Global and Planetary Change 115 (2014) 16–23

Contents lists available at ScienceDirect

Global and Planetary Change

journal homepage: www.elsevier.com/locate/gloplacha

Sensitivity of evapotranspiration to climatic change in different climates

Hossein Tabari [a,*], P. Hosseinzadeh Talaee [b]

[a] Hydraulics Division, Department of Civil Engineering, KU Leuven, Kasteelpark Arenberg 40, BE-3001 Leuven, Belgium
[b] Young Researchers and Elite Club, Hamedan Branch, Islamic Azad University, Hamedan, Iran

ARTICLE INFO

Article history:
Received 8 July 2013
Received in revised form 28 August 2013
Accepted 14 January 2014
Available online 23 January 2014

Keywords:
Sensitivity analysis
Penman–Monteith equation
Percent change
Meteorological parameters
Climate type

ABSTRACT

This paper presents a study of the sensibility of evapotranspiration (ET) to climatic change in four types of climates (i.e., humid, cold semi-arid, warm semi-arid and arid). The use of a reference crop ET (ET_o) permits the standardization of ET estimates across varying conditions. So, ET_o was estimated with the FAO-56 Penman–Monteith equation using data from eight Iranian sites over a 41-year period (1965–2005). The sensitivity analyses were carried out for air temperature, wind speed and sunshine hours within a possible range of $\pm 20\%$ (i.e., -5%, -10%, -20%, $+5\%$, $+10\%$, $+20\%$) from the normal long-term climatic variables. The sensitivity of ET_o to the same climatic variables revealed significant differences among climates. From the comparison of the sensitivity of ET_o to climatic change in different climates, it can be inferred that the sensitivity of ET_o to wind speed and air temperature decreased from arid to humid climate, whereas its sensitivity to sunshine hours increased from arid to humid environment. Furthermore, the greatest change in ET_o (about $\pm 9\%$) was found in arid climate in response to ± 20 change in wind speed.

1. Introduction

The topic of climate change and its impacts have been a key research area in recent years and have attracted much attention of the researchers on various time and space scales in the world. Climate change can be defined as any systematic change in the long-term evolution describing the climate system that is sustained over several decades or longer (Gil-Alana, 2012). Generally, it has been demonstrated that global surface warming has been taking place at a rate of 0.74 ± 0.18 °C over the recent 100-year period (1906–2005) and the warming rate over the last 50 years of this period is almost twice that of the 100-year period (IPCC, 2007).

One major challenge of recent hydrological modeling activities is the assessment of the effects of climate change on the terrestrial water cycle (Bormann, 2011). Climate changes have exerted significant impacts on hydrological parameters, viz. runoff, evapotranspiration (ET), soil moisture, ground water etc. (Goyal, 2004; Yin et al., 2010). Evapotranspiration as the major component of hydrological cycle is influenced by several climatic parameters, viz. air temperature, wind speed, humidity, sunshine hours etc. Any change in climatic parameters due to global warming will affect ET (or crop water requirement) and future planning and management of water resources (Goyal, 2004).

As one of the most important hydrological parameters for scheduling irrigation plan, preparing input data for hydrological water-balance models, and computing actual ET for a watershed, reference evapotranspiration (ET_o) has received a great deal of attention from many international research programmes, e.g. World Climate Research Programme (WCRP), International Geosphere-Biosphere Programme (IGBP), International Human Dimensions Programme on Global Environmental Change (IHDP) and United Nations Educational, Scientific and Cultural Organization (UNESCO) (Liang et al., 2008).

A sensitivity analysis of ET_o to perturbations (all sorts of data errors or, actual climatic changes) associated with one or more climatic variables is important to improve our understanding of the connections between climatic conditions and ET_o variability, and between data availability and estimation accuracy of ET_o (Gong et al., 2006). Results of sensitivity analyses make it possible to determine the accuracy required when measuring climatic variables used to estimate ET_o (Irmak et al., 2006). Several studies of the sensitivity of ET_o have been made to determine the expected change in ET_o in response to a known change in one of the climatic variables (e.g., Ley et al., 1994; Rana and Katerji, 1998; Irmak et al., 2006; Bormann, 2011). Goyal (2004) studied the sensitivity of ET_o to global warming for arid regions of Rajasthan, India. The Penman–Monteith equation was used to estimate ET_o, and sensitivity of ET_o has been investigated in terms of change in temperature, wind speed, vapor pressure and solar radiation within a possible range of $\pm 20\%$ from the normal long-term meteorological parameters of 32 years (1971–2002). The results showed that ET_o is less sensitive to change in net solar radiation, followed by wind speed and vapor pressure in comparison to temperature. Gong et al. (2006) carried out a sensitivity analysis to predict responses of ET_o estimated by the FAO-56 Penman–Monteith equation to perturbations of air temperature, wind speed, relative humidity and sunshine duration in Yangtze River basin in China. ET_o was estimated with the FAO-56 Penman–Monteith equation. They found that relative humidity was the most sensitive variable, followed by shortwave radiation, air temperature and wind speed.

* Corresponding author. Tel.: +32 16 321174; fax: +32 16 321989.
E-mail address: tabari.ho@gmail.com (H. Tabari).

0921-8181/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.gloplacha.2014.01.006

Table 1
Geographic and climatic characteristics of the study stations.

Station	Latitude (N)	Longitude (E)	Altitude (m)	T (°C)	U (m/s)	n (hr)	ET_o (mm/day)	Climate type
Zahedan	28 29	53 60	1370	18.47	3.19	9.26	5.91	Arid
Yazd	54 31	17 54	1237	19.22	2.59	9.28	5.58	Arid
Shahroud	25 36	57 54	1345	14.64	2.02	8.12	3.92	Warm semi-arid
Semnan	35 35	33 53	1131	18.12	1.37	8.20	3.91	Warm semi-arid
Oroomieh	32 37	05 45	1316	11.22	1.55	7.90	3.10	Cold semi-arid
Tabriz	05 38	17 46	1361	12.59	3.03	7.56	4.18	Cold semi-arid
Rasht	15 37	36 49	−7	15.99	1.20	4.59	2.31	Humid
Bandar-Anzali	28 37	28 49	−26	16.22	3.81	4.92	2.36	Humid

T: Air temperature; U: Wind speed; n: Sunshine hours.

Liang et al. (2008) examined the sensitivity of ET_o to four climate variables of air temperature, wind speed, relative humidity and sunshine hours in Tao'er River Basin of the northeastern China. They showed that relative humidity variable was the most sensitive one in general for the Tao'er River Basin, followed by sunshine hours, wind speed and air temperature. Estevez et al. (2009) analyzed the sensitivity of ET_o values to temperature, relative humidity, solar radiation and wind speed in the semi-arid regions of southern Spain. According to their results, ET_o overestimations were produced using positive errors in temperature, solar radiation and wind speed data, while these errors in relative humidity resulted in ET_o underestimations. Furthermore, the sensitivity of ET_o to the same climatic variables showed significant differences among locations. Ali et al. (2009) studied the sensitivity of the ET_o calculated by the FAO Penman–Monteith equation under the environment of a semi-humid sub-tropic region of Bangladesh. The results indicated that the ET_o estimates are most sensitive to maximum temperature, relative humidity, sunshine duration, wind speed and minimum temperature, respectively.

Iran, mainly an agrarian society is seriously vulnerable to the anthropogenic-induced climate change as most of the geographical area falls under the arid and semi-arid type of climate (Dinpashoh et al., 2011). Changes in climatic regimes due to warming of the earth-atmosphere system may affect agricultural water demand, because ET may be affected by changes in climatic variables (Tabari et al., 2012). It seems very likely that any change in the availability of water will play a key role in the sustainable development of agriculture and environment in Iran (Dinpashoh et al., 2011). In addition, there has been much discussion recently about virtual water trade and the links between hydrology and food security. Iran is considered a highly food insecure nation, largely due to the poor water resources available (Tabari et al., 2012). Thus, assessment of climate change impacts on ET variability can be helpful in determining appropriate adaptation strategies for mitigating the probable damage from these impacts (Shadmani et al., 2012).

The previous researches were limited to a one type of climate, and the studies on the sensitivity of ET_o to climatic variables under different climatic conditions are rare in the literature. Thus, this research was conducted in the context of an on-going project to analyze the sensitivity of the ET_o values estimated by the FAO Penman–Monteith equation to climatic change under four climate conditions viz., humid, cold semi-arid, warm semi-arid and arid. For this purpose, the sensitivity of ET_o was investigated in terms of change in air temperature, wind speed and sunshine hours within a possible range of ±20% from the normal long-term climatic variables over a 41-year period (1965–2005).

2. Data and methods

Iran, with an area of more than 1,648,000 km^2, is located in the southwest of Asia (approximately between 25°00′ N and 38°39′ N latitudes and between 44°00′ E and 63°25′ E longitudes). The two highest mountain systems, the Alborz and the Zagros and two great deserts called Dasht-e Lut and Dasht-e Kavir strikingly affect the climate of Iran. The Alborz and north Zagro Mountains make up the major northern highlands of the country. The Mediterranean-type climate is dominant over the foothills of these ranges, but most of the country is classified as arid or semi-arid according to various climate classifications.

The meteorological parameters for calculating ET_o by the Penman–Monteith method were obtained from eight stations located in four climatic regions for the period 1965–2005. The meteorological data were provided by the Islamic Republic of Iran Meteorological Organization (IRIMO). The selected stations are located in different climates. According to the Koppen climate classification, Zahedan and Yazd weather stations are in arid climate, Semnan and Shahroud weather stations in warm semi-arid climate, Tabriz and Oroomieh weather stations in cold semi-arid climate and Bandar-Anzali and Rasht weather stations in humid climate (which located on the southern cost of the Caspian Sea). The geographic and climatic characteristics of the selected stations are presented in Table 1.

The International Commission for Irrigation and Drainage (ICID) and Food and Agriculture Organization of the United Nations (FAO) have proposed using the Penman–Monteith method as the standard method for estimating ET_o (Allen et al., 1994a,b). In addition, numerous researchers have accepted this model as the most precise for estimating ET_o in various climates throughout the world (e.g., Trajkovic et al., 2003; Garcia et al., 2004; Popova et al., 2006; Sabziparvar et al., 2010; Sentelhas et al., 2010; Tabari, 2010; Tabari and Hosseinzadeh Talaee, 2011; Tabari et al., 2013). The Penman–Monteith method assumes the ET_o as that from a hypothetical crop with an assumed crop height (0.12 m) and a fixed canopy resistance (70 sm^{-1}) and albedo (0.23), closely resembling the evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, and not short of water, which is given by Allen et al. (1998) as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_{mean} + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

Table 2
Sensitivity of ET_o to climatic change in arid climate.

Station	Climatic variables	Change in ET_o (%) with respect to change in climatic variables					
		−20%	−10%	−5%	+5%	10%	20%
Yazd	T	−6.36	−3.20	−1.49	2.08	3.98	7.99
	U	−8.94	−4.25	−1.99	2.43	4.56	8.74
	n	−1.90	−0.83	−0.30	0.79	1.32	2.23
Zahedan	T	−5.36	−2.63	−1.19	1.83	3.41	6.73
	U	−8.58	−4.05	−1.85	2.40	4.43	8.40
	n	−2.22	−0.96	−0.34	0.93	1.54	2.65
Average	T	−5.86	−2.92	−1.34	1.96	3.70	7.36
	U	−8.76	−4.15	−1.92	2.42	4.50	8.57
	n	−2.06	−0.90	−0.32	0.86	1.43	2.44

T: Air temperature; U: Wind speed; n: Sunshine hours.