PROJECTED IMPACTS OF CLIMATE CHANGE ON MAJOR CROPS' VIRTUAL WATER IN SOUTHERN IRAN

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ABSTRACT

Global warming and climate change have caused major conflicts especially in agricultural water management. The aim of this research is investigation of climate change effects on virtual water of several crops i.e. Wheat, barley, potato and tomato in Kerman province, south of Iran. For projection of virtual water of selected crops under RCP4.5 and RCP8.5 climate change scenarios (IPCC Fifth Assessment Report) during period of 2010-2100 in three study stations, crop evapotranspiration were worked out using downscaled outputs of CNRM-C5 climate model. Also crops yield were simulated using Aqua Crop model. By choosing new date of sowing, temperature, rainfall and evapotranspiration during projected growing season were determined. Based on the maximum simulated yield for the study crops, the optimum date of sowing for future periods were chosen. Finally the crops virtual water (evapotranspiration divided by yield) was calculated.Besides, the trend analysis of temperature, rainfall and evapotranspiration variables during future periods were performed using Mann-Kendall and Sen's slope estimator test in three study stations . The results showed that there exist an increasing trend in air temperature time series, in all month. Also, the Maize crop yield would decrease in all three stations (with highest decrease in Jiroft station with 52 and 56 % under RCP 4.5 and RCP 8.5 in 2018-2039 period comparing to baseline period, respectively.) The virtual water of all selected crops is projected to increase, but this increase would be higher for wheat and barley crops. The lowest increase in virtual water was observed in tomato crop during the future period of 2018-2100.In Bam station, the highest amount of virtual water belongs to barley crop during the period of 2040-2069, i.e. 4853 and 5153 cubic meter per ton under two RCP scenarios, respectively. In Jiroft wheat crop has the highest virtual water during the period 2040-2069 projected to be 4984 cm^3/ton. In case of Kerman station, largest amount of virtual amount under RCP4.5 belongs to wheat during the period 2040-2069 and under RCP 8.5 corresponds to barley with amount of 4256 cm^3/ton. Further studies in other climatic regions of the country are recommended for more precise decisions in agricultural water management.

Keywords: Evapotranspiration, crop yield, Trend, Climate Change.Iran

1. INTRODUCTION

Man made increases in atmospheric concentrations of greenhouse gases has significantly raised the global temperatures. The study of climate change effects on crop water demand and virtual water volume (VWC) as measure of water trade is becoming increasingly important in recent decades.(Fang et.al 2015) Climate change will cause changes in climate variables affecting potential evapotranspiration and crop yield. Virtual water or embedded water or embodied water, or hidden water refers to the water used in the production of goods or services. For examle, it takes 1,300 m of water on an average to produce 1 t of wheat (Majumder et.al 2010) The precise volume can be more or less depending on climatic conditions and agricultural practice. In recent decades,the notable increase in number of climate models has

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enabled the scientists to estimate a wide range of main climate variables such as precipitation and temperature in fine temporal and spatial resolution. Although the uncertainty in model outputs remains a main challenge. Upon release of new scenarios based on Radiative Forcing which are known as Representative Concentration Pathway scenarios (RCP scenarios), by Intergovernmental panel on climate change (IPCC) in fifth assessment report (AR5), a new set of 42 global climate models (GCMs) have been proposed for future climate projections (Ghahreman et al.2015) .United Nation Food and Agriculture Organization proposed the new approach of climate smart agriculture in 2010, as a guideline for adapting agriculture to climate change sequences.(IPCC,2013) .Zhao et.al(2014) used a GIS-based Environmental Policy Integrated Climate (GEPIC) model to analyze the current spatial distribution of VWC of various crops in China and the impacts of climate change on VWC in different future scenarios. The results show that C4 crops (e.g. irrigated maize with a VWC of 0.73 $m^3\ kg^{-1}$ in baseline) generally have a lower VWC than C3 crops (e.g. irrigated wheat with a VWC of 1.1 $m^3\ kg^{-1}$ in baseline), and the VWC of C4 crops responds less sensitively to the CO_2 concentration change in future climate scenarios.In a review study using the Global Trade Analysis Project model to estimate bilateral crop trade under changes in agricultural productivity for rice, soy, and wheat, it was found that the total volume of virtual water trade is likely to decrease under climate change. This is due to decreased crop trade from higher crop prices under scenarios of declin-ing crop yields and due to decreased virtual water content under high agricultural productivity scenarios. The pattern of global water savings for aggregate crops mirrors the wheat-only commodity trade, since such large volumes of water are embodied in the wheat trade (Konar et.al 2013). Few studies on impact assessment of climate change on crop virtual water using RCP scenarios have been performed so far, in Iran, hence this research was aimed to project the virtual water values of several major crops in southern region of Iran

2. METHODS

2.1. Study Station

Kerman province is located in southeast of Iran. The main synoptic station in study region with long historical dataset is kerman (Figure 1). The geographical and climatic characteristic of this station is provided in Table 1.The station observed climatic data for baseline period of 1990-2017 were collected from Iran Meteorological Organization (IRIMO).

Figure 1: Geographical location Kerman province, south of Iran

kerman

Table 1. Geographic and climatic information of synoptic stations used in the study

Station	Longitude(◦)	Latitude(◦)	Altitude(m)
Bam	58.35	29.1	1101.1
Jiroft	57.74	28.67	686.6
Kerman	57.08	30.29	1759.2

2.2. Climate Model Data

The climate projections used for the study were CNRM-CM5 global climate model outputs which were dynamically downscaled by Swedish Meteorological and Hydrological Institute (SMHI) under CORDEX project were calibrated used and calibrated based on observed data. After calibrating, the changes of temperature, precipitation, crop evapotranspiration and length of growth period of two crops have been studied using different date of sowing. The projected values obtained from climate models were corrected based on a proposed method for correction of standard deviation and mean of historical data for baseline period. In this method, the observed and hindcast data values for baseline period are used to correct the projected values of future, as follows:

$$STD_{fut} = \frac{STD_{base}^{obs}}{STD_{base}^{GCM}} \times STD_{fut}^{GCM} \quad (1)$$

Where, STD_{fut} standard deviation for future period, STD_{base}^{obs}, standard deviation of observed data for baseline period. STD_{base}^{GCM} , standard deviation of data for baseline period, STD_{fut}^{GCM} standard deviation of projected data for future period. Similarly, the mean values were corrected as suggested by deCarvalho et al. (2015):

$$Mean_{fut} = \frac{Mean_{base}^{obs}}{Mean_{base}^{GCM}} \times Mean_{fut}^{GCM} \quad (2)$$

The corresponding daily values of rainfall and precipitation obtained by equation 1 and 2 were converted to monthly and annual values to be used for calculation of evapotranspiration by Penman–Monteith equation.(Allen et al.2006)

$$PET = -\frac{0.408\Delta(R_{net}-G)+\gamma\frac{900}{T_{2m}}U_{2m}(e_s-e_{a})}{\Delta+\gamma(1+0.34U_{2m})} \quad (3)$$

2.3. Performance Estimation

The AquaCrop model was used to estimate performance. Model inputs include four categories: climate data, vegetation, soil, and farm management.

2.4. Crop Coefficients

The required crop coefficients for calculation of wheat and maize evapotranspiration were retrieved from FAO 56 publication (Allen et al. 2006), they were adjusted according to climatic conditions of the region and compared with published data provided by other scientist in this region. Projected length of period for entire growing season (LGP) under RCP 4.5 and 8.5 were worked out and compared with baseline values in each study stations.

2.5. Climate Change Scenarios

In this study, two scenarios from fifth assessment report of IPCC (AR5) namely 4.5 and 8.5 were used.

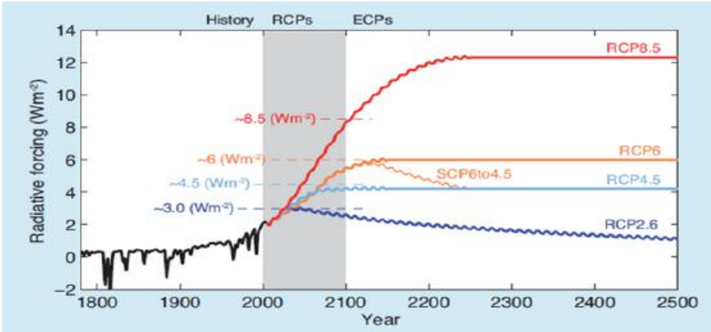

Figure 2. Different RCP scenarios based on radiative forcing (IPCC, 2013)

2.6. Virtual Water Calculation

The amount of water (VWC) consumed by a product is the amount of water needed to produce a unit of product. the virtual water values were calculated as follows (Fang et al., 2010):

$$VWC = 10 \times \frac{ET_c}{Y} \quad (4)$$

Where, ETc is potential evapotranspiration and Y is the crop yeild. This amount was determined for future period under RCP4.5 and 8.5 accordingly.

3. RESULTS

3.1 Wheat Crop

The projections virtual water for wheat crop in study stations are depicted in figures 3 to 6**.**

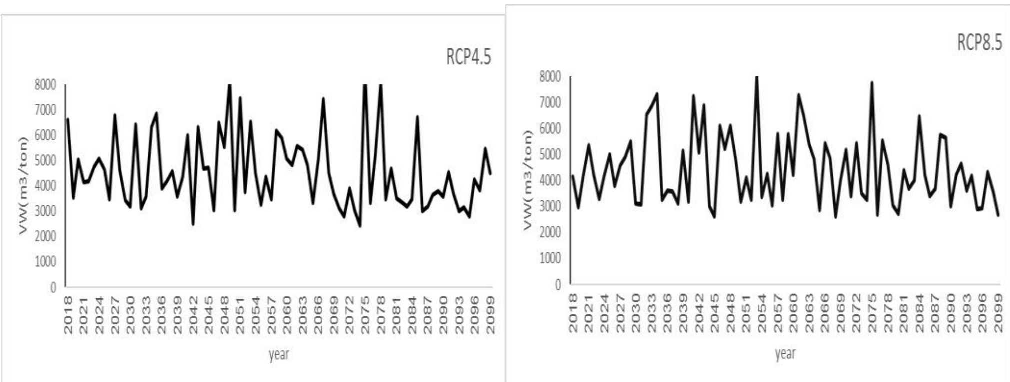

Figure 3. virtual vater of wheat crop, under RCP 4.5 and RCP 8.5 scenarios in bam station (2018-2100)

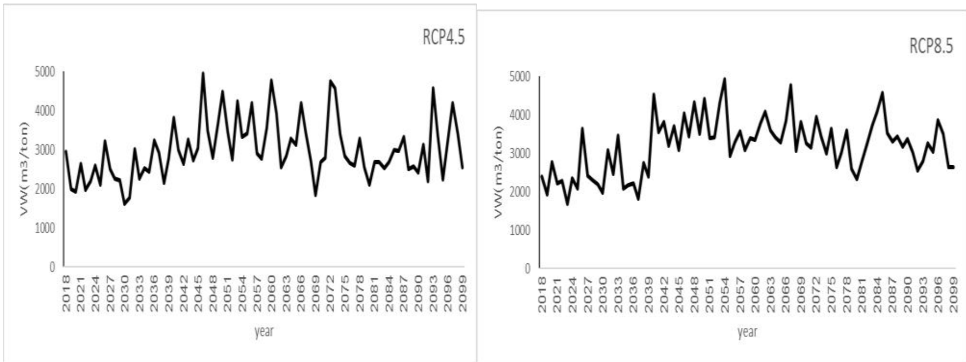

Figure 4. virtual water of wheat crop growing season, under RCP 4.5 and RCP 8.5 scenarios in jiroft station (2018-2100)

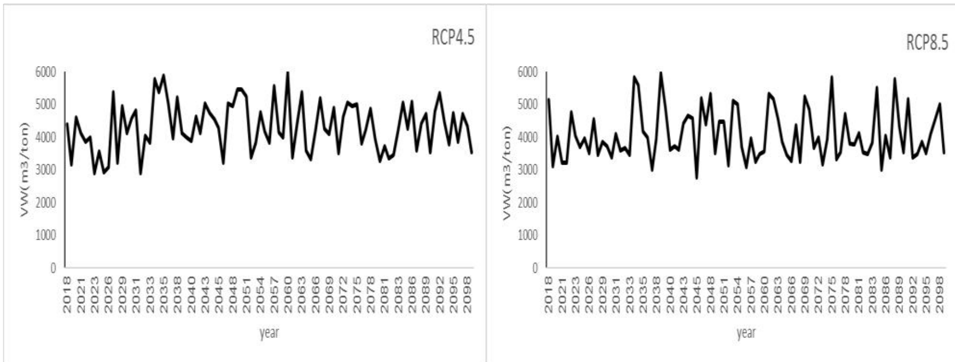

Figure 5. virtual water of wheat crop, under RCP 4.5 and RCP 8.5 scenarios in kerman station (2018-2100)

Under the scenario RCP4.5, the average of virtual wheat water at Kerman station was less than Bam, Bam less than Jiroft and under RCP8.5 scenario.Average virtual water in Jiroft station was less than Kerman, Kerman less than Bam.

3.2. Barley Crop

The projections of virtual water for barley crop in study stations are depicted in figures 6 to 8.

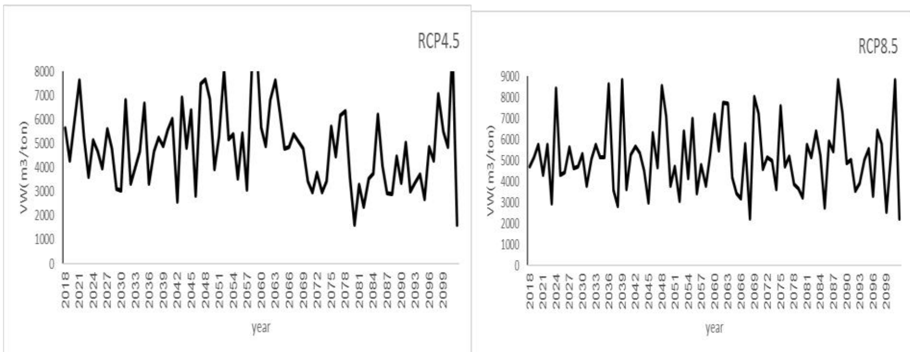

Figure 6. virtual water of barley crop, under RCP 4.5 and RCP 8.5 scenarios in bam station (2018-2100)

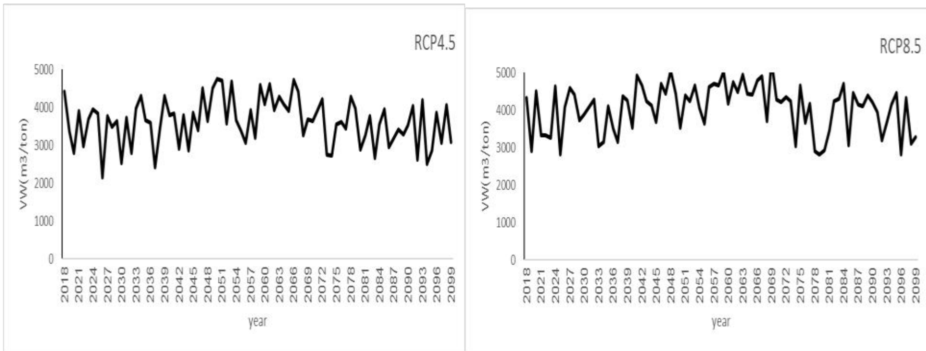

Figure 7. virtual water of barley crop, under RCP 4.5 and RCP 8.5 scenarios in jiroft station (2018-2100)

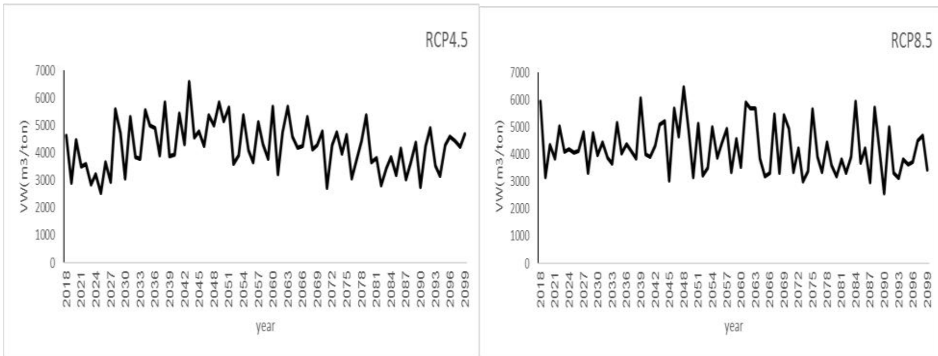

Figure 8. virtual water of barley crop, under RCP 4.5 and RCP 8.5 scenarios in Kerman station (2018-2100)

Considering the obtained values, Barly cultivation may not be recommended in Jiroft.

3.3. Maize Crop

The projections of virtual water for maize crop in study station are depicted in figures 6 to 8**.**

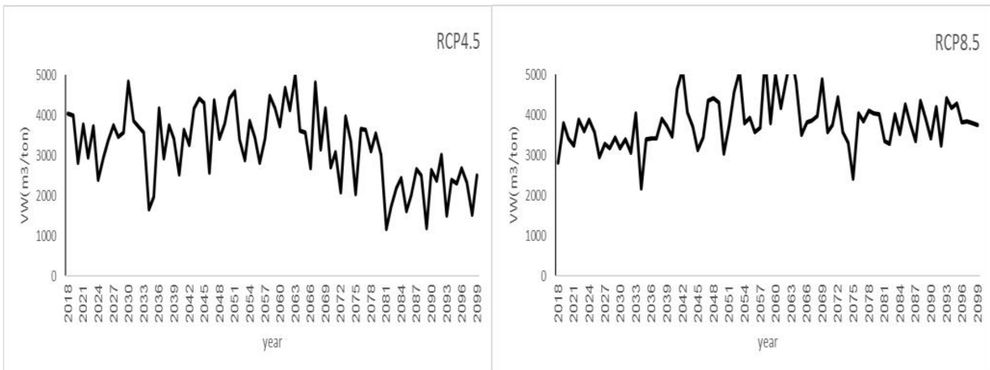

Figure 9. virtual water of maize crop, under RCP 4.5 and RCP 8.5 scenarios in bam station (2018-2100)

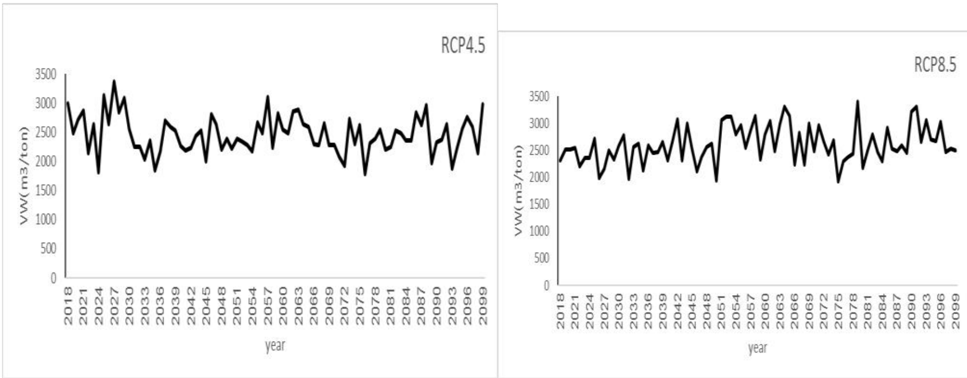

Figure 10. virtual water of maize crop, under RCP 4.5 and RCP 8.5 scenarios in jiroft station (2018-2100)

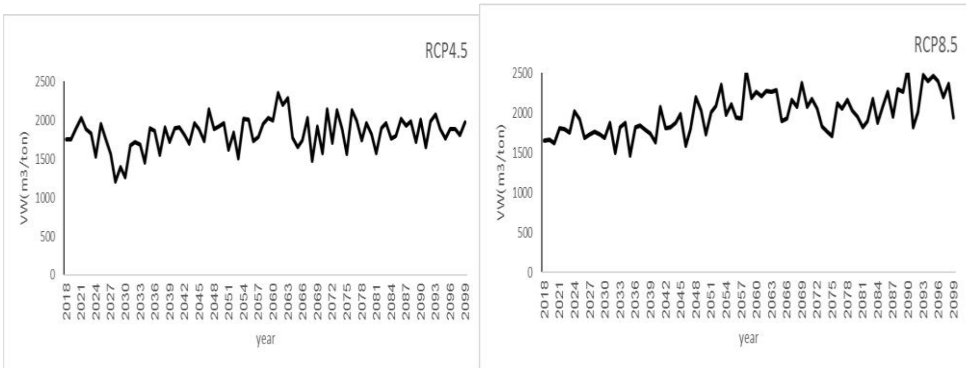

Figure 11. Virtual water of maize crop, under RCP 4.5 and RCP 8.5 scenarios in kerman station (2018-2100)

Under the scenario RCP4.5 and RCP8.5, the average of virtual water of maize in Kerman is less than Jiroft and Jiroft than Bam. Therefore, the continued cultivation of corn in Bam in future period is not suitable.

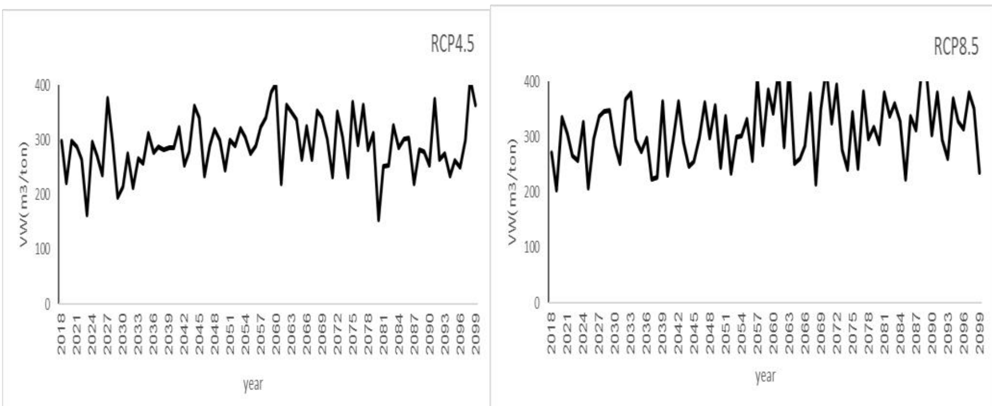

Figure 12. virtual water of potato crop, under RCP 4.5 and RCP 8.5 scenarios in bam station (2018-2100)

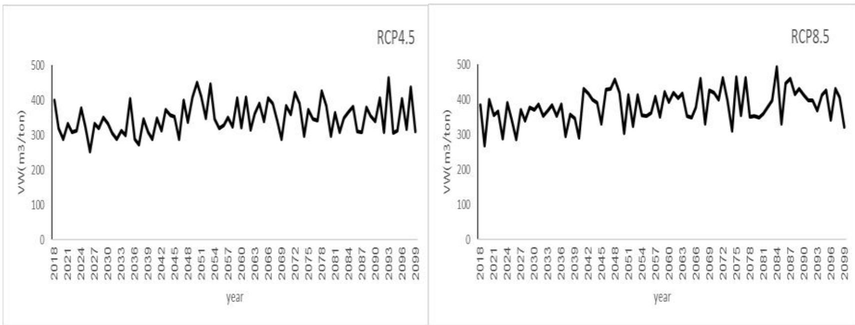

Figure 13. virtual water of potato crop, under RCP 4.5 and RCP 8.5 scenarios in jiroft station (2018-2100)

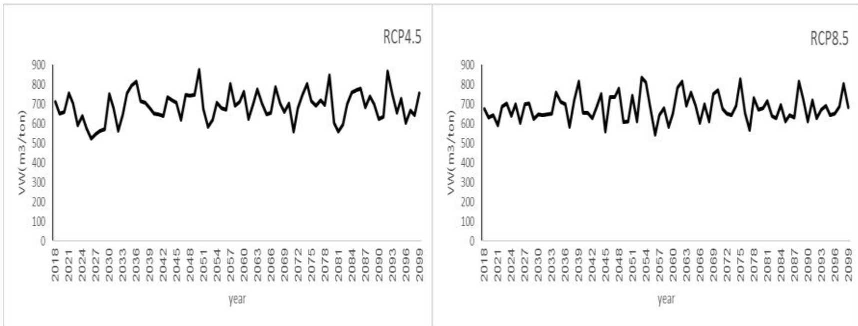

Figure 14. virtual water of potato crop, under RCP 4.5 and RCP 8.5 scenarios in kerman station (2018-2100)

3.4. Potato Crop

Under the RCP4.5 and RCP8.5 scenarios, the average virtual water of potato is lower than that of Jiroft and Kerman. Therefore, potato crop cultivation under both scenarios is not recommended in Kerman.

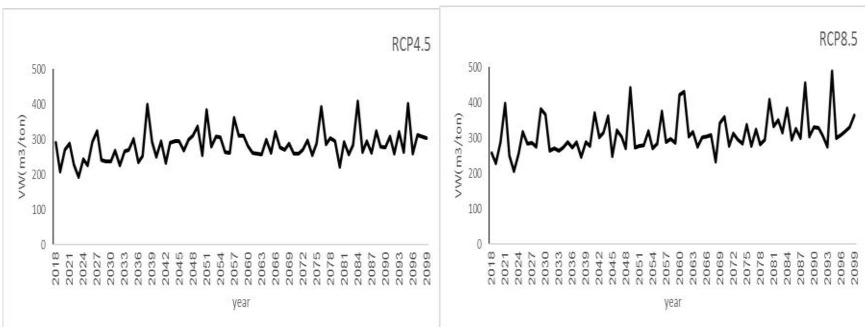

Figure 15. virtual water of tomato crop, under RCP 4.5 and RCP 8.5 scenarios in bam station (2018-2100)

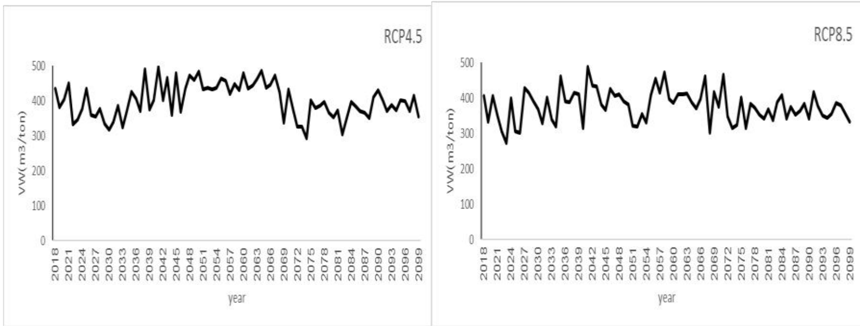

Figure 16. virtual water of tomato crop, under RCP 4.5 and RCP 8.5 scenarios in jiroft station (2018-2100)

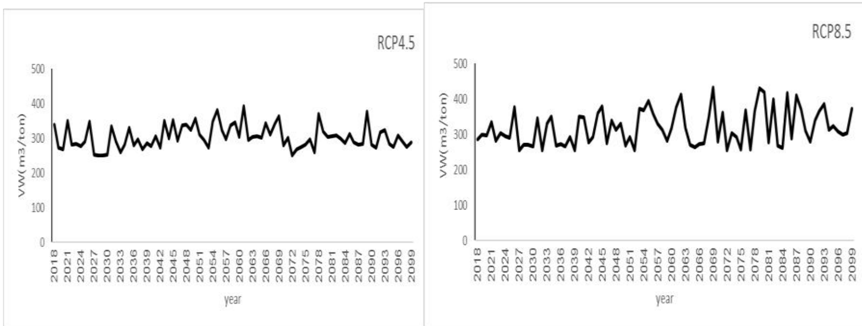

Figure 17. virtual water of tomato crop, under RCP 4.5 and RCP 8.5 scenarios in kerman station (2018-2100)

3.5 Tomato Crop

Under the RCP4.5 and RCP8.5 scenarios, the average water content of tomato, Bam is less than Kerman and Kerman less than Jiroft, and it seems that tomato cultivation in Jiroft would face water shortage.

4. CONCLUSION

The virtual water of all selected crops is projected to increase, but this increase would be higher for wheat and barley crops. The lowest increase in virtual water was observed in tomato crop during the future period of 2018-2100.In Bam station, the highest amount of virtual water belongs to barley crop during the period of 2040-2069, i.e. 4853 and 5153 cubic meter per ton under two RCP scenarios, respectively. In Jiroft wheat crop has the highest virtual water during the period 2040-2069 projected to be 4984 m3/ton. In case of Kerman station, largest amount of virtual amount under RCP4.5 belongs to wheat during the period 2040-2069 and under RCP 8.5 corresponds to barley with amount of 4256 m3/ton. Further studies in other climatic regions of the country are recommended for more precise decisions in agricultural water management.

5. REFERENCES

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M., 1998, Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. FAO, Rome.

Fang, S., Pei, H., Liu, Z., Beven, K., and Wei, z. (2010). Water resources assessment and regional virtual water potential in the Turpan Basin, China. Water resources management, 24:3321-3332.

Ghahreman, N., Tabatabaei, M., & Babaeian, I., (2015). Investigation of uncertainty in the IPCC AR5 precipitation and temperature projections over Iran under RCP scenarios, our common future under climate change conference, Paris, France.

Giorgi, F., 2009. NN5: A neural network based approach for the downscaling of precipitation fields–Model description and preliminary results. Journal of hydrology, 367(1), pp.14-26.

Hoekstra, A. Y., and Hung, P. Q. (2005). Globalisation of water resources: international virtual flows in relation to crop trade. Global environmental change, 15:45-56.

IPCC, 2013 SBSTA-IPCC special event on Working Group I contribution to the IPCC Fifth Assessment Report Climate Change 2013: The Physical Science Basis 12 November 2013 (Warsaw, Poland)

Mueller, B., Hauser, M., Iles, C., Rimi, R., Zwiers, F., Wan, H., 2015, Lengthening of the growing season in wheat and maize producing regions, Weather and Climate Extremes, 9: 47-56.

Majumder, M., Pramanik, S., Barman, R.N., Roy, P.K., & Mazumdar, A. (2010). Impact of climate change on the availability of virtual water estimated with the help of distributed neurogenetic models. DOI:10.1007/978-90-481-3581-3_2

Murphy, J. (1999). An evaluation of statistical and dynamical techniques for downscaling local climate. Journal of Climate, 12(8), 2256-2284.

Shuval, H. (2007). Virtual water in the Water Resource Management og the Arid Middle East. In Water Resources in the Middle East, pp. 133-139.

Ummenhofer, C., Xu, H., Twine, T., Girvetz, E., McCarthy, H., Chhetri, N., Nicholas, K., 2015, How climate change affects extremes in maize and wheat yield in two cropping regions, Journal of Climate, 28: 4653-4687

Velaquez, E. (2007). Water trade in Andalusia. Virtual water: An alternative way to manage water use. Ecological Economics, 63:201-208.

Yang, H., Wang,L., Abbaspour, K. c., and Zehnder, A. j. (2006). Virtual water trade: an assessment of water use efficiency in the international food trade. Hydrology and Earth System Sciences, 10:443-454.

Yano, T., Aydin, M., & Haraguchi, T. (2007). Impact of climate change on irrigation demand and crop growth in a Mediterranean environment of Turkey. Sensors, 7(10), 2297-2315.

Zhao, Q., Junguo, L., Nikolay, K.H., Obersteiner, M. and Westphal, M. (2014). Impacts of climate change on virtual water content of crops in China. Ecological Informatics, 19:26-34.