American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-6, Issue-3, pp-197-201
www.ajer.org
Research Paper Open Access

Analysis of Reference Evapotranspiration under Climate Change Conditions in The Lerma-Chapala Basin, Mexico

Gerardo Núñez-González
(Engineering Department, University Center of the South Coast/University of Guadalajara, Mexico)

ABSTRACT: *Evapotranspiration is one of the main factors determining the crop water requirements. Evapotranspiration depends on climate conditions, which suggest that under climate change conditions, it can increase in the future threatening the satisfaction of the crop water needs especially in the case of rainfed agriculture. In this manner, the objective of the study was to analyze the behavior of the reference evapotranspiration (ETo) in the Lerma-Chapala basin using the FAO Penman-Monteith method and then evaluates the sensitivity of ETo to changes in the climate conditions as predicted by global circulation models. Results show that during the rainy season the evapotranspiration in the Lerma-Chapala basin is highly variable, showing a decreasing pattern from May to September. Sensitivity analysis showed that ETo is very sensitive to increases in temperature and radiation as well as to decrease in air humidity. Impacts on ETo due to simultaneous changes in the behavior of multiple variables are greater than that observed when only presents an increase in temperature. Therefore, it could be expected that under the climate change conditions predicted for the study area at the end of this century, a higher evapotranspiration could be observed.*

Keywords: *climate change, evapotranspiration, FAO-Penman-Monteith method, temperature scenarios*

I. INTRODUCTION

Agriculture is by far the largest land use worldwide, where rainfed agriculture dominates, accounting for 80% of cultivated land, while the remaining 20% is under irrigation [1]. Rainfed agriculture is mainly dependent in the quantity and distribution of rainfalls which are considered as the major limiting factors for increasing the crop production [2]. Low yields are obtained when the rainfall volume is less than crop requirements. In practice, crop water demand is calculated based on the crop evapotranspiration (ETc) which is commonly obtained through the reference evapotranspiration and one crop coefficient [3]. ETo can be obtained by many estimation methods, however the Penman-Monteith is the standard method recommended by FAO [4]. FAO Penman-Monteith method is dependent on radiation, temperature, soil heat flux, humidity and wind speed which make it difficult to apply mainly in developing countries where the low availability of complete climate datasets is present. In Mexico, since the late 90s the National Weather Service has promoted the installation of an automatic weather station network in order to improve climatic databases. Thus, to date, the National Weather Service has installed 133 automatic weather stations and 44 automatic meteorological synoptic stations. This represents a major step forward in climate monitoring because in most cases records are ten or more years.

Since the publication of the First Assessment Report of the Intergovernmental Panel on Climate Change in 1990, global warming has become familiar to many people as one of the most important issues of concern of our days [5]. According to several studies, an increase in global air temperature between 0.4 and 0.8ºC has occurred since the late 19^{th} century [6]. In Latin America, changes in climate during the last century showed an increase in the mean temperature, particularly in medium and high latitudes [7]. The climate of Mexico is influenced both by, the position and strength of the subtropical high pressure systems of the North Atlantic and the North East Pacific oceans, and the location of the inter-tropical convergence zone lying to the south of the country [8], which makes it highly vulnerable to climatic variability. Global climatic changes will affect agriculture through their direct and indirect effects on crops, soils, livestock and pests [9]. Global studies have indicated a loss of 5–40% of cereal production by 2100 due to global warming, threatening the food security of several countries [10]. The Lerma-Chapala basin is located in the central western part of Mexico and partly covers five states: State of Mexico, Queretaro, Michoacan, Guanajuato and Jalisco. The basin has an area of 53,591 km^2. The average historic annual precipitation in the basin is about 725 mm. Average monthly temperatures vary from 14.6°C in January to 21.3°C in May. The basin is the homeland of a dynamic agricultural sector including both rainfed and irrigated agriculture. The main crops grown under rainfed conditions are maize, sorghum and beans, being the most predominant the maize which is considered as basic in the population diet. Recently, publications such as the National Water Program 2007-2012 [11] have stated that Lerma-Chapala basin could be one of the most vulnerable basins in Mexico by climate change. Some of the expected effects over this basin includes an increase of the mean temperature and a decrease of the annual average precipitation [12]. Knowledge of the potential impacts of climate change on agriculture can be a useful tool in the planning of mitigation measures for government and policy makers in order to avoid negative impacts on the population, especially in the case of rainfed agriculture, which produces most food for poor communities [13]. Therefore, the objective of the study was to analyze the behavior of the reference evapotranspiration (ETo) in the Lerma-Chapala basin using the FAO Penman-Monteith method and then evaluates the sensitivity of ETo to changes in the climate conditions as predicted by global circulation models.

II. MATERIALS AND METHODS

Climatic data series for a period of ten years from 2000 to 2010 including daily minimum and maximum temperature, radiation, pressure, relative humidity and wind speed were obtained from five automatic weather stations located inside the Lerma-Chapala basin (Table 1) through the National Weather Service. The climatic series were divided in order to take into account for the calculations only the rainy station which covers from May to September. The analysis under climate change conditions was based in the database of the regionalized scenarios for Mexico. They were retrieved from the Information System of Regionalized Climate Change Scenarios generated by the Coordination of Climate Change Program of National Institute of Ecology. The expected average temperature rise at the end of this century for each of the climate change scenarios are presented in Table 1. A detailed description of each scenario can be founded in [14] and [15].

Reference evapotranspiration was calculated according to FAO Penman-Monteith method which is expressed as (Allen et al., 1998):

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

where ETo is the reference evapotranspiration (mm/day), Rn the net radiation at the crop surface (MJ/m^2/day), G soil heat flux density (MJ/m^2/day), T mean daily air temperature (°C), u_2 wind speed (m/s), e_s the saturation vapor pressure (kPa), e_a the actual vapor pressure (kPa), Δ is the slope vapor pressure curve (kPa/°C) and γ the psychrometric constant (kPa/°C).

The sensitivity analysis used in this research is linearized and relative because it is based only on the linear terms of the Taylor series expansion of the ETo equation and because each component of the sensitivity equation was made dimensionless to make valid comparisons of the results [16]. In order to study the sensitivity of reference evapotranspiration it was established a base scenario which consisted in the observed mean monthly values of the climatic variables. Thus, once the reference evapotranspiration for the base scenario was calculated using FAO Penman-Monteith method, it was changed the values of the main variables in the formulae, in this case the variables changed were: temperature, radiation, relative humidity and wind speed. The range of variation considered for changes in a single variable consisted in a rise of up to 25% from the base condition for temperature, radiation and wind speed while in the case of relative humidity a decrease of up to 25% from the base condition was considered. Simultaneous changes in multiple variables differed from changes in a single variable only in the range of variation which ranged from 0 to 20%. The definition of the variation in the variables of ETo was based on the expected scenarios of Climate Change for the study area.

Table 1 Weather stations selected for the study and projection of temperature increase

Station	Latitude (ºN)	Longitude (ºW)	Altitude (m.a.s.l.)	A2 (ºC)	A1B (ºC)	B1 (ºC)	Committed (ºC)
Angamacutiro	20º07'31"	101º43'21"	1730	3.7	3.0	2.0	0.9
Atlacomulco	19º47'30"	99º52'11"	2600	3.7	2.8	1.9	1.0
Chapala	20º17'25"	103º12'06"	1493	3.8	3.0	1.9	1.1
Huimilpan	20º23'24"	100º17'00"	2280	3.5	2.7	1.8	1.0
Presa Allende	20º50'54"	100º49'33"	1915	3.6	2.8	1.9	1.0

III. RESULTS AND DISCUSION

III.1 REFERENCE EVAPOTRANSPIRATION (SCENARIO BASE)

The reference evapotranspiration (ETo) obtained with data from five weather stations located in the Lerma-Chapala basin showed a similar behavior. Greater differences were founded for Atlacomulco weather station (Table 2). In the obtained results it can be appreciated that in average ETo oscillates between 0.1 and 9.95 mm/day. These values are in concordance with the results obtained by [17] and [18] near the study area. The observed values also show a good agreement with those reported for arid and semiarid regions with moderate climate and warm climate by [19]. The comparison of the results for each station on a daily base show statistical significant differences between the stations ($p < 0.05$) with the exception of the stations of Chapala and Huimilpan.

Table 2 Descriptive statistics for daily mean evapotranspiration

Weather station	Range (mm/d)	Min (mm/d)	Max (mm/d)	Mean (mm/d)	Std. deviation (mm/d)	Variation Coef.
Angamacutiro	10.54	0.00	10.54	3.7532	1.77541	0.473
Atlacomulco	8.17	0.01	8.18	2.6579	1.57602	0.593
Chapala	10.56	0.01	10.57	3.4408	1.69678	0.493
Huimilpan	10.36	0.01	10.37	3.2969	1.77412	0.538
Presa Allende	10.06	0.02	10.08	3.9732	1.73415	0.436

On the other hand, on a monthly base, the behavior through the rainy season shows a gradual decrease in ETo from May to September, which accounts in average between 60 and 75% of the quantities observed at the beginning of the rainy season (Fig. 1). According to [20], the evapotranspiration has three necessary requisites: availability of water, availability of energy to drive the phase change of the water, and a moisture deficit in the air. In this manner, the observed reduction in ETo could be attributed to the progresses of the rainy season which generates an increase in the air humidity, decreasing thus the moisture deficit of the air, and an decrease in the available energy due to the cloudiness. In this way, the results show that ETo is highly sensible to changes in the availability of energy and in the moisture deficit.

III.2 SENSITIVITY ANALYSIS

The results of the sensitivity analysis for a single variable show that radiation is the most sensitive parameter followed by temperature and relative humidity, as is illustrated in Table 3 as an example for the station Huimilpan. This behavior is in concordance with the results obtained by [21] and [22] in sensitivity analysis of ETo carried out in Spain and Iran, respectively. Figure 2 shows the expected change in ETo due to the change in temperature as predicted for the scenarios: committed, B1, A1B y A2. These results show an increase in ETo ranging in average from 3.1 to 14.4% for the weather station Huimilpan. In the same figure it is observed that the increases in ETo are dependent on the scenario of greenhouse gases emission as well as the month under consideration. The analysis at monthly level shows that the higher increments are founded at the end of the rainy season due to an increase in the availability of energy to drive the evapotranspiration process. In the same manner, based on the climate change scenarios, the higher change in ETo is due to the scenario A2 which according to the Intergovernmental Panel on Climate Change contemplates a very heterogeneous world where the underlying theme is self-reliance and preservation of local identities with fertility patterns across regions converge very slowly, which results in continuously increasing global population where economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines. A1B and B1 scenarios in turn show a lower change than that caused by A2 scenario; however, they remain higher than expected according to the scenario of commitments to reduce emissions of greenhouse gases.

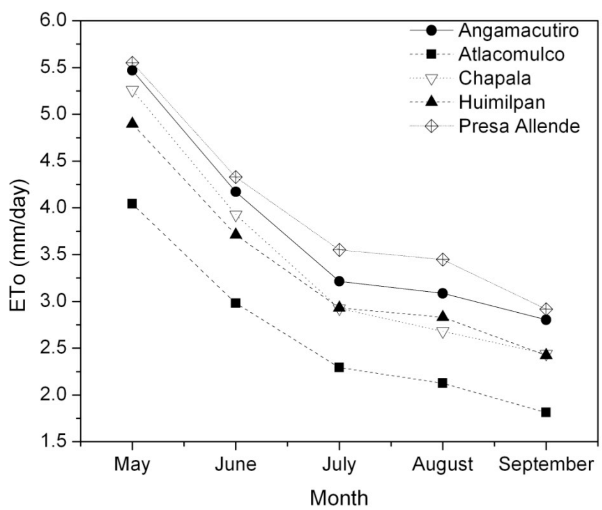

Fig. 1 Mean monthly evapotranspiration for the rainy station in the study site

Table 3 Gradient of linear relationship between ETo and climatic variables for station Huimilpan

Month	Slope			
	Radiation	Temperature	Humidity	Wind Speed
May	0.984	0.645	-0.256	0.063
June	1.077	0.674	-0.537	-0.077
July	1.780	0.736	-1.632	-0.679
August	1.451	0.680	-0.949	-0.385
September	1.739	0.821	-1.724	-0.616

Sensitivity to changes in multiple variables is showed in Table 4. This table presents the results for the months of May, July and September of four comparisons which contemplate simultaneously: 1) an increase in temperature and radiation, 2) an increase in temperature and a decrease in relative humidity, 3) an increase in temperature and wind speed, and 4) an increase in temperature and radiation, and a decrease in relative humidity. According to the comparisons, it is observed that the largest changes in ETo are presented with a combination of a greater availability of energy and a higher moisture deficit, which is in concordance with the expected climate behavior for the study area. In the same manner, it can be appreciated that the major impacts are observed at the end of the rainy season which can threatening the final stage of the crops. At the same time, it can be appreciated that the impacts on ETo due to simultaneous changes in the behavior of multiple variables is greater than that observed when only presents an increase in only one variable.

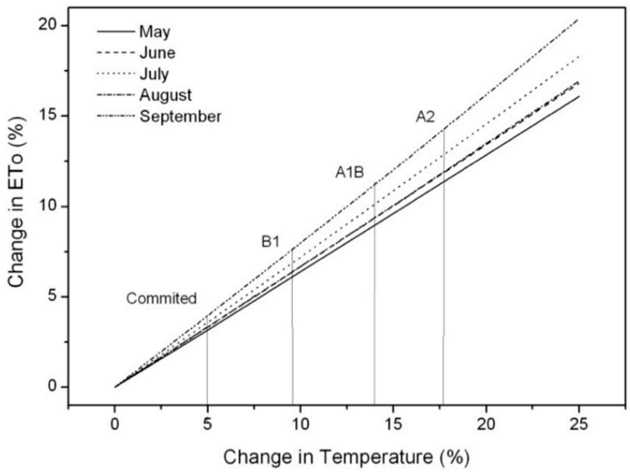

Fig. 2 Sensitivity of ETo to the changes projected in temperature for station Huimilpan

Table 4. Percentage of change in ETo due to an increase in multiple climatic parameters.

Test	Change in				Change in ETo		
	Temperature	Radiation	Humidity	Wind Speed	May	July	September
1	5	5	0	0	8.2	12.2	13.7
1	10	10	0	0	16.7	25.2	26.8
1	15	15	0	0	25.3	38.7	40.4
1	20	20	0	0	34.1	52.4	54.3
2	5	0	-5	0	4.5	7.7	12.2
2	10	0	-10	0	9.1	23.7	25.1
2	15	0	-15	0	13.6	36.3	38.3
2	20	0	-20	0	18.2	49.2	52.2
3	5	0	0	5	3.6	-0.4	1.7
3	10	0	0	10	7.3	-0.4	2.3
3	15	0	0	15	11.2	-0.3	2.9
3	20	0	0	20	15.2	-0.2	4.0
4	5	5	-5	0	9.8	20.7	22.9
4	10	10	-10	0	19.4	41.8	45.5
4	15	15	-15	0	29.2	64.5	67.6
4	20	20	-20	0	39.5	86.9	91.8

IV. CONCLUSION

According to the results, it was observed that during the rainy season the evapotranspiration in the Lerma-Chapala basin is highly variable, showing a decreasing pattern from May to September, decreasing between 60 to 75% of the observed value at the beginning of the season. Sensitivity analysis showed that ETo is very sensitive to increases in temperature and radiation as well as to decrease in air humidity. Impacts on ETo due to simultaneous changes in the behavior of multiple variables are greater than that observed when only presents an increase in temperature. Therefore, it could be expected that under the climate change conditions predicted for the study area at the end of this century, a higher evapotranspiration could be observed, threatening the satisfaction of the crop water needs especially in the case of rainfed agriculture. However, it is recognized the need of more research to understand how the evapotranspiration could be affected not only by climatic variables but also for plant physiology parameters.

REFERENCES

[1] J Rockström, Water for food and nature in drought-prone tropics: vapor shift in rain-fed agriculture. Phil. Trans. R. Soc. Lond. B, 358, 2003, 1997-2009.
[2] HO Ogindo and S Walker, Comparison of measured changes in seasonal soil water content by rainfed maize-bean intercrop and component cropping systems in semi-arid region of southern Africa, Phys. Chem. Earth, 30, 2005, 799-808.
[3] RG Allen, LS Pereira, D Raes and M Smith, Crop evapotranspiration, guidelines for computing crop water requirements, Irrigation and Drainage Paper No. 56 (FAO, Rome Italy, 1998).
[4] YM Wang, S Traore and T Kerh, Applying evapotranspiration reference model and rainfall contribution index for agricultural water management plan in Burkina Faso, Afr. J. Agric. Res, 4, 2009, 1493-1504.
[5] J Houghton, Global Warming, Reports on Progress Physics, 68, 2005, 1343-1403.
[6] IPCC, Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, (Metz et al. (eds), Cambridge University Press, Cambridge, 2007).
[7] IETCC, Regional impacts of Climate Change: Vulnerability assessment in Latin America, (Intergovernmental Expert Team on Climate Change, 2000).
[8] B Mendoza, V García-Acosta, V Velasco, E Jáuregui and R Díaz-Sandoval, Frequency and duration of historical droughts from the 16th to the 19th centuries in the Mexican Maya lands, Yucatan Peninsula, Climatic Change, 83, 2007, 151-168.
[9] PK Aggarwal, Determinants of crop growth and yield in a changing climate (Wani et al. (eds) Rainfed Agriculture: Unlocking the Potential, CAB International, UK, 2009).
[10] WE Easterling, PK Aggarwal, P Batima, KM Brander, L Erda, SM Howden, A Kirilenko, J Morton, JF Soussana, J Schmidhuber and FN Tubiello, Food, fibre and forest products. (Parry et al. (eds) Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 2007).
[11] MENR, National Water Program 2007-2012 (Ministry of Environment and Natural Resources, Mexico, 2008).
[12] V Magaña, C Conde, O Sánchez and C Gay, Assessment of current and future regional climate scenarios for Mexico, Climate Research, 9, 1997, 107-114.
[13] SP Wani, TK Sreedevi, J Rockström and YS Ramakrishna, Rainfed agriculture – Past trends and future prospects (Wani et al. (eds) Rainfed Agriculture: Unlocking the Potential, CAB International, UK, 2009).
[14] V Magaña and E Caetano, Seasonal climate forecast regionalized to Mexico as an element for risk reduction, to identify options for adaptation to climate change and the system power: climate change by state and sector (National Autonomous University of Mexico, 2007).
[15] IPCC, Emissions Scenarios: Summary for Policymakers. Special Report of IPCC Working Group III (Nakicenovic et al. (eds), Cambridge University Press, Cambridge, 2000).
[16] RH McCuen, Modeling hydrologic change: statistical methods (Lewis Publishers, 2003).
[17] E González-Sosa, CA Mastachi-Loza, JB Rivera-Vázquez, A Gutiérrez-López, J Lafragua and A Guevara-Escobar, Evaporation in the Lake Patzcuaro watershed, Mexico, Water Technology and Sciences, I, 2010, 51-69.
[18] RC Vásquez-Méndez, E Jr Ventura-Ramos and JA Acosta-Gallegos, Suitability of evapotranspiration estimation methods for semiarid central Mexico, Revista Mexicana de Ciencias Agrícolas, 2, 2011, 399-415.
[19] A Rahimikhoob, Estimation of evapotranspiration based on only air temperature data using artificial neural networks for a subtropical climate in Iran, Theor. Appl. Clim, 101, 2009, 83-97.
[20] P Martin, NJ Rosenberg and MS McKenney, Sensitivity of evapotranspiration in a wheat field, a forest, and a grassland to changes in climate and direct effects of carbon dioxide, Climatic Change, 14, 1989, 117-151.
[21] J Estévez, P Gavilán and J Berengena, Sensitivity analysis of Penman-Monteith type equation to estimate reference evapotranspiration in southern Sapin, Hydrological Processes, 23, 2009, 3342-3353.
[22] B Bakhtiari and AM Liaghat, Seasonal sensitivity analysis for climatic variables of ASCE-Penman-Monteith model in semi-arid climate, J. Agr. Sci. Tech., 13, 2011, 1135-1145.