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GROUNDWATER STORAGE POTENTIAL IN DINABANDHU ANDREWS COLLEGE, GARIA, KOLKATA

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ABSTRACT

Groundwater storage becomes an important phenomenon in the current century throughout the entire globe. Basically, groundwater is the water stored deep beneath the earth's surface in underground aquifers and it is less vulnerable to pollution than surface water. Thus, it is an essential source for drinking water. But today, severe decline in water table due to anthropogenic activities becomes a critical problem particularly in the metropolitan cities with high population density. This water storage capacity primarily depends on the balance between precipitaion and evapotranspiration (ET). Various meteorological parameters like temperature, wind speed, humidity, solar radiation etc. have considerable impact on the groundwater storage. It is extremely necessary to understand the ET of the region before town and country planning. Rainwater harvesting is a common practice for groundwater recharge. In urban areas, water bodies like ponds and lakes may play a crucial role for groundwater storage. The present study focused on the role played by a pond as natural water harvesting system in an academic institution in Kolkata. FAO56 Penman-Monteith method has been extensively used for estimating reference evapotranspiration for the study area from 2011to 2016. The results indicate higher ET_0 during the summer season while higher water storage in the monsoon season. The months from June to September have considerably high water storage. 47.16 % of the total annual rainfall has been stored in the pond for the last five years continuously. It reflects a great potential of groundwater storage using natural rainwater harvesting system in the adjacent locality.

KEYWORDS: FAO56 Penman-Monteith Method, Groundwater Storage, Meteorological Parameters, Rainwater Harvesting, Reference Evapotranspiration

INTRODUCTION

Groundwater is recharged from, and eventually flows to, the surface naturally; natural discharge often occurs at springs and seeps, and can form oases or wetlands. Groundwater is also often withdrawn for agricultural, municipal, and industrial use by constructing and operating extraction wells. Groundwater primarily depends on precipitation and evapotranspiration. It is directly related to the occurrence of rainfall and inversely related to the evaporation and surface runoff. Geology, soil and natural vegetation play an important role in groundwater storage. Permeable rock with water retention capacity or aquifer is essential for groundwater recharge. Clay soil with high porosity provides obstruction in groundwater recharge. Grassland region has more potential for groundwater storage than dense forest due to its low rate of evapotranspiration.

Evaporation comprises an important part of the thermal balance occurring on the earth surface. It is also a part of water budget and the surface heat and water conditions are the determinants of formation of the surface ecological environment. Thus the study of evaporative capacity of the land is always one of the major problems in hydrology and geosciences (Ping et al., 2009). The rate of reference evapotranspiration is generally calculated from a reference surface where it is denoted as ET_0 but adequate amount of water is required there. Reference surface for the purpose is a hypothetical grass which is a reference crop with specific characteristics. With the help of ET_0, many research have been done like aridity/humidity conditions (Wu et al., 2006), ecosystem models (Fisher et al., 2005), estimation of rainfall-runoff and water use in agriculture (Allen, 2000; Hunsaker et al., 2002). The evapotranspiration of reference crop is found on the basis of the meteorological data and the calculation is given by FAO depending on the meteorological parameters and meteorological data.

Thus it is difficult to apply the method in the areas where there is lack of meteorological observation data, and recommended the use of evaporating pan observation data for determining the reference crop evapotranspiration by FAO (Allen et al., 1998). Various methods for empirical estimation of ET_0 requires proper and accurate measurements of different parameters like temperature, humidity, wind speed, sunshine, solar radiation etc. But measurement of all these parameters in a place is quite few particularly in any developing country. There are also local changes in ET_0 on the basis of distance from the weather station (Hubbard, 1994; Pielke et al., 2000) and proper integration of different climatic parameters are required which also affect the accuracy of ET_0 (Meek and Hatfield, 1994; Allen, 1996). Various methods for calculations are there among which pan evaporimeter and some ET models use only temperature and thus are less complex (Magliulo et al., 2003). The Hargreaves equation also needs only minimum and maximum temperature (Hargreaves and Samani, 1985) and extraterrestrial radiation (Droogers and Allen, 2002). Thus ET_0 can be measured by various models and methods by different weather parameters (Thornthwaite, 1948; Penman, 1948; Priestley and Taylor, 1972; Hargreaves, 1994; Hargreaves and Allen, 2003). Allen et al., (1998) developed a model for ET_0 which was published by the Food and Agriculture Organization of the United Nations as Penman–Monteith (FAO56-PM) by using a hypothetic reference crop which is approved for the arid and humid climatic conditions. A number of research works and applications on natural rainwater harvesting have been experienced in parts of South Indian states. A pond and its surroundings were considered for the current work which may be treated as a model study for further application. Present study involves the groundwater storage estimation through ET_0 computation and analysis of variation for the combined area of pond, play ground and shaded portion in the Dinabandhu Andrews College premises with parameters like minimum and maximum temperature, humidity, wind speed, sunshine hours and solar radiation for the last five years (2011 to 2016).

STUDY AREA

The study area is a pond lies in Dinabandhu Andrews College premises, Garia, Kolkata, India which extends from $22^0$28'04"N to $22^0$28'06"N latitude and from $88^0$22'41"N to $88^0$22'43"E longitude with an area of 1459.92 sq m. The total area including the shaded area and the ground area used to estimate the recharge the groundwater level beneath the surface of the pond is 4600 sq m. The climate is mostly humid and witnesses an annual average rainfall of 140.27 mm. The location map of the study area is presented in Figure 1.

A number of satellite data acquired to show the seasonal synoptic views of the pond and the adjacent parts of the Dinabandhu Andrews College Premises (Figure 2). The shaded area is made of asbestos and it is slightly inclined to the pond. Thus, there is an artificial runoff process observed over the asbestos shade. The ground is partially covered with grass and bordered by a number of trees. Moreover, the ground has a very gentle slope to the pond and there is a channels between the ground and the pond. Hence, the surface runoff water flows over the play ground is normally accumulated into the pond. Besides, the pond has no significant outlet or no domestic use.

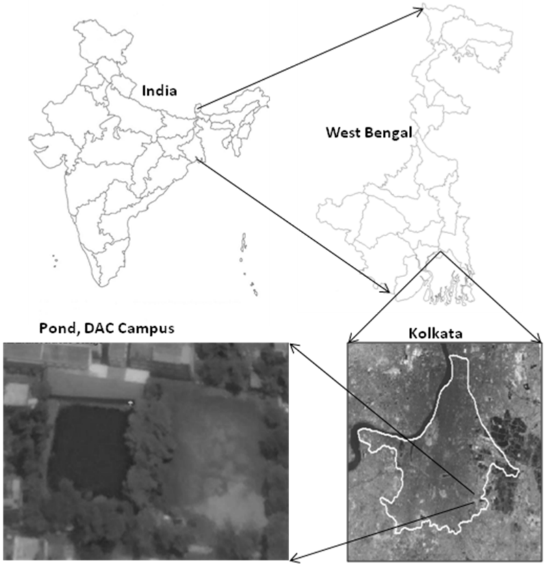


Figure1: Location of the Study Area

Figure 2: Multi-Temporal Satellite Imageries of Different Seasons Showing Pond, Play Ground and Shaded Area in Dinabandhu Andrews College Premises

MATERIALS AND METHODS

Estimation of ET_0 with Penman-Monteith Equation

For calculating the ET_0, climatic station in Kolkata was used in the study. Different climatic variables like rainfall, minimum and maximum air temperature, relative humidity, air pressure, wind speed and solar radiation of last five years (2011 to 2016) were considered. Average monthly datasets have been used for estimating the average monthly ET0 taken from the Water Development and Management Unit and the Climate Change and Bio-energy Unit of FAO, 2006.

The Penman-Monteith model was formulated on the basis of hypothetical green grass reference surface in which case the height of the grass is presumed to be 0.12m with a surface resistance of 70s m-1 and with an albedo of 0.23 (Allen et al., 1998). It has been approved by Food and Agriculture Organization (FAO- 56). Penman Monteith equations are given below in sequence:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

Where,

ET_o = reference evapotranspiration [mm day^{-1}]

R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}]

G = soil heat flux density [MJ m^{-2} day^{-1}]

T = mean daily air temperature at 2 m height [°C]

u_2 = wind speed at 2 m height [m s^{-1}]

e_s = saturation vapour pressure [kPa]

e_a = actual vapour pressure [kPa] e_s - e_a = saturation vapour pressure deficit [kPa]

Δ = slope vapour pressure curve [kPa $°C^{-1}$]

γ = psychrometric constant [kPa $°C^{-1}$]

ET_0 = reference evapotranspiration (mmd-1)

Slope of Saturation Vapour Pressure (Δ)

The slope of the relation between saturation vapour pressure and temperature Δ is required for calculating reference evapotranspiration. At a given temperature, the slope is given by:

$$\Delta = \frac{4098 e^{o}(T)}{(T + 237.3)^2} = \frac{2504 \exp\left(\frac{17.27T}{T + 237.2}\right)}{(T + 237.3)^2} \quad (2)$$

Where,

Δ = slope vapour pressure curve [kPa C^{-1}]

T = air temperature [°C]

e° (T) = saturation vapour pressure at temperature T [kPa]

Atmospheric Pressure (P)

$$P = 101.3\left(\frac{293 - 0.0065z}{293}\right)^{5.26} \quad (3)$$

Where,

P = atmospheric pressure (KPa)

Z = elevation above sea level (m)

Psychrometric Constant (γ)

$$\gamma = \frac{c_p P}{\varepsilon \lambda} \times 10^{-3} = 0.00163 \frac{P}{\lambda} \tag{4}$$

Where,

γ= psychrometric constant [kPa C^{-1}]

c_p = specific heat of moist air = 1.013 [kJ kg^{-1} °C^{-1}]

P = atmospheric pressure [kPa]

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

λ= latent heat of vaporization [MJ kg^{-1}]

Saturation Vapour Pressure (e_s)

As saturation vapour pressure is related to air temperature, it can be calculated from the air temperature. The relationship is expressed by:

$$e^{o}(T) = 0.611 \exp\left(\frac{17.27T}{T + 237.3}\right) \tag{5}$$

Where,

e°(T) = saturation vapour pressure function [kPa]

T = air temperature [°C]

Due to the non-linearity of the above equation, the mean saturation vapour pressure for a day, week, decade or month should be computed as the mean between the saturation vapour pressure at the mean daily maximum and minimum air temperatures for that period:

$$e_s = \frac{e^{o}(T_{max}) + e^{o}(T_{min})}{2} \tag{6}$$

3.1.5 Actual Vapour Pressure (e_a)

$$e_a = \frac{e^{o}(T_{min}) \frac{RH_{max}}{100} + e^{o}(T_{max}) \frac{RH_{min}}{100}}{2} \tag{7}$$

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]

RH_{max} = maximum relative humidity [%]

RH_{min} = minimum relative humidity [%]

Extraterrestrial Radiation for Daily Periods (R_a)

The extraterrestrial radiation, R_a, for each day of the year and for different latitudes can be estimated from the solar constant, the solar declination and the time of the year by:

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)] \quad (8)$$

Where,

R_a = extraterrestrial radiation [MJ m^{-2} day^{-1}]

G_{sc} = solar constant = 0.0820 MJ m^{-2} min^{-1}

d_r = inverse relative distance Earth-Sun

w_s = sunset hour angle [rad]

φ = latitude [rad]

δ= solar decimation [rad]

R_a is expressed in the above equation in MJ m^{-2} day^{-1}. The corresponding equivalent evaporation in mm day^{-1} is obtained by multiplying R_a by 0.408. The latitude, φ, expressed in radians is positive for the northern hemisphere and negative for the southern hemisphere.

Solar Radiation (R_s)

If the solar radiation, R_s, is not measured, it can be calculated with the Angstrom formula which relates solar radiation to extraterrestrial radiation and relative sunshine duration:

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a \quad (9)$$

Where,

R_s = solar or shortwave radiation [MJ m^{-2} day^{-1}]

n = actual duration of sunshine [hour]

N= maximum possible duration of sunshine or daylight hours [hour]

n/N = relative sunshine duration [-]

R_a = extraterrestrial radiation [MJ m^{-2} day^{-1}]

a_s = regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days

(n = 0)

a_s+b_s = fraction of extraterrestrial radiation reaching the earth on clear days (n = N)

Clear-Sky Solar Radiation (R_{so})

The calculation of the clear-sky radiation, R_{so}, when n = N, is required for computing net longwave radiation.

$$R_{so} = (a_s+b_s)R_a \quad \textbf{(10)}$$

When calibrated values for a_s and b_s are available

$$R_{so} = (0.75 + 2\ 10^{-5}z)\ Ra \quad \textbf{(11)}$$

When calibrated values for a_s and b_s are not available

3.1.9 Net Solar or Net Shortwave Radiation (R_{ns})

The net shortwave radiation resulting from the balance between incoming and reflected solar radiation is given by:

$$R_{ns} = (1-\alpha)\ Rs \quad \textbf{(12)}$$

Where,

R_{ns} = net solar or shortwave radiation [MJ m^{-2} day^{-1}]

α = albedo or canopy reflection coefficient, which is 0.23 for the hypothetical grass reference crop [dimensionless]

R_s = the incoming solar radiation [MJ m^{-2} day^{-1}]

Net Longwave Radiation (R_{nl})

The rate of longwave energy emission is proportional to the absolute temperature of the surface raised to the fourth power. This relation is expressed quantitatively by the Stefan-Boltzmann law. The net energy flux leaving the earth's surface is, however, less than that emitted and given by the Stefan-Boltzmann law due to the absorption and downward radiation from the sky. Water vapour, clouds, carbon dioxide and dust are absorbers and emitters of longwave radiation. Their concentrations should be known when assessing the net outgoing flux. As humidity and cloudiness play an important role, the Stefan-Boltzmann law is corrected by these two factors when estimating - the net outgoing flux of longwave radiation. It is thereby assumed that the concentrations of the other absorbers are constant:

$$R_{nl} = \sigma\left[\frac{T_{max}K^4 + T_{min}K^4}{2}\right]\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\frac{R_s}{R_{so}} - 0.35\right) \quad \textbf{(13)}$$

Where,

R_{nl} = net outgoing longwave radiation [MJ m^{-2} day^{-1}]

s = Stefan-Boltzmann constant [4.903 10^{-9} MJ K^{-4} m^{-2} day^{-1}]

$T_{max, K}$ = maximum absolute temperature during the 24-hour period [K = °C + 273.16]

$T_{min, K}$ = minimum absolute temperature during the 24-hour period [K = °C + 273.16]

e_a = actual vapour pressure [kPa]

R_s/R_{so} = relative shortwave radiation (limited to ≤ 1.0)

R_s measured or calculated. (Equation 35) solar radiation [MJ m^{-2} day^{-1}]

R_{so} calculated (Equation 36 or 37) clear-sky radiation [MJ m^{-2} day^{-1}]

Net Radiation (Rn)

The net radiation (R_n) is the difference between the incoming net shortwave radiation (R_{ns}) and the outgoing net longwave radiation (R_{nl}):

$$R_n = R_{ns} - R_{nl} \quad \textbf{(14)}$$

Where,

R_{ns} = incoming net shortwave radiation

R_{nl} = outgoing net longwave radiation.

Wind Speed (u_2)

For the adjustment of the wind speed data obtained from instrument which is placed at elevations other than the standard height of 2 m, following calculation is done:

$$u_2 = u_z \frac{4.87}{\ln(67.8z - 5.42)} \quad \textbf{(15)}$$

Where,

u_2 = wind speed at 2 m above ground surface [m s^{-1}],

uz = measured wind speed at z m above ground surface [m s^{-1}],

z = height of measurement above ground surface [m].

Soil Heat Flux (G)

Complex models are available to describe soil heat flux. Because soil heat flux is small compared to R_n, particularly when the surface is covered by vegetation and calculation time steps are 24 hours or longer, a simple calculation procedure is presented here for long time steps, based on the idea that the soil temperature follows air temperature:

$$G = c_s \frac{T_i - T_{i-1}}{\Delta t} \Delta z \quad \textbf{(16)}$$

Where,

G = soil heat flux [MJ m^{-2} day^{-1}]

c_s = soil heat capacity [MJ m^{-3} $°C^{-1}$]

T_i = air temperature at time i [°C]

T_{i-1} = air temperature at time i-1 [°C]

Δ t = length of time interval [day]

Δ z = effective soil depth [m]

As the soil temperature lags air temperature, the average temperature for a period should be considered when assessing me daily soil heat flux, i.e., Δ t should exceed one day. The depth of penetration of the temperature wave is determined by the length of the time interval. The effective soil depth, Δ z, is only 0.10-0.20 m for a time interval of one or a few days but might be 2 m or more for monthly periods. The soil heat capacity is related to its mineral composition and water content.

RESULTS & DISCUSSIONS

Different climatic variables of minimum and maximum temperature, humidity, wind speed, sunshine duration and radiation have been shown for 5 years from 2011 to 2016. The minimum temperature is highest in May-June up to September after which it started to decrease. The minimum temperature varies from 26.5^{0}C in May) to 13.8^{0}C in January. The average monthly maximum temperature is highest in the month of April and May with more than 35^{0}C and lowest in January and December (< 27^{0}C). The relative humidity is maximum from June to September (> 90%) while lowest humidity is found from February to March (< 66%). Wind speed is maximum from April to July. It varies from 69.1 km/day in October-January to 190.1km/day during April-May. The maximum and minimum sunshine hours varies from 8.19 hr/day in April when sky remains very clear to less than 4.8 hr/day during the monsoon period. The solar radiation is highest in April of around 21.8 $MJm^{-2}d^{-1}$ to around 14.85 $MJm^{-2}d^{-1}$ during December. Rainfall varies from 5.32 mm in December to 357.55 mm in August. Reference evapotranspiration (ET_0) has been calculated with the Penman-Monteith method in mm/day. The value of ET_0 is ranging between 2.52 in December to 5.24 in April and May (Figure 3).

The mean monthly ET_0 was calculated with help of FAO 56 Penman-Monteith method to show the variation of ET_0 in the study area which is an extremely important variable to be considered for groundwater storage. The result indicates that ET_0 is highest in the month of May (5.24 mm day^{-1}) to lowest in the month of December (2.52 mm day^{-1}). Mean monthly ET_0 of the area is 3.68 mm day^{-1}. To calculate the total water loss due to evapotranspiration, impact of crop coefficient (K_c) should be considered which varies with different land use and land cover types.

In the crop coefficient approach the crop evapotranspiration (ET_c) is calculated by multiplying the reference crop evapotranspiration, (ET_o) by a crop coefficient (K_c):

$$ET_c = K_c \times ET_0 \quad \textbf{(17)}$$

Where,

ET_c = crop evapotranspiration [mm d^{-1}]

K_c = crop coefficient [dimensionless]

ET_0 = reference crop evapotranspiration [mm d^{-1}]

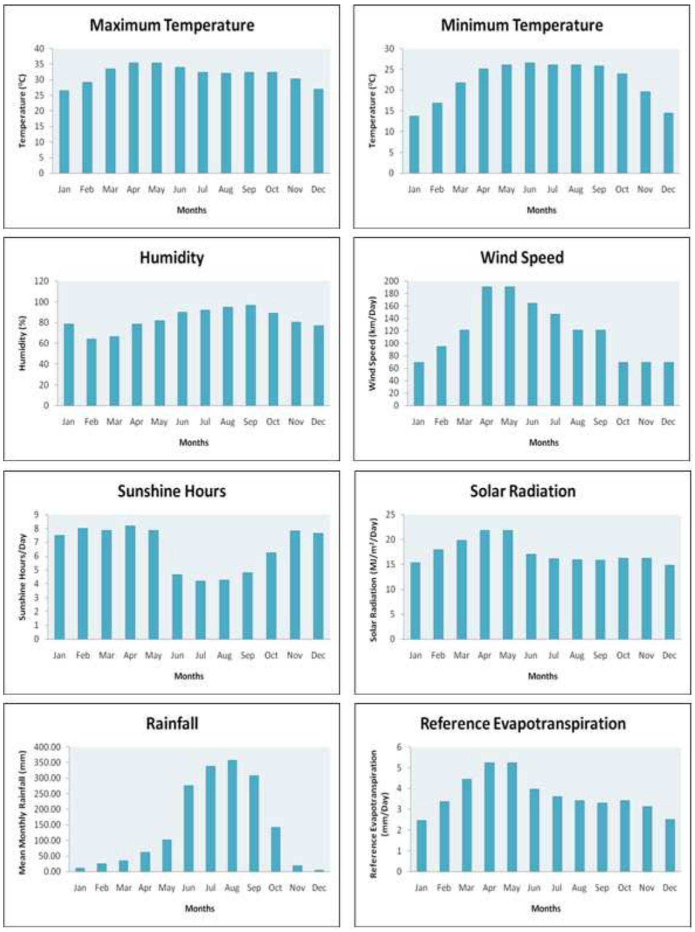
The soil surface wetness and the fraction of ground covered by vegetation influence the surface resistance, r_s. Following soil wetting, the vapour transfer rate from the soil is high, especially for crops having incomplete ground cover. The combined surface resistance of the canopy and of the soil determines the (bulk) surface resistance, r_s. The surface resistance term in the Penman-Monteith equation represents the resistance to vapour flow from within plant leaves and from beneath the soil surface.

In the present research work, values of K_c are considered as 1.05 for open water source of the pond, 0.4 for silty clay soil surface of the play ground and 0.1for the shaded area in the college premises. The annual actual water loss through evapotranspiration is estimated as 3618.72 cubic metre[(2056.9 cubic metre from pond) + (1517.38 cubic metre from play ground) + (44.44 cubic metre from shaded area)].

The play ground has mainly silty clay type of soil texture. It shows a low rate of infiltration (5-10 mm/hour) during heavy precipitation. This type of soil allows high rate of surface runoff. Apart from that, the ground has numerous channels through which water can move into the pond. Actually, this ground is considered as an inlet of the pond. Approximate 10% of the total volume of rainfall is infiltrated through the play ground.

The total volume of groundwater storage in the pond is computed as 3651.37 cubic metre per year. It means that the study area is annually recharged with 47.16% of the total annual precipitation. The results vividly indicate that the pond of the college premises may be considered as a highly effective groundwater recharge potential zone.

Figure 3: Pond Acts as a Natural Water Harvesting System (Dinabandhu Andrews College, Kolkata)



Source: Indian Meteorological Department

Figure 4: Average Monthly Climatic Variables (2011-2016)

CONCLUSIONS

The study involves the computation and analysis of one of the most important climatic variable, i.e. evapotranspiration for the computation of annual groundwater storage. This study shows the monthly ET variation which is very useful for analysis of variation in land use and land cover planning. The disparity of ET in different parts of the area indicates the potential of water storage by means of proper planning and conservation of water resources. It can solve the problem of water scarcity of the locality in the very near future. Dinabandhu Andrews College plays a major role in the groundwater storage through natural water harvesting technique and its proper conservation. FAO-56 Penman-Monteith method is a globally accepted and extremely important empirical model to calculate ET_0 which is also an important meteorological parameter. This research may be considered as a positive outset for the entire locality and the city to groundwater storage through natural harvesting.

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REFERENCES

1. X. Ping, C. Xiaohong and W. Zhaoli, Comparison of Actual Evapotranspiration and Pan Evaporation, *Acta Geographica Sinica 64(3)*, 2009, 270-277.
2. S.H. Wu, Y.H. Yin, D. Zheng and Q.Y. Yang, Moisture conditions and climate trends in China during the period 1971–2000, *International Journal of Climatology 26(2)*, 2006, 193–206.
3. J.B. Fisher, T.A. DeBiase, Y. Qi, M. Xu and A.H. Goldstein, Evapotranspiration models compared on a Sierra Nevada forest ecosystem, *Environmental Modelling and Software 20(6)*, 2005, 783–796.
4. R.G. Allen, Using the FAO-56 dual crop coefficient method over an irrigated region as part of an evapotranspiration intercomparison study, *Journal of Hydrology 229(1–2)*, 2000, 27–41.
5. D.J. Hunsaker, P.J. Pinter and H. Cai, Alfalfa basal crop coefficients for FAO-56 procedures in the desert regions of the southwestern US, *Journal of Translation ASAE 45(6)*, 2002, 1799–1815.
6. R.G. Allen, L.S. Pereira, D. Raes and M. Smith, Crop Evapotranspiration-Guidelines for Computing Crop Water Requirements. FAO Irrigation and drainage paper 56, United Nations Food and Agriculture Organization, Rome, 1998.
7. K.G. Hubbard,, Spatial variability of daily weather variables in the high plains of the USA, *Agricultural and Forest Meteorology, 68*, 1994, 29–41.
8. R.A. Pielke, T. Stohlgren, W. Parton, N. Doesken, J. Moeny, L. Schell and K. Redmond, Spatial representativeness of temperature measurements from a single site, *Bulletin of the American Meteorological Society AMS 81(4)*, 2000, 826–830.
9. D.W. Meek and J.L. Hatfield, Data quality checking for single station meteorological databases, *Agricultural and Forest Meteorology 69*, 1994, 85–109.
10. R.G. Allen, Assessing integrity of weather data for reference evapotranspiration estimation, *Journal of Irrigation and Drainage Engineering ASCE, 122(2)*, 1996, 97–106.
11. V. Magliulo, R. d'Andria and G. Rana, Use of the modified atmometer to estimate reference evapotranspiration in Mediterranean environments, *Agricultural Water Management 63*, 2003, 1–14.
12. G.H. Hargreaves and Z.A. Samani, Reference crop evapotranspiration from temperature, *Applied Engineering in Agriculture 1(2)*, 1985, 96–99.
13. P. Droogers and R.G. Allen, Estimating reference evapotranspiration under inaccurate data conditions, *Irrigation and Drainage Systems, 16*, 2002, 33–45.
14. C.W. Thornthwaite, An approach toward a rational classification of climate, *Geographical Review, 38*, 1948, 55–94. *Series a 193*, 1948, 454–465.
15. C.H.B. Priestley and R.J. Taylor, on the assessment of the surface of the heat flux and evaporation using large scale parameters, *Monthly Weather Review 100(2)*, 1972, 81–92.

16. H.L. Penman, Natural evaporation from open water, bare soil and grass, *Proceedings of the Royal Society of London Series A, 193*, 1948, 454–465.
17. G.H. Hargreaves, Defining and using reference evapotranspiration, *Journal of Irrigation and Drainage Engineering ASCE 120(6)*, 1994, 1132– 1139.
18. G.H. Hargreaves and R.G. Allen, History and evaluation of Hargreaves evapotranspiration equation, *Journal of Irrigation and Drainage Engineering ASCE, 129 (1)*, 2003, 53–63.