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Possible Scenarios of Global Climate Change on the Evaporation in the Lerma River Basin, Mexico

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Abstract*— Five possible scenarios were constructed to define the impacts of global climate change on evaporation and soil water moisture content deficiency in the Lerma River basin in Central Mexico, based on forecasts of the Hadley Centre. The Hadley Centre predicts an increase in air temperature between 3-5 °C at the end of the XXI century for Mexico. Based on this forecast, an increase in air temperature of 1, 2, 3, 4 and 5°C above the current conditions, were used to construct five possible scenarios for two surfaces: water and short grass. Then, the impact of each of these five possible scenarios was analyzed with regard to potential evaporation and soil water moisture content deficiency for the two selected surfaces. The results showed that the increases in air temperature mentioned before, will produce an increase in potential evaporation between 2.2% for 1°C of increase in air temperature and 14.2% for 5°C of increase in air temperature, compared with the current values. As a consequence of this, the soil water moisture content deficiency will increase between 3.0% for 1°C of increase in air temperature and 25.6% for 5°C of increase in air temperature, compared with the current values. It was noted that the forecasted increase in the annual rainfall in the basin has a modest contribution in reducing the potential evaporation in the Lerma River Basin. In the most adverse scenario, reductions in food production will be in the order of 36.3%, composed by a need for 14.2% of additional water that the crops will require for their growth and an additional 22.1% of potential evaporation coming from existing surface storages, like lakes and reservoirs, in the Lerma River basin. These results indicate that there is an urgent implementation of measures to mitigate the adverse effects of global climate change impacts in the Lerma River basin.

Index Terms— **Global climate change, potential evaporation, soil water moisture content deficiency, water, short grass, reduction of food production.**

I. INTRODUCTION

Global climate change is occurring, mainly by global warming that is being caused by the so-called greenhouse gases (GHG), which are mainly water vapor, carbon dioxide (CO2), methane (CH4) and nitrous oxide (NO), the last three have increased their concentrations at dangerous levels from the Industrial Revolution that occurred in the mid-nineteenth century. Water vapor, the most abundant of the greenhouse gases so far, is the one that has had the most beneficial effects on Planet Earth, and that has made the average global temperature is now 14 °C and not -18 °C if there is no greenhouse gases effect exist in the upper atmosphere. The greenhouse gas emissions that are produced by human activities, it has been accepted that it is the main mechanism that is causing global warming and therefore the main cause of global climate change ([1] and [2]).

The Lerma River basin, Mexico is considered an important area in food production for domestic consumption and for the exportation of vegetable produce into the United States of America. From the point of view of demographic, economic, political and social reasons, it is extremely important for the states that are part the Lerma River watershed, such as: the states of Mexico, Guanajuato, Michoacan, Queretaro, and Jalisco, in Central Mexico. 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 this basin, as well as to build possible scenarios whose results allow to define strategies for integrated watershed management to help mitigate the negative effects that have been detected.

Unfortunately, global climate change had been losing weight in the public policies of Mexican government, because although it was included as part of the National Development Plan 2013-2018, [3], it was not considered with the same prominence as in the previous six years; despite 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 old 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, [4]. 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."

According to the above statement, this paper attempts to shed some light on the possible consequences that global climate change will have in the Lerma River basin, with regard to potential evaporation and in soil water content moisture deficiency in such area. In this study we have chosen two areas of coverage: water and short grass. The short grass is a reference culture that allows extrapolate the results obtained in it to other crops for human and animal consumption.

II. THE PENMAN EQUATION

The Penman formula is the main tool used in this study, the form used for this particular study is, [5]:

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

$$+\left(1-\frac{\Delta}{\Delta+\gamma}\right)\left\{0.26\left(1+\frac{U}{160}\right)(e_s-e)\right\} \quad (1)$$

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 a temperature T, mm / day
T = average temperature of the daily maximum and minimum temperatures in °C
U = wind run per day in m / 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 can be applied in places where there is no information on the net radiation and the maximum number of hours of sunshine, these values may be obtained from tabulated values depending on the latitude, [5]. Likewise, values of outgoing longwave radiation, the slope of the saturated vapor pressure curve and the saturation pressure of water vapor may be obtained from tabulated values as a function of average daily temperature values, [5] . The formula was applied to an open water surface and to a short grass coverage in various scenarios of annual accumulated precipitation and air temperatures.

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It is noteworthy to consider that potential evaporation produced by 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.

III. DISCUSSION OF RESULTS

With forecasts of increased air temperature at the end of XXI Century, [6], see Figure 1, were applied to the Lerma River basin, and possible scenarios were constructed at three sites strategically distributed within such basin. The selected sites are those for weather stations Guadalajara, Queretaro and Toluca, and they are climatically representative of the entire basin that was analyzed in this study. The location of the Lerma River basin, in Central Mexico, can be observed in the map shown in Figure 2. The Guadalajara climatological station is located at the exit of the basin (downstream) and has a climate which is very dry and very warm, the Queretaro climatological station is at the middle basin with a climate that is dry and semi-warm and finally the weather station Toluca is in the upper basin with a climate semi-dry and very warm. The increase of rainfall expected for this area of Mexico by the end of the XXI Century, [6], can be seen in Figure 3. The effect of such increase in rainfall showed to have a little contribution in the increase of soil water moisture content deficiency.

Five possible scenarios were constructed on each of the climatological stations mentioned before, that are located within the Lerma River basin under study, the increases in air temperature above the current conditions were 1, 2, 3, 4 and 5°C, respectively. The results obtained for this watershed showed that with an increase in air temperature of 1°C, the values of potential evaporation will increase between 2.2% and 2.8% compared to current values, see Figures 4, 6 and 8. As a direct consequence of this result, soil water moisture content deficiency values increase between 3% and 5.1% compared to current values, see figures 5, 7 and 9.

With an increase in air temperature of 2°C, the values of potential evaporation will have an increase between 4.4% and 5.7% above the current values, see Figures 4, 6 and 8. In this case, the soil water moisture content deficiency will increase their values between 6% and 10.2% compared to current values, see figures 5, 7 and 9.

For an increase in air temperature of 3°C, the values of potential evaporation will rise between 6.6% and 8.5% above the current values, see Figures 4, 6 and 8. In this case, the soil water moisture content deficiency have their values increased between 9% and 15.3% compared to current values, see figures 5, 7 and 9.

For an increase in air temperature of 4°C, the values of potential evaporation will increase between 7.8% and 11.3% compared to current values, see Figures 4, 6 and 8. As a direct consequence of this result, an increase in the soil water moisture content deficiency will be between 12% and 20.4% compared to the current values, see figures 5, 7 and 9.

The results obtained for this watershed showed that with an increase in air temperature of 5°C, the values of potential evaporation will increase between 11% and 14.2% compared to current values, see Figures 4, 6 and 8. As a direct consequence of this result, soil water moisture content deficiency values will increase between 11.4% and 25.6% compared to current values, see figures 5, 7 and 9.

An interesting feature that can be seen, see Figures 5, 7, and 9, it is that the more humid the climate in the Lerma River, for example the climatological station Toluca (semi-dry very warm climate) compared to the climatological stations Queretaro (very warm very dry climate) and Guadalajara (semi-warm dry climate), the effects of climate change will be more pronounced in the two hydrological variables considered, namely evaporation and soil water moisture content deficiency.

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 forseeable future.

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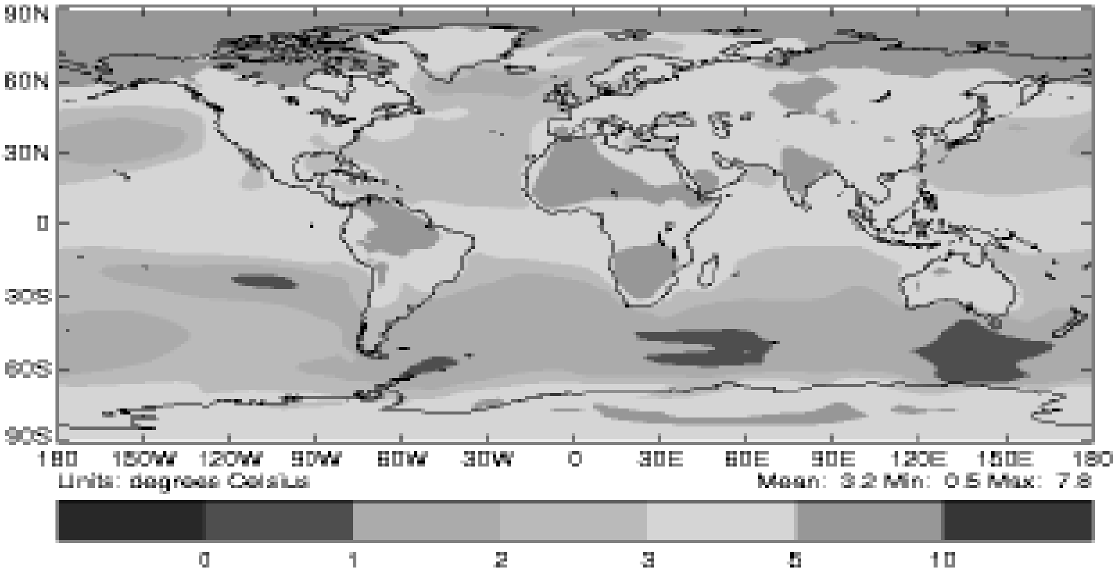

Fig 1. Forecast of air temperature increase due to global warming at the end of the XXI century, [6].

Fig 2. Location of the Lerma River basin, México, [7].

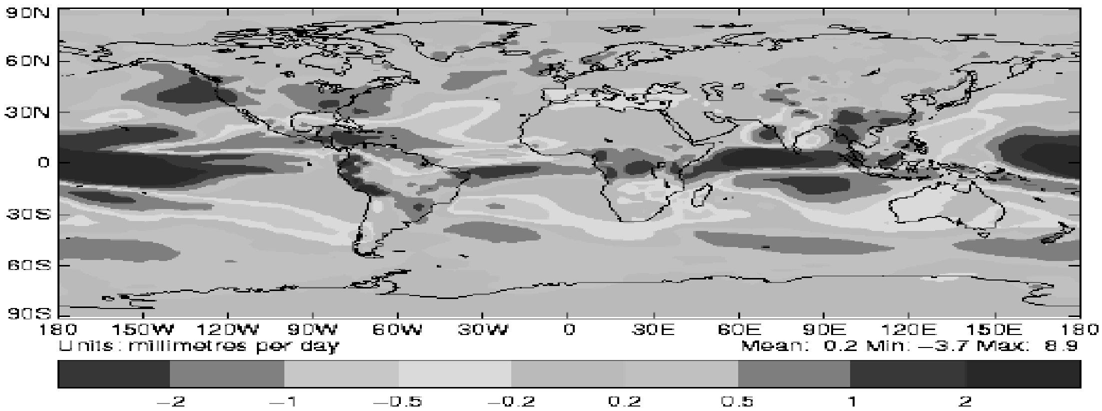

Fig 3. Variations on the precipitation due to global warming at the end of the XXI century, [6].

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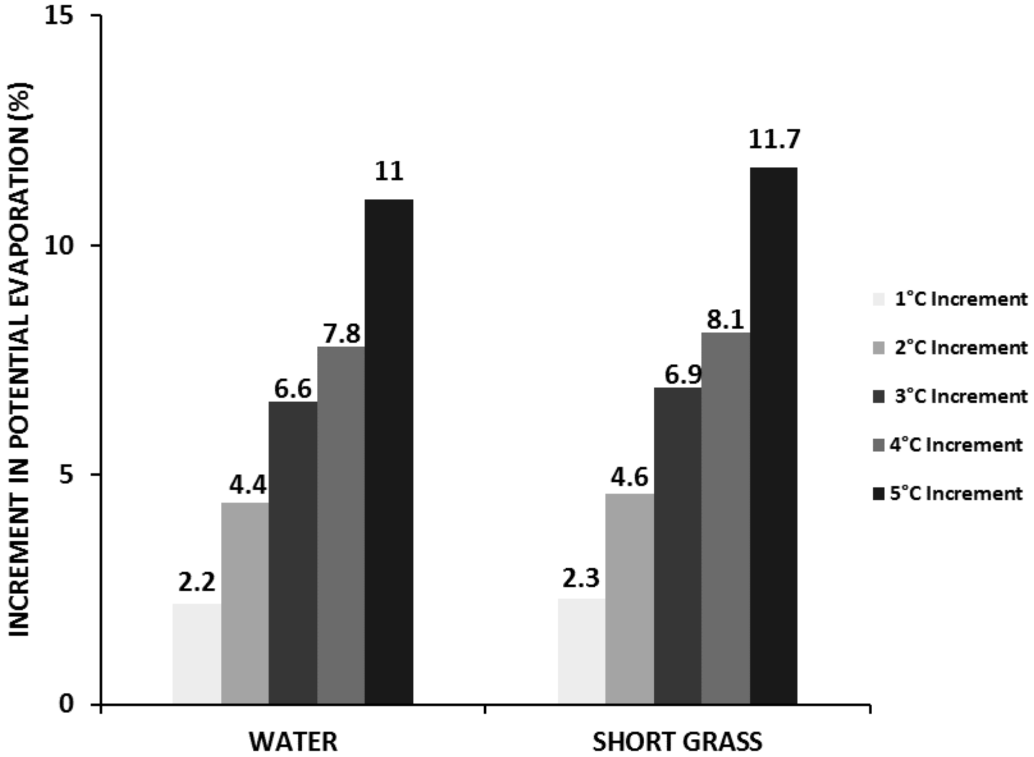

Fig 4. Increase in potential evaporation at climatological station Guadalajara, Mexico.

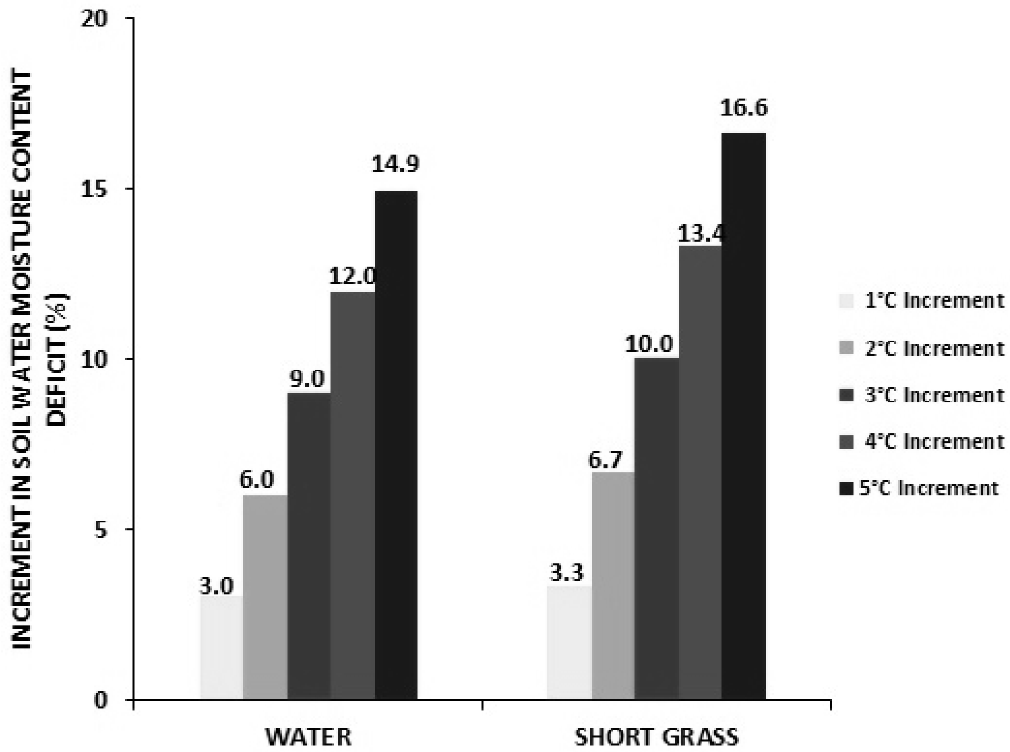

Fig 5. Increase in soil water content moisture deficiency at climatological station Guadalajara, Mexico (water and short grass).

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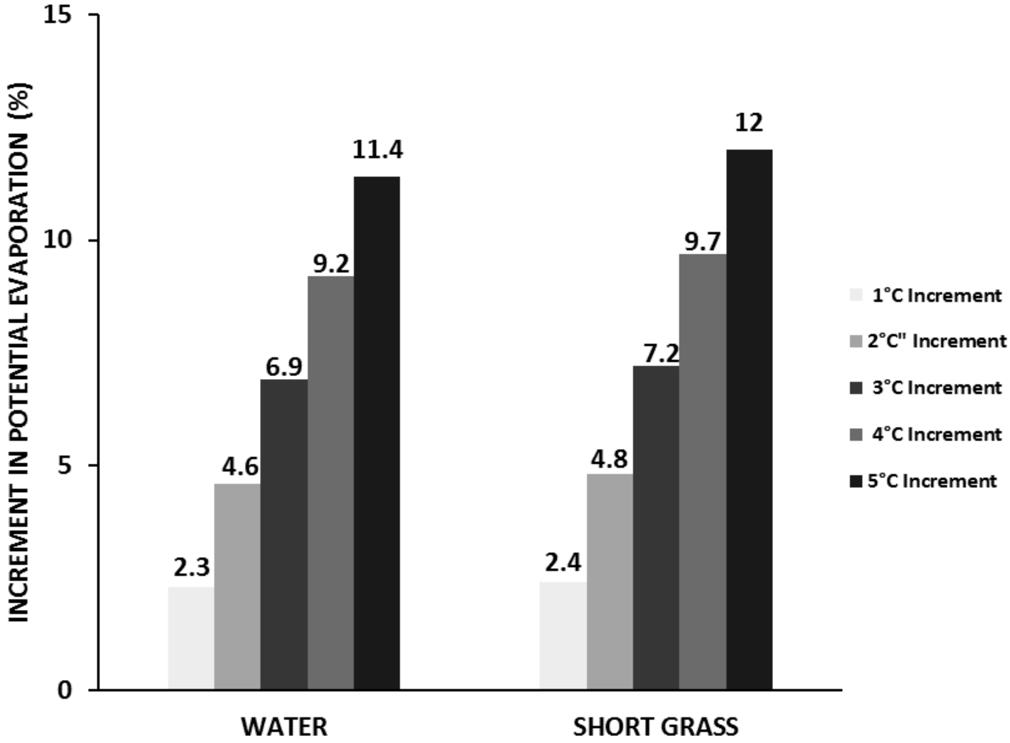

Fig 6. Increase in potential evaporation at climatological station Queretaro, Mexico.

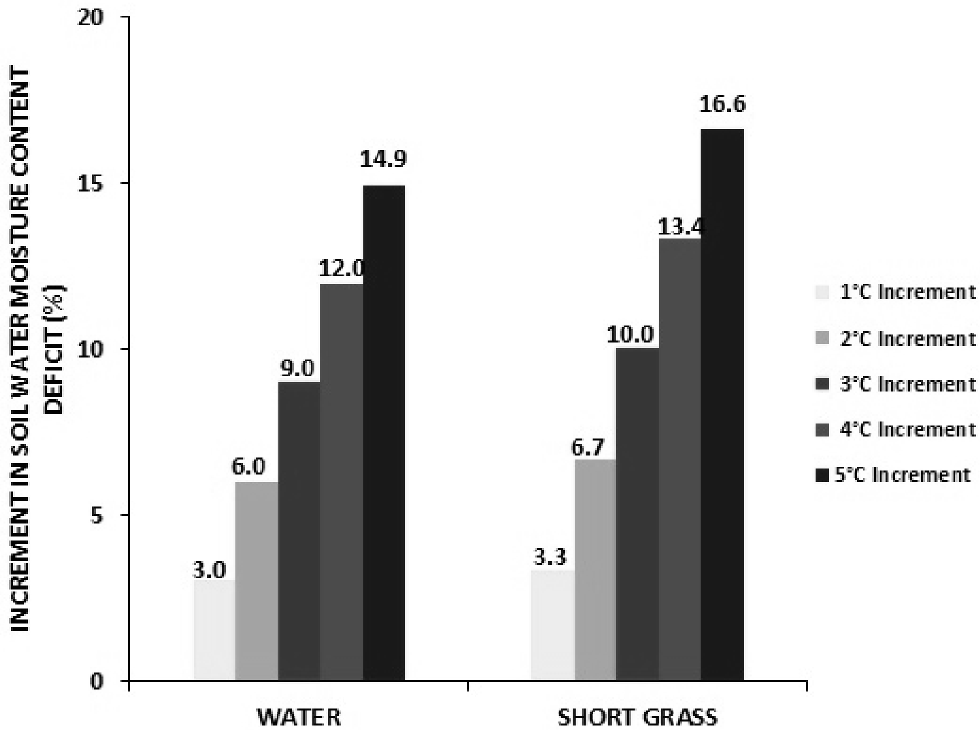

Fig 7. Increase in soil water content moisture deficiency at climatological station Queretaro, Mexico (water and short grass).

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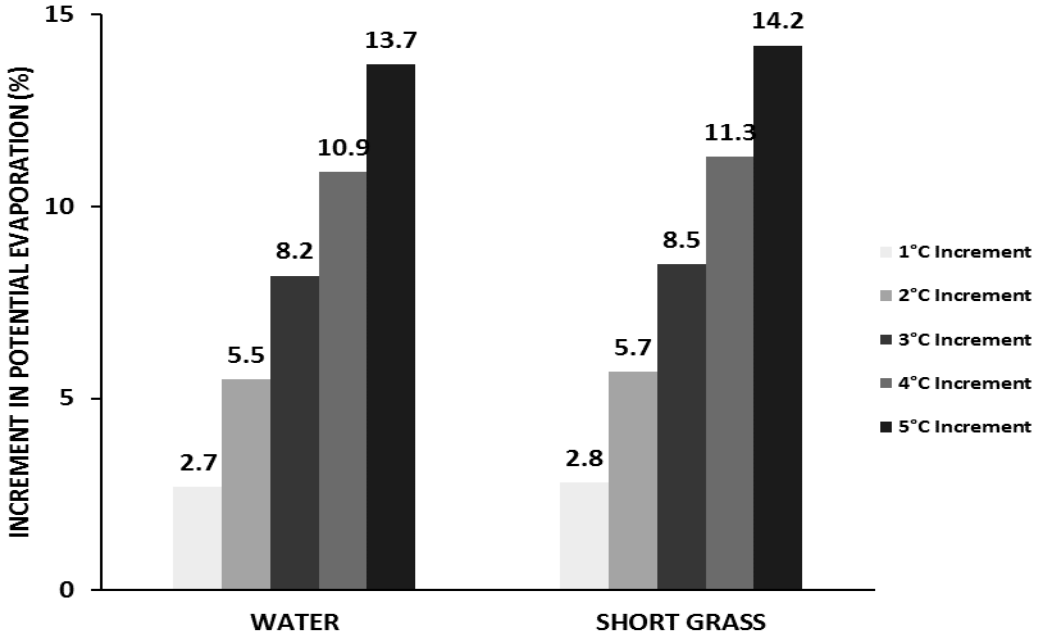

Fig 8. Increase in potential evaporation at climatological station Toluca, Mexico.

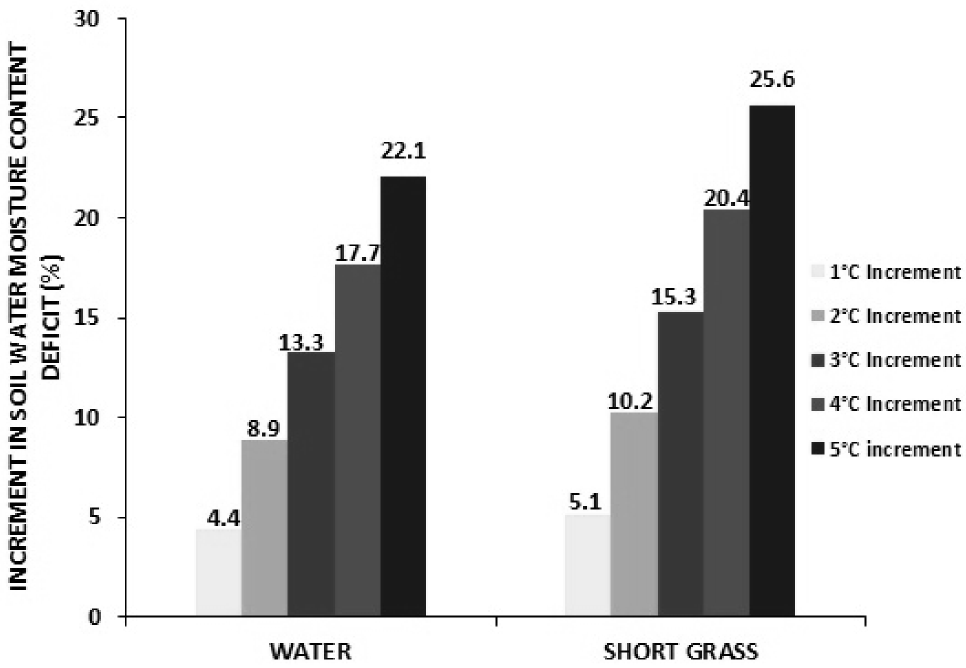

Fig 9. Increase in soil water content moisture deficiency at climatological station Toluca, Mexico (water and short grass).

IV. CONCLUSIONS

Based on the analysis in the Lerma River basin, Mexico, with respect to the five possible scenarios for potential evaporation and soil water moisture content deficiency, and the predicted increases in annual precipitation due to the increase in air temperature, caused by global climate change, there will be a significant increase in potential evaporation and in the soil water moisture content deficiency. Another important observation is that the more humid the climate, in the Lerma River basin, the greater the effects with regard to the increases in potential evaporation and soil water moisture content deficiency in such basin.

This results produces a two-fold critical situation for the development of agriculture in the Lerma River basin, Mexico. First, it will be needed larger volumes of water to produce the same amounts of food in such basin, because of the increase that will have on the potential evaporation; second, an increase on the soil water moisture content deficiency in surface water bodies, like lakes and reservoirs, will produce less available surface water within the basin. These two combined effects represent an expected reduction in water availability in the Lerma River basin that are in the order of 36.3%. This scenario, which is the most adverse as it is linked to an increase of 5°C in air temperature, it is a very worrying issue in a country like Mexico that have to develop basic infrastructure to serve a population growth of 33% for year 2025. The results obtained in this study, indicate a pressing need to establish, as soon as possible, a set of coordinated actions in the Lerma River basin to mitigate the impacts of global climate change would have in such area, if the mentioned forecasts in this paper will materialize in the near future.

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