapotranspiration: Direct measurement of potential evapotranspiration (PET) across locations is cost prohibitive and therefore an indirect method using meteorological data was used as an alternative. In order to calculate potential evapotranspiration, Thornwaite's method (1948) was used. The inputs required in this method are daily air temperature and average monthly number of daylight hours. The monthly daylight hours were obtained from ICAR Research Complex, Barapani, Meghalaya. The formula used in this method is as follows:-

$$PET= 1.6x(10\ T_a /I)^a$$

where T_a is the mean monthly air temperature, and I is the heat index

and $a = .49 + .0179 * I - .0000771 * I^2 + .000000675 * I^3$, where air temperature is summed over a 12-month period to a power.

Statistical relationship was computed using SPSS 16. The average of daily data was used as monthly value for all the methods for regression and error analysis.

RESULTS AND DISCUSSION

The pan data was collected from January to December 2014 using Class A pan evaporimeter and refers to actual evaporation. The monthly variation in actual evaporation is graphically presented in Fig. 3. A histogram of standardized residuals comparing the distribution of standardized residuals to a normal distribution was computed and the same is presented in Fig. 4.

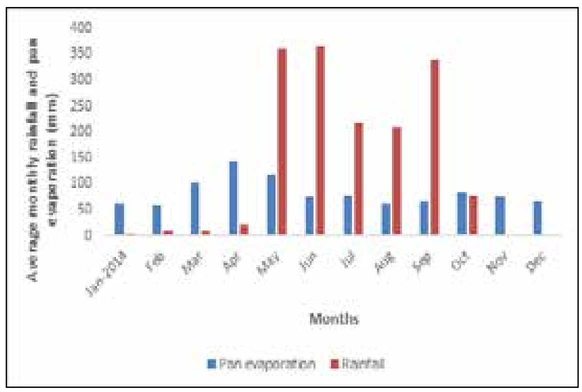

Fig.3. Monthly pan evaporation and rainfall (in mm)

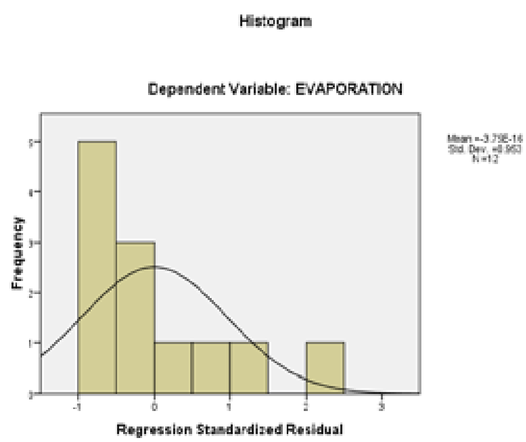

Fig. 4. Histogram showing the relationship between rainfall and pan evaporation

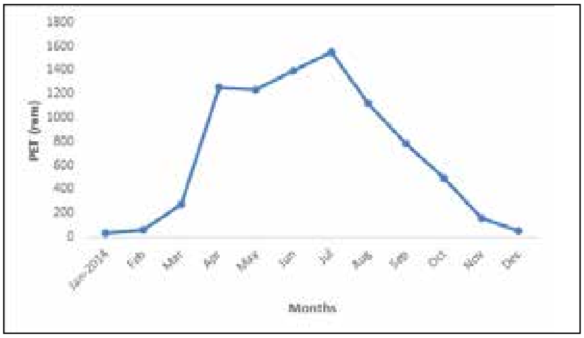

Fig. 5. Monthly variation in potential evapotranspiration using Thornwaite's method

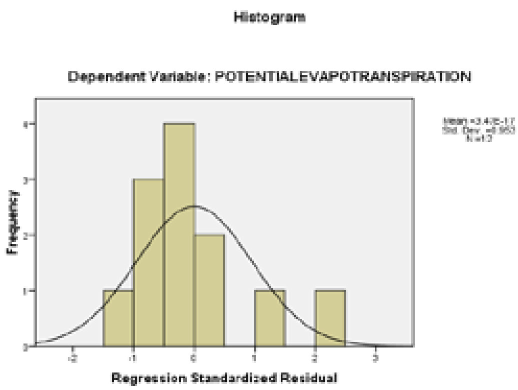

Fig. 6. Histogram showing the relationship between rainfall and evapotranspiration

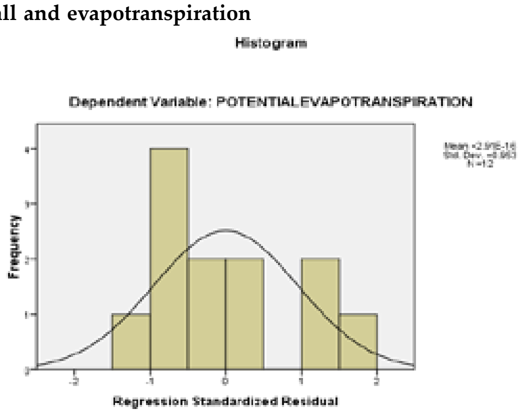

Fig.7. Histogram showing the relationship between pan evaporation and evapotranspiration

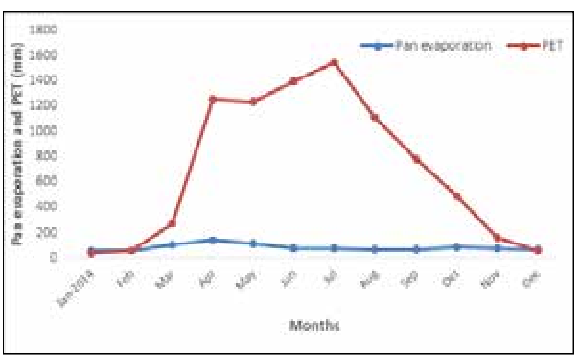

Fig. 8. Comparison between pan evaporation and potential evapotranspiration

Table 1. Table showing the regression relation among the variables

Factors	R Square	Adjusted R Square	Standard Error
Rainfall vs Pan Evaporation	0.0004	-0.099	27.24
Rainfall vs potential evapotranspiration	0.54	0.50	412.50
Pan Evaporation vs potential evapotranspiration	0.16	0.08	560.16

Fig. 3. shows that the highest evaporation occurred in the months of March, April, May and maximum being in the month of April. The rainfall in the summer exceeded evaporation, and while during winter and premonsoon, the evaporation exceeded rainfall. Fig. 4. shows the uncertain relationship between rainfall and evaporation. The histogram deviates from the normal probability plot concluding that rainfall does not have much influence on the pan evaporation. This is further confirmed by the data analysis presented in Table 1. R^2 value shows little or no association between the rainfall and evaporation. Potential evapotranspiration obtained from Thornwaite's equation is presented in Fig. 5. The months which recorded maximum PET follow the trend: July>June>April> May> August. The standardized residuals in case of PET followed the normal probability plot to an average (Fig. 6) with R^2 being 0.54 (Table 1). It is seen that the PET is more related with rainfall than evaporation (Table 1). There is negligible relationship between pan evaporation and potential evapotranspiration (Fig. 7. and Table 1). This provides an explanation for the fact, that in the case of short-term unscaled data the complementary features of pan evaporation and apparent potential evapotranpiration (estimated from Thornwaite's equation) are not always very obvious and may often remain hidden. As Thornthwaite's estimate is manifold higher than measured in Class A pan (Fig. 8), it is clear that this method overestimates evapotranspiration. This is in conformity with the findings of Chapas and Rees (1963) who also found that Thornthwaite's method overestimated potential evapotranspiration.

The precipitation recorded during the year 2014 in Pahamsyiem microwatershed was 1619. 5 mm. The mean pan evaporation and estimated PET in Pahamsyiem microwatershed was 2.74 mm/day and 23.06 mm/day respectively. The evaporation and PET rates measured/estimated in this study are in close conformity with the values reported by Rao, et. al., (2012) from Jorhat, Ranichauri, Umiam, Raipur and Puttur located in different agroecological zones of India. The pan evaporation at an annual basis was found to be low. Other studies that have reported similar results include Peterson, et. al., (1995), who observed a decreasing trend in pan evaporation over large areas in different regions throughout the world during past 50 years. Brutsaert and Parlange (1998) suggested that a decrease in pan evaporation could signal an increase in actual evaporation or terrestrial evaporation as increasing terrestrial evaporation will increase moist air over the evaporation pan, thus reducing evaporation from the pan. Roderick and Farquhar (2002) showed a new proof that the globally observed decreasing solar radiation mainly accounts for the decrease in pan evaporation trend. This indicates that further studies are needed to test the complementary relationship hypothesis between actual evaporation and potential evapotranspiration (Ohmura and Wild, 2002). Decrease in pan evaporation is a consequence of reductions of wind speed and an increase in soil moisture (Chen et al., 2005; Gao et al., 2006). The relationship between pan evaporation and PET may vary as one moves from arid to humid regions as along such gradient an increase in the actual evapotranspiration and a reduction in pan evaporation is expected. Lawrimore and Peterson (2000) have reported that in the USA the complementary relationship between pan evaporation and actual evapotranspiration even holds for the wettest soils. This concludes that the atmospheric humidity and soil moisture are the prime factors governing the rates as well as the interrelations between pan evaporation and evapotranspiration.

The PET estimated during the monsoon and post monsoon periods are comparable with that estimated in Umiam by Rao, et. al., (2012). Precipitation and others meteorological factors such as radiation, wind speed, and humidity have a bearing on the potential evapotranspiration which is reflected in the seasonal variation in PET (Liu et.al., 2002). Similar findings in seasonal variation in pan evaporation and PET were reported by Chattopadhyay and Hulme (1997) who observed maximum decreases in pan evaporation during the pre-monsoon and monsoon seasons, whereas maximum decrease in PET occurred during the monsoon and post-monsoon seasons. They also reported that increase in humidity caused a decrease in pan evaporation. In this study also the maximum evaporation was recorded in the month of April when the atmospheric humidity was lowest (Fig 2). Oishi et al. (2010) studied the transpiration of a mature oak-hickory forest in North Carolina and reported that huge variation in interannual precipitation (ranging from 934 to 1346 mm), did not cause any concomitant variation in annual evaporation which varied within a narrow range (610–668 mm). This suggests that annual evaporation is least affected by annual precipitation. This observation is also supported by Ryu et. al. (2008) who reported that annual evaporation varied within a narrow range despite a twofold variation in precipitation. Therefore annual evaporation does not appear to be sensitive to annual precipitation as also found in this study. An analysis of data pertaining to variability and relationship between evaporation and evapotranspiration showed that pan evaporation and potential evapotranspiration follow a dissimilar distribution pattern in the microwatershed (Figs.7 and 8). This distribution pattern provides a valuable information for understanding regional hydrological processes since it is one of the most important factors determining regional actual evaporation, which, in turn, is a key parameter in assessment and management of water resources of the region.

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