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Estimating Pan Evaporation in Kabul, Afghanistan

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Abstract: Pan evaporation has been widely used as an estimate of potential or reference evapotranspiration. It is also an important variable in making crop management decisions such as irrigation scheduling for crops. However, Afghanistan has many issues in agricultural development due to two decades of conflict and a prolonged drought, poor irrigation facilities, etc. In particular, the basic data for irrigation scheduling, such as pan evaporation and meteorological data, are still poor. The objective of this study is to clarify meteorological properties and to develop an applicable method for estimating pan evaporation in Afghanistan. Finally, we developed a method for estimating pan evaporation for locations where it is not usually being measured. It is clear that this method is slightly more accurate than the Penman model. Therefore, the use of this method is recommended for irrigation scheduling in Afghanistan.

Key Words: Conflict, Crop production, Effective water use, Irrigation scheduling, Penman model.

1. Introduction

Afghanistan is a landlocked country that is located approximately in the center of Asia. It is bordered by Pakistan on the south and east; Iran on the west; Turkmenistan, Uzbekistan, and Tajikistan on the north; and China on the far northeast (**Fig. 1**).

Agriculture employs 80% of the Afghan population and sustains more than half its gross domestic product (Gregory *et al*., 2010). Afghanistan, with an area of 652,000 km^2, is a landlocked mountainous country located between Central and South Asia. Afghanistan is divided into 34 administrative divisions, 40 watersheds, and 5 main river basins (Shobair and Alim, 2004).

Winter precipitation occurs in the form of snow. Agricultural production depends on the availability of water, either as direct rainfall or in the form of snow. However, two decades of conflict and prolonged drought have destroyed irrigation systems and vineyards, and livestock numbers have been greatly diminished. Afghanistan faced a lack of technical guidelines for irrigation planning and a shortage of irrigation water during the cultivation and growing season, resulting in low agricultural productivity.

Moreover, demands on the resources have grown, and Qureshi (2002) has estimated that long-term water availability is about 2,500 m^3 head per year, enough to irrigate 4 million hectares, which is significantly higher than the current 2.6 million hectares in the command area.

Otherwise, Afghanistan is an arid to semi-arid country whose agricultural production depends on the availability of water, either as direct rainfall or in the form of irrigation. In Afghanistan, rainfall data is difficult to access due to the fact that most of the old time-series was stopped in 1977 or, in some cases, in 1992.

Meteorological stations have been damaged and rainfall data were not collected (except at four agro-meteorological stations -Kabul, Jalalabad, Mazare Sharif and Herat- installed in 1999 under the FAO project).

The Afghan Meteorological Department and Institute of Meteorology are not functioning. Due to this particular situation, agro-meteorological observations have become a very important task for the country. Because of the very

Fig.1. Location map of Afghanistan.

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erratic spatial distribution of rainfall in the mountainous regions, data from a large network of rain gauges are required. In addition to rainfall, other parameters are highly important and needed in Afghanistan. They are snowfall and snow cover, upon which most of the country's irrigated sector depends, frost, and low temperature. Accurate and timely information on agro-meteorological observations, including all weather parameters, actual planting times, areas planted, harvested crops, and crop conditions and pasture, are highly needed for each agro-ecological zone and each district in Afghanistan.

In other words, the agro-meteorological approach to helping agriculture can only be effective if reliable, real-time, and timely data are available. Rabah *et al*. (2004) suggested that the timely collection and proper utilization of agro-meteorological information could help promote increased farm profits under favorable weather conditions or decreased farm losses under unfavorable conditions. It is necessary to get it on the orbit of sustainable agricultural development for the stability and the property of this country.

2. Previous Studies

Pan evaporation is an important weather variable that can be applied to decision making in agriculture, forestry ecology, hydrology, and other fields. Many studies on estimating evapotranspiration and evaporation in various countries have been conducted (Sheffield *et al*., 2009; Coulomb *et al*., 2001; Hedayat *et al*., 2012; Kisi, 2010). Abdollahzadeh *et al*. (2011) studied soil erosion in Tanakami, Japan, using an artificial neural network. It has also been used for agriculture and for estimating evaporation and transpiration. Hedayat *et al*. (2012) examined evaluating the artificial neural network for estimating the reference evapotranspiration with the least meteorological data. Kisi (2010) developed generalized regression neural networks (GRNN) based on evapo-transpiration (ET) estimation. The potential of GRNN models for estimating ET using climatic variables has been illustrated. Kisi's study demonstrated that the modelling of daily reference evapotranspiration is possible by using the GRNN technique. The GRNN model, whose inputs are wind speed, solar radiation, relative humidity, and air temperature, performs the best of the input combinations tried in the study. This indicates that all of these variables are needed for better evapotranspiration modelling. For the correct estimation of ET, many studies have been conducted on different underlying conditions to promote the effective use of water resources and to introduce this management into long-term rainfall runoff models. Many approaches regarding different climatic or underlying conditions for estimating actual ET have been

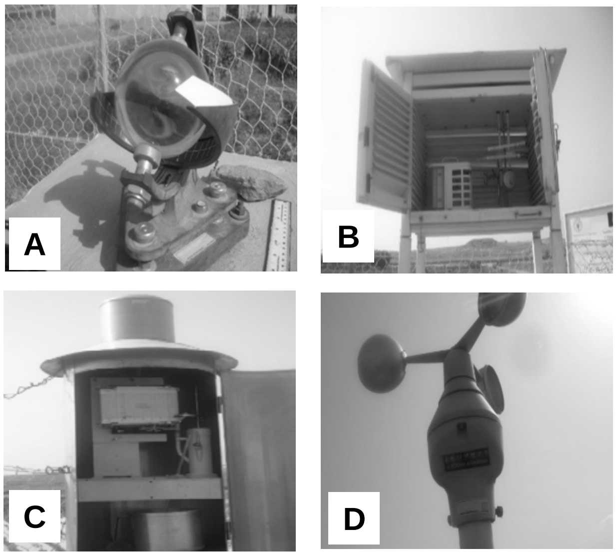

Fig. 2. (A) Sunshine hours, (B) Air temperature and relative humidity, (C) Rain gauge and (D) Wind speed.

proposed (Wanchang *et al*., 1999). A comparison of 20 different methods for estimating ET has shown that Morton's complementary equation provides the most accurate estimate of monthly ET from well-watered grassland under varied climatic conditions.

However, the applicability of the equations on different time and space scales has not yet been clearly understood. Only a few studies of estimating evaporation have been conducted in cold alpine regions, owing to the difficulties in measuring the necessary meteorological parameters, especially evaporation observation, in such regions. Three decades of conflict in Afghanistan have brought destruction, and weather stations and weather data are not registered. Thus, more studies are needed. It is very important for the efficient use of water and the development of agriculture in Afghanistan.

The purposes of this study are to clarify meteorological properties in Kabul and to introduce a method for estimating pan evaporation.

3. Materials and Methods

Meteorological data were collected in the Qargha experimental research center in Kabul Afghanistan, which is managed by the Research Institute, the Ministry of Agriculture, Irrigation and Livestock. The station is located 10 km west of the city center of Kabul, latitude: 34º53'N, longitude: 69º8'E and altitude: 1,834 m. The data were collected during a three-year period from January, 2010, through December, 2012. These data consist of the air temperature, relative humidity, wind speed, sunshine hours and rainfall (**Fig. 2**).

Daily pan evaporation data were also observed at this research station. Pan evaporation data have been measured using a "Class A" evaporation pan, which is a cylinder with a diameter of 47.5 inch (120.7 cm) and a depth of 10 inch (25 cm).

However, evaporation is difficult to measure directly, and, therefore, many theoretical and empirical approaches have been developed. Some of the commonly used techniques include the Penman model (Penman, 1948), the Priestly-Taylor model (Priestley and Taylor, 1972) and the energy balance method. For open water bodies, the Penman combination approach is often used, and it is recommended as the preferred method for estimating the rate of evaporation from open water.

Evaporation pans are another common method of estimating evaporation, although the problems introduced by adopting a suitable pan coefficient lead to doubts about the reliability of the open water body evaporation estimates. Johnson *et al*. (2007) suggested that use of evaporation pans with a pan coefficient can give only a "rough estimate of lake evaporation, mostly on an annual basis". Despite the inaccuracies of the indirect evaporation estimates, the Penman model and evaporation pans are commonly used in research and in practice to predict evaporative losses.

In this study, the Penman model (Penman, 1948) was used for estimating pan evaporation. The following equation was used:

$$ET_p = \frac{\Delta}{\Delta+\gamma}\cdot\frac{S}{I}+\frac{\gamma}{\Delta+\gamma}f(u_2)\cdot(e_{sa}-e_a)$$

where Δ is the saturation vapor pressure at air temperature (hPa/ºC), S is the net radiation (MJ/m^{2}day), γ is the psychometric constant (hPa/ºC), $f(u_2)$ is the wind speed at 2 m height (m/s), e_{sa} is the saturation vapor pressure at air temperature (hPa), and e_a is the vapor pressure (hPa).

This equation demonstrates that the mass-transfer and energy-balance approaches could be combined to arrive at an evaporation equation that does not require surface temperature data. The first term shows net radiation, and the second term shows mass transfer.

4. Results and Discussion

4.1. Overview of the climate in Afghanistan

Most of Afghanistan has a subarctic mountain climate with dry and cold winters, except for the lowlands, which have arid and semi-arid climates. In the mountains and a few of the valleys bordering Pakistan, a fringe effect of the Indian monsoon, coming usually from the southeast, brings moist maritime tropical air in the summer. Afghanistan has clearly defined seasons; summers are hot and winters can be bitterly cold. Summer temperatures as high as 49°C have been recorded in the northern valleys. Midwinter temperatures as low as -9°C are common around 2,000 m above sea level in the Hindu Kush. The climate in the highlands varies with the elevation. The coolest temperatures usually occur on the heights of the mountains. Temperatures often range greatly within single day. Temperature variations in a single day may range from freezing conditions at dawn to the upper 30s°C at noon. Most of the precipitation falls between October and April. The deserts receive less than 100 mm of annual rain, whereas the mountains receive more than 1,000 mm of precipitation, mostly as snow.

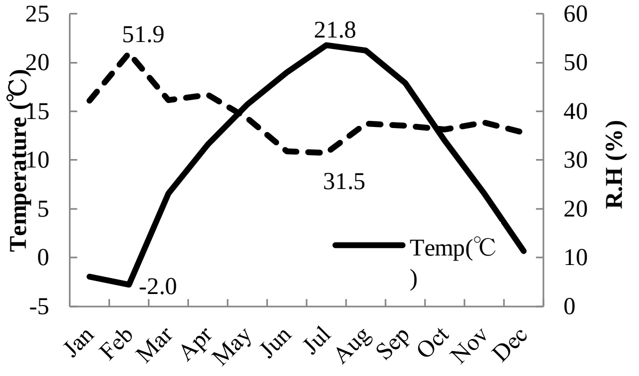

Fig. 3. Changes of monthly air temperature and relative humidity in Kabul.

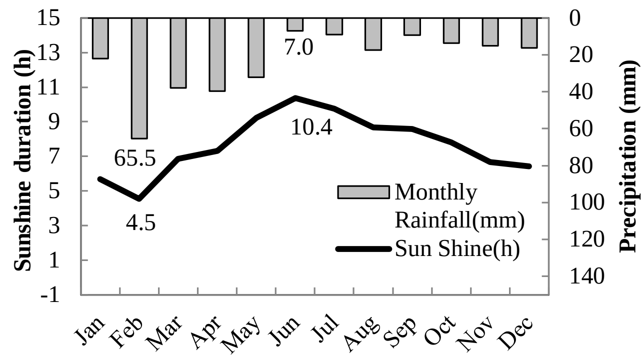

Fig. 4. Changes of monthly precipitation and sunshine duration in Kabul.

4.2. Meteorological properties of Kabul

Kabul is also classified as a semi-arid region. Air temperatures in the summer are high and hot, but winter is cold. The maximum average summer temperature is 21.8ºC in July. The minimum average temperature is -2.8ºC in February. Otherwise, Afghanistan has an arid to semi-arid climate and a low humidity, with a maximum relative humidity of 51.9% in February and a minimum of 31.5% in July (**Fig. 3**).

The average annual precipitation is approximately 250 mm/years (**Fig. 4**). The maximum rainfall of 65.5 mm in in February is in the winter season and is not useful for agricultural purposes, while June and July receive the minimum rainfall of approximately 7 mm. Most importantly,

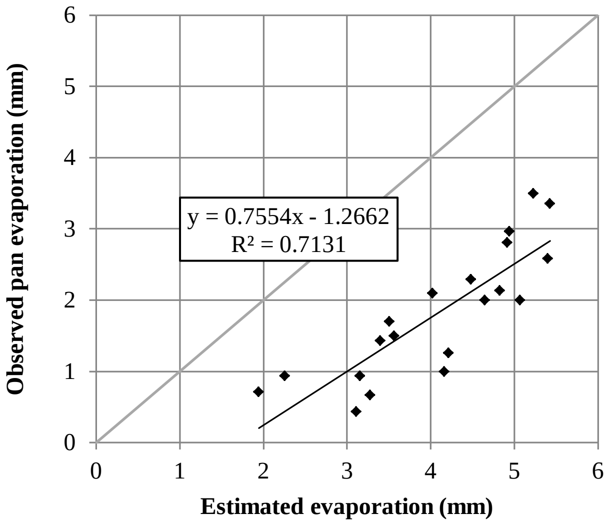

Fig. 5. Comparison of estimated evaporation using the Penman model and observed pan evaporation.

it hardly rains from May through November or December. Additionally, agricultural productivity has declined further because of the decreasing water resource, the precipitation deficit, and traditional inefficiency. Therefore, it is essential that all crops be irrigated; however, lower relative humidity and higher temperatures cause more water evaporation.

4.3. Estimating pan evaporation

Pan evaporation is used to estimate crop evapotranspiration (ETcrop), which can be used to estimate water requirement for crops. There is a correlation between ETcrop and pan evaporation. Basically, ETcrop is equal to the evapotranspiration ratio in multiplying pan evaporation. Therefore, pan evaporation can be estimated easily so that ETcrop may estimate irrigation scheduling for crops.

Figure 5 shows a comparison of the estimated evaporation using the Penman model and observed evaporation with a pan.

There is great variation between estimated evaporation and that observed, due to the changing climate of Afghanistan from November to April. Temperatures at this time are low, sometimes below the freezing point. Therefore, evapotranspiration during this time becomes small, and it is thought that estimates become uneven.

We tried to estimate pan evaporation using other meteorological parameters, such as air temperature, relative humidity, sunshine hour, and wind speed. When we estimated pan evaporation with the relative humidity, there was a large inequality; because Afghanistan is located in a dry area, relative humidity values mostly varied from 30 to 35%. We also tried to estimate pan evaporation with sunshine hours. There was a good relationship between pan evaporation and air temperature as compared to pan evaporation's relationship with relative humidity and wind speed. Similarly we estimated pan evaporation values with air temperature.

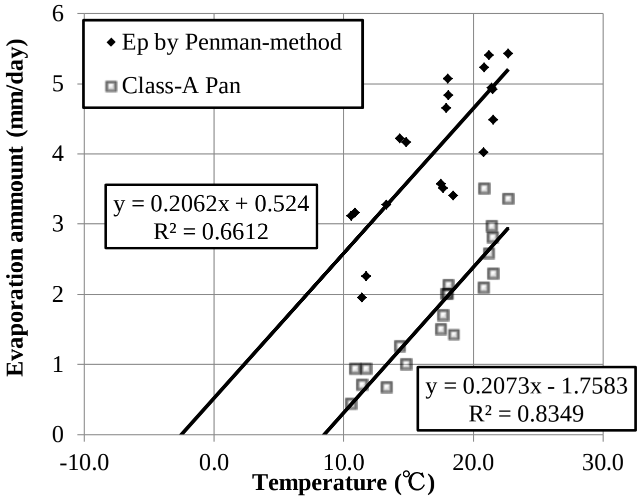

Fig. 6. Relationship between air temperature and pan estimated evaporation and observed pan evaporation amount.

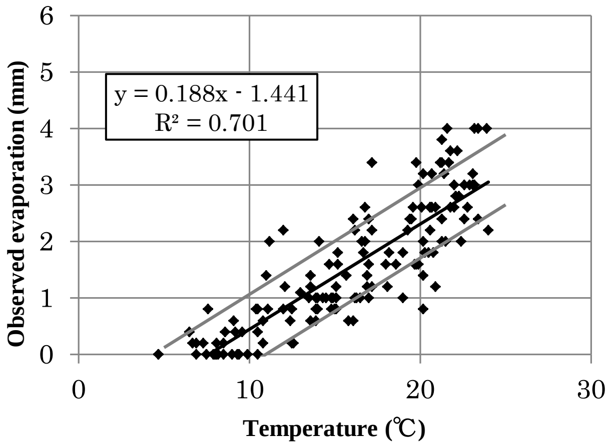

Fig. 7. Relationship between 5-day average temperatures and observed pan evaporation.

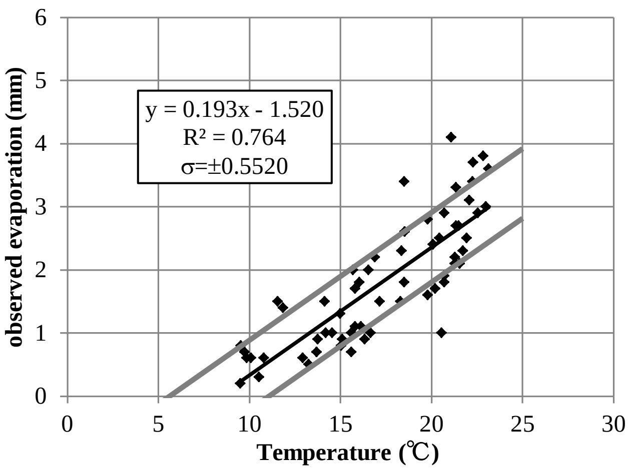

Fig. 8. Relationship between 10-days average temperatures and observed evaporation.

Finally, we found that air temperature was a crucial parameter for estimating pan evaporation values (**Fig. 6**) and determined the appropriate data set for estimating pan evaporation, which were average air temperatures and pan evaporation values in 5- and 10- days periods (**Figs.7** and **8**).

There is a good relationship between 10-day average air temperature and pan evaporation as compared to 5-day average air temperature and pan evaporation, as shown in Figure 7.

5. Conclusions

Afghanistan was classified as an arid and semi-arid region with hot, little precipitation, and low relative humidity in the summer. In this period, a lot of irrigation water has been used for agricultural purposes. Winter is from November to March. Most of the precipitation fell between October and April. However, farmers could not fully cultivate due to the cold weather, which resulted in wasting all of the unusable irrigation water.

Therefore, crop cultivation activities in Afghanistan were limited in the summertime. Monthly precipitation data showed that irrigation was required from May to October.

There was good agreement between the observed air temperature and pan evaporation values. It was concluded that the relationship (Eq. $y = 0.193x - 1.520$) could be applicable as a practical indicator for estimating pan evaporation.

This simple approach may help to minimize the amount of irrigation water required for crop cultivation in Kabul, Afghanistan. It is important to conduct further research in Kabul and others provinces of Afghanistan to propose the best practice for estimating crop water requirements in field tests.

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