ISO 9001 - 2015

ISSN 2349 - 4891

Monthly

IJRRAS

IF
4.665

Volume 4,Issue 9, September 2017

International Journal of Recent Research and Applied Studies

SURRAGH PUBLICATIONS
SURRAGH PUBLICATIONS

Original Article

ISSN: 2349 - 4891

International
Journal of Recent Research and Applied Studies
(Multidisciplinary Open Access Refereed e-Journal)

Possible Scenarios of Global Climate Change Impacts on the Evaporation in Northwestern Mexico Basins

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Received 28th July 2017, Accepted 11th August 2017

Abstract

We constructed five possible scenarios, with an increase of 1°C above current conditions and up to 5°C, to define the possible impacts of global climate change on evaporation and soil water moisture content deficiency in the selected Northwestern Mexico basins, based on forecasts of the Hadley Centre. We constructed five possible scenarios for two cover surfaces: water and short grass. In these scenarios, the evaporation will increase between 2.1% and 15%.The evaporation of short grass surfaces will increase between 2.2% and 15.5%.Soil water moisture content deficiency will increase between 4.1% and 35%, all of these compared with the current values. In this study, we observed that the forecasted increases in the annual rainfall in the basins that we analyzed, has a modest contribution in reducing the potential evaporation in the Northwestern Mexico basins. In the most adverse scenario, reductions in food production will be in the order of 31%, composed by a need for 15.5% of additional water that the crops will require for their growth and an additional 15% of potential evaporation coming from existing water surface storages. These results indicate an urgent implementation of measures to mitigate the adverse effects of global climate change impacts in the Northwestern Mexico basins.

Keywords: Global climate change, potential evaporation, soil water moisture content deficiency, water, short grass, reduction of food production.

Introduction

Global climate change is occurring, mainly by the increase of global warming that is being produced by the so-called greenhouse gases (GHG), which are mainly water vapor, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (NO), the last three have increased in their concentrations at dangerous levels since the Industrial Revolution that occurred in the mid-nineteenth century. Water vapor, the most abundant of the GHG so far, is the one that has had the most beneficial effects on Planet Earth, given that its contribution made the average global temperature beat 14 °C and not -18 °C in the absence of GHG effects existing in the upper atmosphere. The GHG produced by anthropogenic activities are the main sources, which in consequence is causing global warming and therefore the main cause of global climate change (IPCC 2014; and Showstack, 2009).

Gosling et al (2017) has produced scenarios for comparison of changes in river runoff from multiple global and catchment-scale hydrological models under global warming scenarios of 1 °C, 2 °C and 3 °C.

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Unfortunately, global climate change had been losing weight in the public policies of the actual Mexican government, even though it was originally included as part of the National Development Plan 2013-2018 (Presidencia 2013). It does not have the same prominence as in the previous six years; despite of the great importance it represents, since it has a considerable impact on the food economy, tourism and environmental conservation, among others. To promote a good quality of life for Mexican society, it is required the implementation of new strategies that contribute to improving the environment and thus mitigate the increase of the adverse effects of global climate change.

Moreover, not much progress was made in the right direction relating to global climate change, although in the previous administration, a chapter with regard to global climate change was included as part of the National Development Plan 2007-2012 (Presidencia 2007). The objective 11, paragraph 4.6 (Climate Change) Chapter 4 (Environmental Sustainability) was established. This objective stated: "Promote measures to adapt to the effects of climate change." With the following goal: "To address the effects of climate change will be necessary to develop preventive and response capabilities for foreseeable adverse impacts. These include the generation of information and knowledge about the vulnerability of different regions and sectors of the country, as well as potential impacts, development of specific strategies and coordinated work of the various levels of government and society."

The Baluarte, Culiacan, Fuerte and Sinaloa river basins, in Northwestern Mexico are very important areas in food production for domestic consumption and for the exportation of vegetables. From the point of view of demographic, economic, political and social reasons, these watersheds are extremely important for the state of Sinaloa, and Mexico as well.

Therefore, it is essential to develop climate models that aid in the development of public policies, to mitigate the effects of global climate change on potential evaporation and other components of the hydrological cycle in these basins. In addition, it is important to build possible scenarios whose results allow defining strategies for integrated watershed management to help the mitigation of the detected negative effects.

According to the above statement, this paper attempts to shed some light on the possible consequences that global climate change will have in the Northwestern Mexico basins considered in this study, with regard to potential evaporation and to soil water content moisture deficiency in such area. In this study, we have chosen two surfaces of coverage: water and short grass. The short grass is a reference crop that allows using its results to obtain the correspondent values for other crops for human and animal consumption.

The Penman Equation

The Penman formula is the main tool used in this study; the form used for this particular study is(Steward and Roberts 1984):

$$E = \frac{\Delta}{\Delta+\gamma}\left\{R_a(1-alb)\left(0.25+\frac{0.5n}{N}\right)-\sigma T^4\left(0.1+\frac{0.9n}{N}\right)(0.34-0.044)\sqrt{e}\right\} + \left(1-\frac{\Delta}{\Delta+\gamma}\right)\left\{0.26\left(1+\frac{U}{160}\right)(e_s(T)-e)\right\}$$

where:
E = evaporation of an open surface water, in mm/day
alb = albedo of the surface considered, in mm/day:alb = 0.05 for an open water surface, alb = 0.25 for a surface covered with short grass
Δ = slope of the saturated water vapor curve, in mb/°C
Ra = solar radiation measured at the top of the atmosphere, in mm/day
n = actual number of hours of sunshine, in hours
N = maximum number of hours of sunshine, in hours
σT^4 = outgoing longwave radiation emitted by a surface at temperature T, in mm/day
T = average temperature of the daily maximum and minimum temperatures, in °C
U = wind run per day, in km/day
e = vapor pressure of mid-morning, in mb
e_s (T) = saturated vapor pressure at temperature T, in mb
γ = psychrometric constant (which has a value of 0.67 mb/°C), in mb/°C

This form of the Penman formula is used in places where there is no information on the net radiation and maximum number of hours of sunshine, these values are obtained from tabulated values depending on the latitude (Steward and Roberts 1984). Likewise, values of outgoing longwave radiation, the slope of the saturated vapor pressure curve and the saturation pressure of water vapor are obtained from tabulated values as a function of data of average daily temperature (Steward and Roberts 1984). We used that formula for two cases: open water surface and a short grass coverage, in various scenarios of annual accumulated precipitation and air temperatures. It is noteworthy to consider that potential evaporation produced by the Penman formula is an upper limit in such hydrologic component, but their quantification and behavior gives a good approximation to the actual physical process of evaporation on such surfaces.

Discussion of Results

With the forecasts for the increase in air temperature emitted by the Hadley Centre (2005), see figure 1, which shows an increase for Mexico between 3°C and 5°C by the end of the XXI Century, we applied such forecasted conditions to the basins of the Baluarte, Culiacan, Fuerte and Sinaloa rivers in Northwestern Mexico. We constructed five possible scenarios, with increases in air temperature of 1°C, 2°C, 3°C, 4°C and 5°C above current conditions, for the potential evaporation and soil water moisture content deficiency, in three strategically distributed sites in each of the referred basins. The scenarios mentioned before contains the increases in air temperature, relative the years from 1986 to2005, in the RCP2.6, RCP4.5, RCP6.0, and RCP8.5 scenarios proposed by IPCC (2014).

The selected sites, corresponding to the Baluarte River basin, were the Rosario, Cucharas and Las Bayas climatological stations. The former climatological station produced the most critical results in the whole region, and its results are shown in figures 2 and 3; therefore, this paper will focus only its results. El Varejonal, Culiacan and San Miguel de los Lobos climatological stations were chosen for the Culiacan River basin. Los Mochis, Miguel Hidalgo Dam and Huites climatological stations were chosen for Fuerte River basin. Guasave, Jaina and Guadalupe y Calvo climatological stations were used in the Sinaloa River basin. These stations are climatically representative in each of the analyzed basins.

The climatological stations of Rosario, El Varejonal, Los Mochis and Guasave are located in the lower basin, and have a very dry climate and very warm. Cucharas, Culiacan, Miguel Hidalgo Dam and Jaina are in the middle basin with a dry and semi-warm climate. Las Bayas, San Miguel de los Lobos, Huites and Guadalupe and Calvo are in the upper basin with semi-dry and very warm climate.

The expected rainfall in the forthcoming years for this area in Northwestern Mexico, has shown to have a small effect with respect to the increase in soil water moisture content deficiency.

The results obtained for the selected watersheds in Northwestern Mexico, showed that with an increase in air temperature of 1°C, the values of potential evaporation would increase between 2.1% and 3.1% compared to current values. As a direct consequence of this result, soil water moisture content deficiency values increase between 3.4% and 6.9% compared to current values.

With an increase in air temperature of 2°C, the values of potential evaporation will have an increase between 2.9% and 6.3% above the current values. In this case, the soil water moisture content deficiency will increase their values between 6.8% and 13.8% compared to current values.

For an increase in air temperature of 3°C, the values of potential evaporation will rise between 6.3% and 9.4% above the current values. In this case, the soil water moisture content deficiency has their values increased between 10.3% and 20.6% compared to current values.

For an increase in air temperature of 4°C, the values of potential evaporation will increase between 8.6% and 12.7% compared to current values. As a direct consequence of this result, an increase in the soil water moisture content deficiency will be between 14% and 27.3% compared to the current values.

The results obtained for this watershed showed that with an increase in air temperature of 5°C, the values of potential evaporation would increase between 10.7% and 15.7% compared to current values. As a direct consequence of this result, soil water moisture content deficiency values will increase between 17.5% and 35.0% compared to current values.

Summary and Conclusions

We constructed five possible scenarios in each of the climatological stations in the basins under study, with increases in air temperature above current conditions of 1°C, 2°C, 3°C, 4°C and 5°C, respectively. The results obtained from these river basins showed that for the Las Bayas climatological station, on the Baluarte river basin, with the range of increase in air temperature mentioned before, the potential evaporation values will increase between 3.0% and 15.5% with respect to current values. As a direct consequence of this result, the deficiency in the soil water moisture content will increase its values between 5.8% and 35% with respect to the present values.

For San Miguel de los Lobos climatological station, in the Culiacan River basin, with the selected increases in air temperature, the potential evaporation values will range between 3.1% and 15.7% above current values. In this case, the values in the soil water moisture content deficiency will increase its values between 4.7% and 25.8% with respect to the current conditions.

For Huitesclimatological station, in the Fuerte River basin, with the selected increases in air temperature the potential evaporation values will be between 2.1% and 11.6% above current values. In this case, the values in the soil water moisture content deficiency will increase its values between 3.4% and 21.5% with respect to the current conditions.

Finally, for the Guadalupe yCalvo climatological station in the Sinaloa River basin, the increase in air temperature will produce that the potential evaporation values range between 2.9% and 14.3% above current values, see figure 13. In this case, the deficiency in the moisture content will increase its values between 5.5% and 31.6% with respect to the current values.

These results show the urgent need for coordinated actions among agencies of the three levels of government in Mexico and Mexican society to mitigate the adverse impacts that global climate change may generate in the near future.

Acknowledgements

The authors wish to express their recognition to the Universidad de las Americas Puebla for the support granted to enable the publication of this paper. The support given to the third author by the XXIV Summer of the Scientific Research program, sponsored by the Mexican Academy of Sciences, is also recognized.

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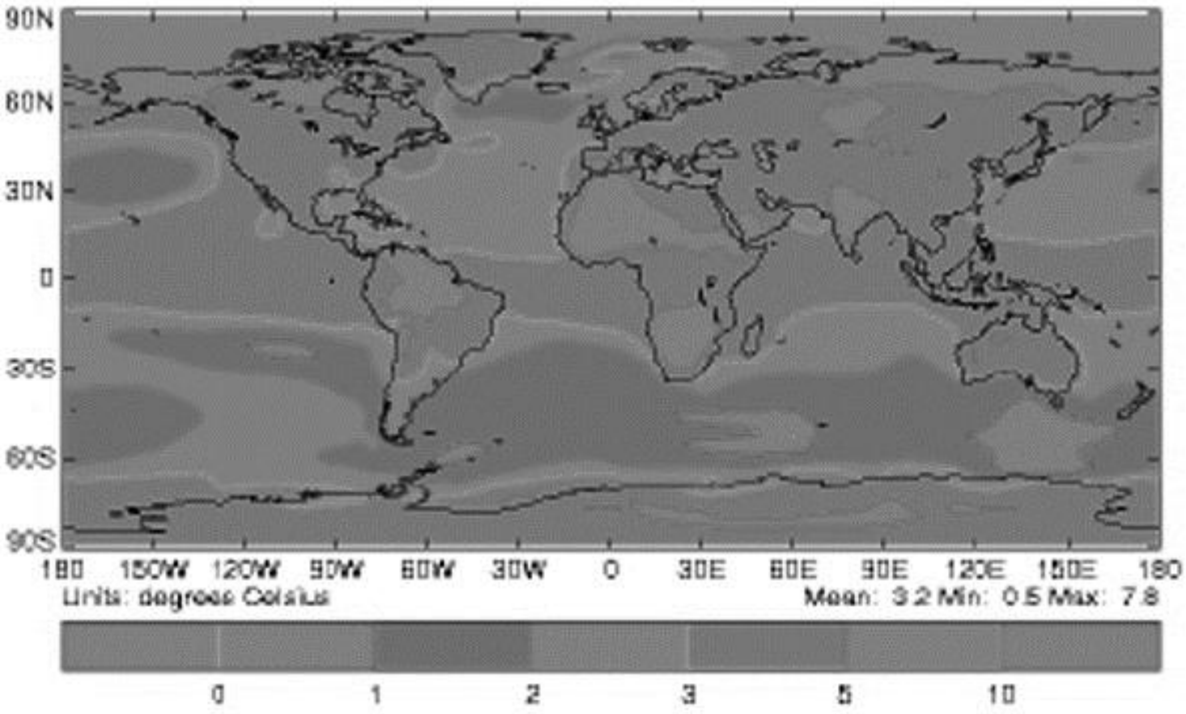

Figure I
Forecast of air temperature increase due to global warming at the end of the XXI century (Hadley Centre 2005)

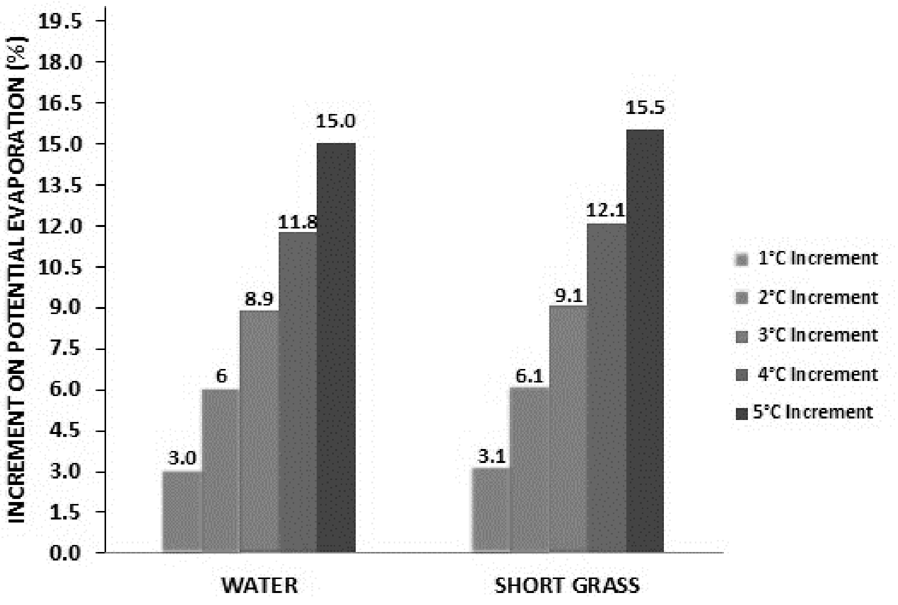

Figure II
Increment on potential evaporation in climatological station Las Bayas, Mexico

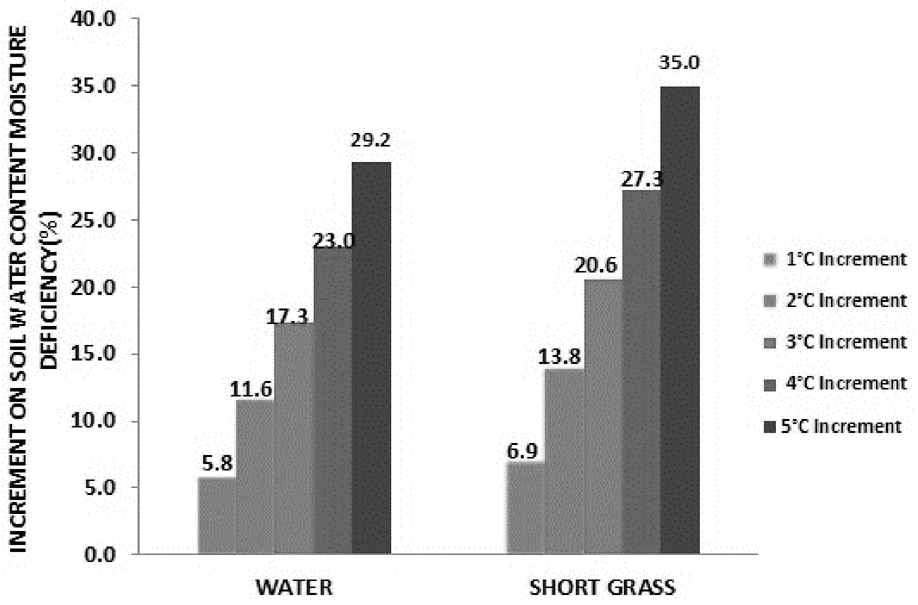

Figure III
Increment on soil water moisture content deficiency in climatological station Las Bayas, Mexico.