# CHANGES IN IRRIGATION WATER USE EFFICIENCY INDICES UNDER THE IMPACT OF UNCERTAINTY OF CLIMATE CHANGE IN THE FUTURE PERIODS CASE STUDY: HASHTGERD PLAIN (IRAN)

# IMPACT DE L'INCERTITUDE DU CHANGEMENT CLIMATIQUE SUR LES INDICATEURS DE L'EFFICIENCE D'UTILISATION DE L'EAU D'IRRIGATION DANS L'AVENIR ETUDE DE CAS : PLAINE DE HASHTGERD

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## *ABSTRACT*

*In this paper, the risk analysis of water use efficiency of Hashtgerd plain is described considering the uncertainty of AOGCM (Atmospheric Ocean General Circulation Model) in simulating climate variables in the future period. The output of nine AOGCMs was used under the A2 scenario. Using Monte Carlo method, weighting approach, and change factor downscaling method, 2000 time series of temperature and precipitation were produced for the study area. AEZ / GIS approach was adopted to calculate potential yield of the crops in 2005 (as the baseline year) and future periods in the study area. Hargrive – Samani method was used to calculate daily potential and reference evapotranspiration. Using soil water balance model net crop-water requirements of each crop of the study area were calculated in 2005 and in the 2010-2100 period. Results shows regional temperature increase in the future years on average between 1.7$^0$C to 3$^0$C. The average precipitation changes in the region would be between -18 and 20 per cent. The range of changes in water use efficiency for alfalfa, barley, maize and wheat, up to year 2100 are 3.8 - 4.5, 0.11 - 0.28, 4.7 - 5.45 and 0.04 - 0.1 $m^3\ kg^{-1}$ potential, respectively.*

**Keywords:** *uncertainty, AOGCM models, AEZ / GIS, water use efficiency.*

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# *RESUME ET CONCLUSIONS*

*L'augmentation des gaz de serre dans de dernières décades a provoqué l'augmentation de température et a changé la balance de système de climat de la Terre. Cela augmentera le taux d'évaporation, le potentiel evapotranspiration des végétations et l'eau d'irrigation demande et vont faire aussi les changements la production de récoltes dans l'avenir. D'autre part à cause des ressources limitées d'eau, la sécurité de nourriture pour les générations futures est en danger ainsi cela peut être les défis agricoles les plus importants dans l'avenir. Le fait d'évaluer dans ce cas-là l'index d'efficacité d'utilisation agricole d'eau est nécessaire dans l'avenir. De nos jours la production d'AOGCM (l'Océan Atmosphérique général Circulation Model) est l'instrument le plus sûr pour les études de changement climatique. Mais la production de juste un modèle est probable pas le représentant de l'avenir. Dans l'étude du présent une nouvelle méthodologie est présentée pour évaluer l'impact d'incertitude AOGCM de l'index d'efficacité d'utilisation agricole d'eau en ce qui concerne la capacité de ces modèles de simuler les conditions climatiques actuelles. On a considéré que la plaine agricole Hashtgerd a accompli cette méthodologie. À ce propos, au début, la région d'étude a été divisée à 5 × 5 réseau de cellules de minute et région cultivée (en incluant du blé d'hiver, une orge d'hiver, un maïs et une luzerne) de chaque cellule ont été calculés dans l'année de ligne des bases (2005).*

*Pour calculer la moyenne à long terme de température et de précipitation de chaque cellule dans l'année de ligne des bases, une fonction de corrélation multivariate a été mise entre l'altitude, la latitude et la longitude de chaque cellule avec la précipitation mensuelle de 35 ans et la température. Pour produire les variables climatiques de la région d'étude dans la période 2010-2100, la production de neuf modèles d'AOGCM sous le scénario d'émission A2 a été utilisée. En lestant les modèles de climat et en utilisant des méthodes de Monte-Carlo, 2000 le nombre de série de temps de température et de précipitation pour chaque cellule ont été produits. Cette série de temps était downscaled à la région d'étude en utilisant la méthode de facteur de changement. La production potentielle de chaque récolte dans chaque cellule a été calculée dans l'année de ligne des bases et l'avenir basé sur l'AEZ / l'approche de GIS. Référez-vous tous les jours à evapotranspiration et le potentiel de récolte evapotranspiration de la région d'étude ont été aussi calculés en utilisant la méthode de Hargreeves-Samani. En utilisant du sol - de l'eau - un modèle de balance d'équipement, la quantité de demande d'eau de récolte nette de chaque cellule a été calculée dans la ligne des bases et la période future. Les résultats montrent que la température de la région d'étude augmentera entre 1.7 à 3 centigrades et la quantité de précipitation dans la région variera-18 à 20 pour cent dans l'avenir. Finalement les résultats montrent que l'index d'efficacité d'utilisation agricole d'eau changera entre 3.8-4.5, 0.11-0.28, 4.7-5.45 et 0.04-0.1 mètres cubiques par production de potentiel de kilogramme pour la luzerne, l'orge d'hiver, le blé d'hiver et le maïs respectent respectivement à l'année de ligne des bases. Ainsi le maïs prendra la moindre partie d'effet de changement climatique du point de vue de l'efficacité d'utilisation d'eau dans la région d'étude dans l'avenir.*

***Mots clés:*** *Uncertitude, modèles AOGCM, AEZ/GIS, efficience d'utilisation de l'eau.*

*(Traduction française telle que fournie par les auteurs)*

# 1. INTRODUCTION

The average land surface temperature has been increasing due to greenhouse gas emissions. The Intergovernmental Panel of Climate Change(IPCC) estimated an increase in average global temperature 6.4$^0$C up to 2100 (IPCC, 2007). Any changes in temperature are expected to increase potential evapotranspiration and subsequently irrigation water requirements and the agricultural production and water use efficiency will change eventually (Alijani & Ghavidele rahimi, 2005). In many studies, researchers investigated the impact of climate change on these parameters using an AOGCMI. For example, Xingguo et al (2009) found that the levels of performance and reference crop evapotranspiration of winter wheat increased and water use efficiency improved due to climate change. But summer corn yields and water requirements of plants has increased and decreased, respectively. Thus the efficiency of water use has decreased.

It should be noted that an AOGCM model can't represent the likely future (Wilby & Harris, 2005). In studies of the impact of climate change on different systems in future periods, variety of sources of uncertainty affect final results, so that ignoring any source of uncertainty in calculations could reduce the applicability of the results (Massah Bavani, 2006). The most important sources of uncertainty in Climate change studies is those related to Atmosphere-Ocean General Circulation Model (AOGCM) (Massah Bavani, 2006) therefore in climate change studies the maximum number of climate models should be used in order to reduce the error due to uncertainty related to these models. In this respect Pearson et. al. (2008) used the results of five AOGCM models to investigate the impact of climate change on crop yield in 101 regions in Canada and showed that crop yield improved in most of the regions. This paper presents a methodology to investigate the effects of AOGCM uncertainty on water use efficiency index of Hashtgerd plain using AOGCM weighting method and Monte-Carlo approach.

# 2. MATERIAL AND METHOD

## 2.1 Data and study area

Study area of this research is Hashtgerd plain, located in the West of Tehran province between 35° 50' to 36° 20' north latitude and 50° 25' to 51° 10' east longitude. Needed climatic parameters for calculations were prepared from the synoptic and climatology of Meteorological Organization stations and the meteorological stations of Ministry of Energy in the study area and surrounding agricultural area for 35-year period (1971-2005). Correction and completion of data was done using appropriate statistical tests. The study area was divided to the 5' × 5' cells and the area of the crop pattern of each cell including winter wheat, winter barley, corn silage and alfalfa were calculated per cell in 2005 (baseline year). To calculate the amount of rainfall and temperature of each cell of the study area, SPSS software was used to correlate 35-year monthly rainfall and temperature with latitude and longitude and altitude of each station. So monthly long-term average of rainfall and temperature of each cell were calculated according to the latitude, longitude and altitude of each cell.

## 2.2 Constructig climate change senario

To produce regional climate scenarios in future periods, data of monthly temperature and precipitation from nine AOGCMs, including; CSIRO MK3, GFDL, CM2.1, CGCM3, GISS E_R, HADCM3, ECHAM5, MIROC-med, PCM, CCSM3, were downscaled using change factor method to Hashtgerd plain. In change factor method, equations 1 and 2 are used for precipitation and temperature, respectively:

$$\Delta P_{future} = MP_{future} / MP_{1971\text{-}2000} \qquad (1)$$

$$\Delta T_{future} = MT_{future} / MT_{1971\text{-}2000} \qquad (2)$$

In this relationship $\Delta P_{future}$ is precipitation climate change scenario, $MP_{future}$ 30-year mean monthly precipitation for the future period from AOGCM, and $MP_{1971\text{-}2000}$ 30-year mean monthly precipitation for the baseline period from AOGCM. For temperature the aforementioned descriptions are the same.

## 2.3 Weighting climate model

In this study each AOGCM is weighted based on the ability of the model to produce the observed climate variables. Equation 3 was used to weight AOGCMs of this study for temperature and precipitation separately.

$$R_i = \frac{\frac{1}{B_{x,i}}}{\sum_{i=1}^{N} \frac{1}{B_{x,i}}} \qquad (3)$$

In this equation, $B_{x,i}$ is the deviation of temperature or precipitation simulated by the AOGCMs in baseline period in each month (x) from the observed data, N is the number of AOGCMs and $R_i$ are weight given to each of the AOGCMs.

After defining the weights of each AOGCM in each month, Monte Carlo method was used to produce 2000 monthly ΔT and ΔP for three periods 2010-2039, 2040-2069 and 2070-2099. Finally by using equations 4 and 5, 2000 monthly time series of precipitation and temperature were simulated for each cell of study area.

$$P_{future} = PL + \Delta P_{future} \qquad (4)$$

$$T_{future} = TL + \Delta T_{future} \qquad (5)$$

In above equations, $P_{future}$ and $T_{future}$, are monthly time series of precipitation and temperature, respectively, for each cell of the region in future period, and the $P_L$ and $T_L$, are observed monthly time series of precipitation and temperature, respectively, for each cell of the region (described in section 2-1). Equation (5) was used for mean, maximum and minimum temperature separately.

## 2.4 Estimation of reference, potential, actual evapotrancpiration

In this study Hargreaves - Samani method (Alizadeh, 2005) was used to estimate potential evapotranspiration (ET). To evaluate the capability of this method, the simulation of observed ET by Hargreaves - Samani method were compared to Penman-Montith model (as the base model), and it was concluded that Hargreaves - Samani can simulate ET of the study area with high accuracy. Afterwards, 2000 time series of temperature of each cell of the study area were introduced to Hargreaves - Samani and 2000 time series of ET were produced for each cell. Finally, according to the crop pattern of every cell of the region, crop water requirement were calculated in each cell according to Equation 6:

$$ETc = Kc.ET0 \tag{6}$$

In this study, relationships and values presented in the FAO paper No. 56 for each crops at different stages of growth was used to calculate $K_c$ value. To calculate actual ET (ETa) Crop-Specific Soil-Water Balance Model was used (Tao, 2003). This model considering soil moisture and lack of soil moisture during the growing season, the amount of actual ET in crops exposed to water deficit stress. Actual ET during the day j ($ET_{a_j}$) is calculated using the following relationship:

$$\begin{aligned} &if\ \left(W_j^c + P_j^r + M_j\right).d \geq Sa.d.(1-p_j) \\ &ET_{a_j} = ET_{p_j} \\ &\quad else \\ &ET_{a_j} = \rho_j . ET_{p_j} \end{aligned} \tag{7}$$

That $\rho_j$ is:

$$\rho_j = \frac{ET_{a_j}}{ET_{c_j}} = \frac{W_j^c + P_j^r + M_j}{Sa.(1-p_j)} \tag{8}$$

$W_j^c$ is soil moisture at the end of day j (mm), $P_j^r$ rainfall at day j (mm), $M_j$ daily snowmelt (mm), $ET_{a_j}$ actual ET at day j (mm), $\rho_j$ coefficient of actual ET, Sa soil water holding capacity (mm / m), d the depth of root development (m) and Pj soil water depletion coefficient when $ET_{a_j} < ET_{p_j}$.

## 2.5 Irrigation water riquirement

Irrigation water requirement (IWR) is the amount of water (in addition to available soil moisture due to rainfall) that a plant needs without any stress for growth in agricultural areas. Net irrigation water requirement calculated during crop growth and daily step per cell, using the Equation 9:

$$IWR = \sum_{j=1}^{n} \sum_{k=1}^{m} (ET_p^i - ET_a^i) \tag{9}$$

In this equation n represent the number of plants in cell i, and m is the number of day of growth. Net volume of irrigation water requirement (WRQ) in cell i is calculated from the Equation 10:

$$WRQ_{i(t)} = IWR_{i(t)} \times A_{i(t)} \quad (10)$$

In this equation t indicate year. $A_i(t)$ is the total amount of irrigated land in each cell in the future which in this study was assume that its value is fixed and equal with water agricultural lands in baseline year (2005). Introducing 2000 time series of potential ET and actual relationship of each cell in the future period to above equations 2000 time series of net irrigation water requirement of each cell were calculated for future years.

## 2.6 Agro-ecological zoning (aez/gis) model

AEZ approach was presented by Kasam in 1979 for calculating potential crop yield by using relationships provided by DeWit (1996) (Jarallhy, 1379). FAO and International Institute of Applied System Analysis (IIASA), developed some method of AEZ for optimum use of land and water resources (Fisher, 1996). To improve the AEZ method, this approach recently was integrated with Geographic Information System (GIS) (Fischer, 2005) and produced AEZ/GIS approach.

## 2.7 Irrigation water use efficiency

Potential irrigation water use efficiency index is the amount of irrigation water needed to produce a unit potential. The index is set using the following equation:

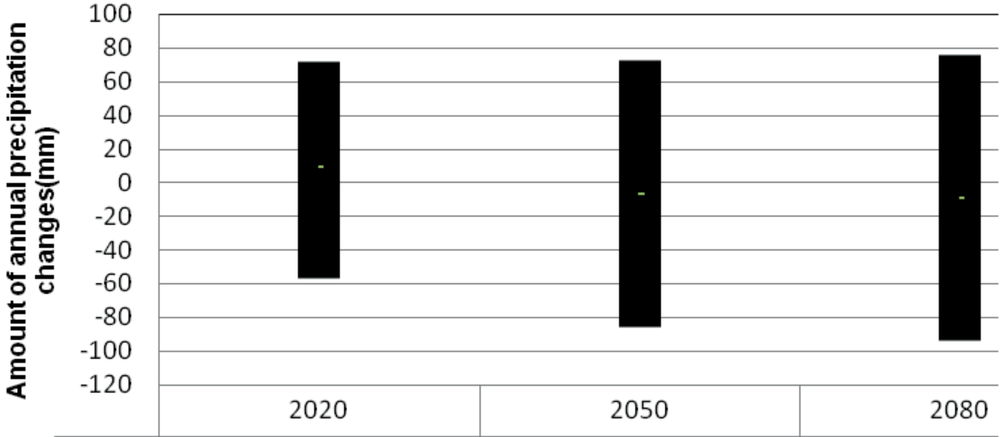
$$PWUE_{i(t)} = WRQ_{i(t)} / Y_{mp\,i(t)} \quad (11)$$

Using this index, the ability to supply water requirement of cultivated crops by water resources in future years was examined (Fischer et al., 2007).

# 3. RESULTS AND DISCUSSION

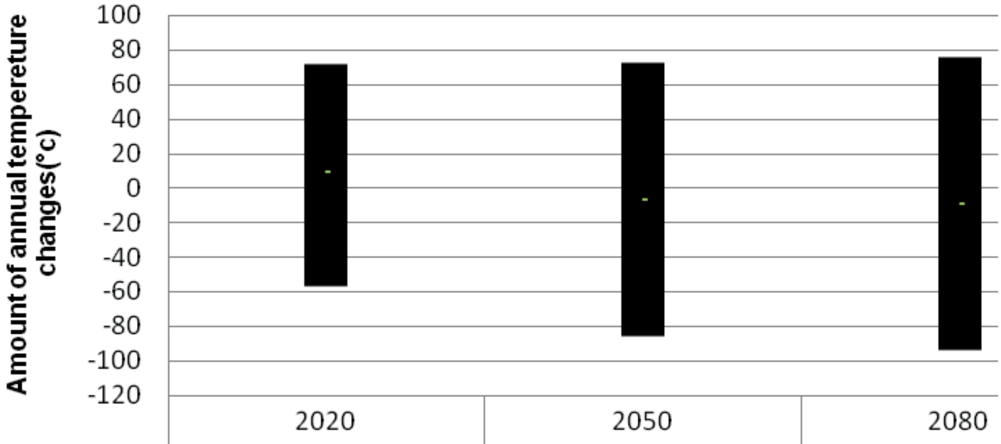
## 3.1 Regonal temperature and precipitation changes in future periods

Regional precipitation and temperature changes in future periods (2010 to 2100) compared to baseline year (2005) are shown in Figure 1 and Figure 2, respectively. It is observed that the average of variation of rainfall in future periods relative to the baseline year shows no significant difference, while the values for these scenarios at minimum and maximum variation have significant changes. Figure 2 also shows the average, minimum and maximum scenarios of temperature changes in future relative to the baseline year. It is concluded that the average of temperature increase 1.8 to 3.1 ° C up to 2080.




| | 2020 | 2050 | 2080 |
|---|---|---|---|
| min | -56.65 | -85.49 | -94.22 |
| max | 71.65 | 72.17 | 75.97 |
| mean | 9.5 | -6.66 | -9.13 |

Fig. 1. Changes in precipitation in future periods relative to the baseline year in Savojbolagh. (Changements dans les précipitations que dans les périodes futures sur la base des Savojbolagh)

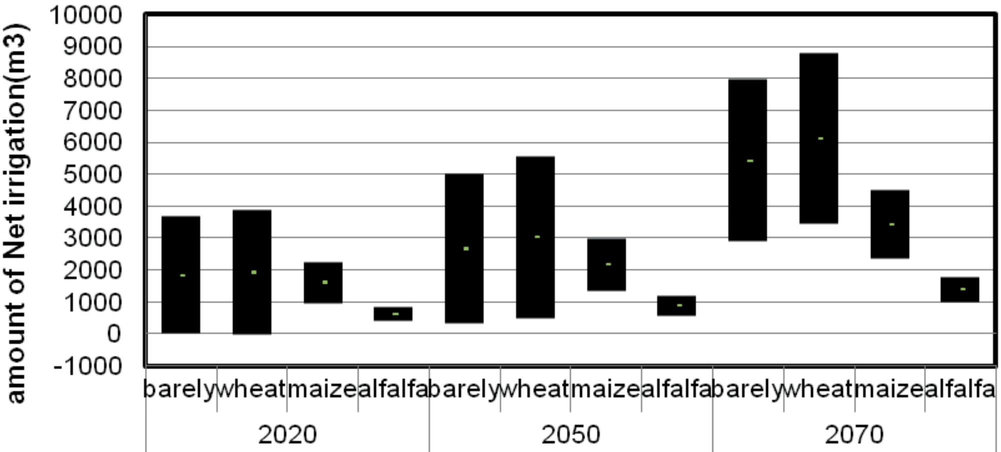



| | 2020 | 2050 | 2080 |
|---|---|---|---|
| min | -56.65 | -85.49 | -94.22 |
| max | 71.65 | 72.17 | 75.97 |
| mean | 9.5 | -6.66 | -9.13 |

Fig. 2. The mean temperature changes in future periods relative to the baseline year in Savojbolagh. (Les changements de température moyenne dans les périodes futures de l'année de référence dans la ville de Savojbolagh)

## 3.2 Assing the net volume of irrigation water requirement of hashtgerd plains in future years

Figure 3 shows the net volume of irrigation water requirement of Hashtgerd Plains in future years. Based on the results, it can be seen that net volume of irrigation water requirement will increase in all future periods in all crops of the study area. Scenarios show that the minimum and maximum of increase volume for alfalfa, is 2501.9 and 4176.2 cubic meters respectively. On the other hand the range of increase for wheat, barley and maize are 11728.30 - 20735, 10207.6 - 18389 and 7468.4 – 12107.7, respectively.

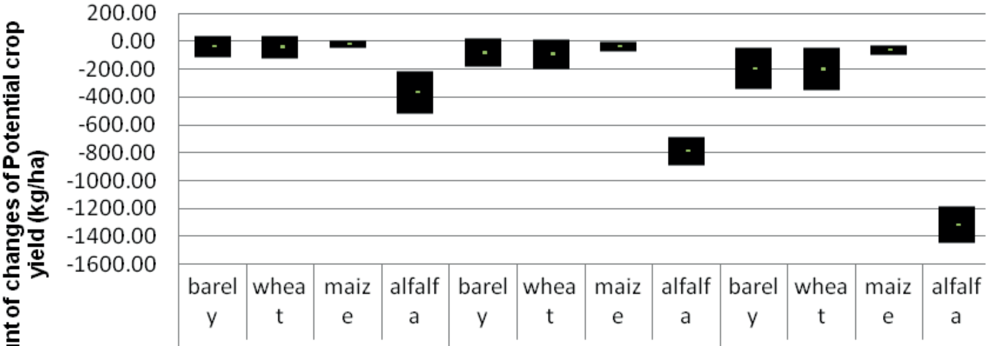



| | barely | wheat | maize | alfalfa | barely | wheat | maize | alfalfa | barely | wheat | maize | alfalfa |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 | | | | 2050 | | | | 2070 | | | |
| min | -1. | -26 | 971 | 398 | 310 | 467 | 132 | 545 | 288 | 343 | 234 | 999 |
| max | 366 | 386 | 223 | 827 | 501 | 557 | 299 | 119 | 795 | 879 | 449 | 175 |
| - mean | 183 | 192 | 160 | 613 | 266 | 301 | 215 | 868 | 541 | 611 | 342 | 137 |

Fig. 3. Uncertainty range of plants WRQ changes in future periods compared to baseline year. (plage d'incertitude de l'évolution des plantes WRQ dans les périodes futures par rapport à l'année de reference)

## 3.3 Assessing the potential crop yield of hashtgerd plains

Based on the results of Figure 4, it is observed that the potential crop yield of all crops of the study area will be reduced until 2090. For example, minimum and maximum yield of alfalfa will decrease in 2090 from 132.9 to 143.1 kg/ha, respectively. The reduction for maize will be 4.2 to 8 kg/ha. But the maximum yield of wheat and barley will increase to 2050 period and then will decrease to 2090. It should be noted that it is more likely (more than 99%) that the yield of all crops of the study area will decrease up to 2100. Meanwhile, the minimum of crop yield will reduce in future period. On the other hand, the minimum and maximum crop yield of wheat and barley will decrease 6.16 to 5.5 kg/ha for wheat and 33.8 to 32.8 kg/ha for barley.

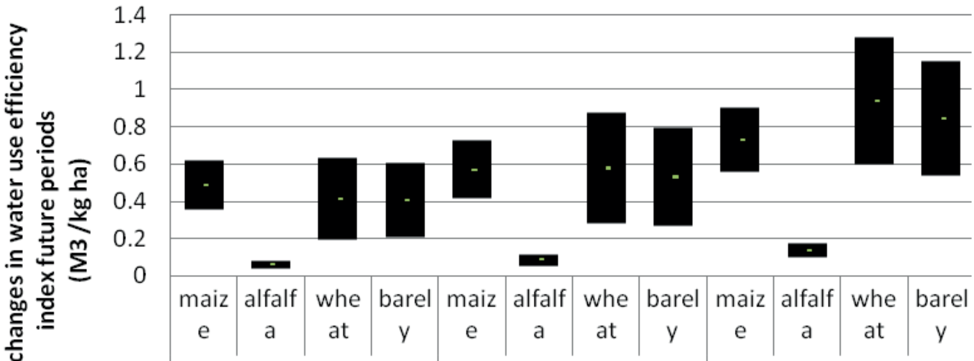



| | 2020 | | | | 2050 | | | | 2070 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | barely | wheat | maize | alfalfa | barely | wheat | maize | alfalfa | barely | wheat | maize | alfalfa |
| mn | -114 | -121 | -48. | -519 | -184 | -199 | -71. | -891 | -343 | -351 | -97. | -144 |
| max | 35.8 | 37.1 | 4.76 | -215 | 19.3 | 13.5 | -7.7 | -685 | -47. | -52. | -33. | -118 |
| - mean | -39. | -42. | -21. | -367 | -82. | -92. | -39. | -788 | -195 | -202 | -65. | -131 |

Fig. 4. Range of uncertainty YMP changes to the baseline year in future periods.( distance des changements PMJ incertitude à l'année de référence dans les périodes futures)

## 3.4 Evaluatiom of crop water use efficiency index

Figure 5 shows the range of water use efficiency index for the study area in the future. Based on these result the range of this index for alfalfa, winter barley, maize and winter wheat are 3.8-4.5, 0.11- 28.0, 4.7-5.45, 0.04-0.1 cubic meters per kilogram potential.




| | 2030 | | | | 2060 | | | | 2090 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | maize | alfalfa | wheat | barely | maize | alfalfa | wheat | barely | maize | alfalfa | wheat | barely |
| min | 0.35 | 0.04 | 0.19 | 0.20 | 0.41 | 0.05 | 0.28 | 0.27 | 0.55 | 0.09 | 0.59 | 0.54 |
| max | 0.62 | 0.07 | 0.63 | 0.60 | 0.72 | 0.11 | 0.87 | 0.79 | 0.89 | 0.17 | 1.28 | 1.14 |
| - mean | 0.48 | 0.06 | 0.41 | 0.40 | 0.57 | 0.08 | 0.57 | 0.53 | 0.72 | 0.13 | 0.94 | 0.84 |

Fig. 5. water use efficiency index in future periods ($m^3$/kg.ha).( Les changements de taux dans les périodes d'utilisation de l'eau indice de l'efficacité future ($m^3$/kg.ha))

# 4. CONCLUSIONS

This study analyzes the impact of climate change uncertainties on crop water use efficiency index of Hashtgerd plain. To produce climatic parameters in future periods data of CSIRO MK3, GFDL CM2.1, CGCM3, GISS E_R, HADCM3, ECHAM5, MIROC_med, PCM, and CCSM3 models under A2 emission scenario were used. Change factor method was also used for downscaling the climate data. To calculate the daily reference evapotranspiration Hargreaves - Samani method was selected. For simulating crop potential evapotranspiration, methods of FAO 56 publication was used, and for simulating actual evapotranspiration soil water balance model was implemented. The net crop water requirements was calculated and by considering the area of each crop, net volume of required water in the baseline year (2005) and future period was evaluated, and then the potential yield of each crops of study area, was calculated. Finally the water use efficiency index was produced for the study area in the future. The results indicate that water use efficiency index increases in the future.

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