CLIMATE CHANGE AND AGRICULTURAL WATER DEMAND: ASSESSING IMPACT OF UNCERTAINTIES OF AOGCM AND DOWNSCALING METHODS

CHANGEMENT CLIMATIQUE ET BESOINS EN EAU AGRICOLE : EVALUATION DE L'IMPACT DES INCERTITUDES DU MODELE AOGCM ET DU MODELE D'ECHELLE REDUITE

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ABSTRACT

One of the most significant consequences of climate change is its impact on agricultural water demand. In Iran, because the most of water recourses were consumed in agricultural sector, study about negative impact of climate change on this sector is important. But due to the uncertainty accompanying the projections of greenhouse-induced Climate change using AOGCMs and downscaling methods, specific impacts predicted by AOGCM may be erroneous and cannot be used for future planning purpose with any sense of dependability. In this research, nine new model AOGCM-AR4 including CCSM3, CGCM3, CSIRO Mk3, GFDL CM2.1, GISS ER, HadCM3, ECHAM5, MIROC-med, PCM (under A2 emission scenario) and two downscaling methods including; change factor and SDSM were used to evaluate the impact of climate change on agriculture water demand in Qazvin irrigation network for 2010-2039 period. Results show that crop water requirement increase through Change factor and SDSM methods at 50% probability up to 40% and 30%, respectively during 2010-2039 period. In other words, this increase, based on the present crops cultivated area, will increase the volume of crop water demand to 173 to 188 MCM/year by SDSM and Change factor methods, respectively.

Key words: *Climate change, Agricultural water demand, AOGCM, Downscaling, Iran.*

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RESUME ET CONCLUSIONS

L'Une des conséquences les plus significatives du changement climatique est son impact sur la demande en eau agricole qui est considéré comme un sérieux défi pour l'avenir de recours de l'eau. En Iran, parce que la plupart des ressources de l'eau ont été consommés dans le secteur agricole, l'étude sur l'impact négatif du changement climatique sur ce secteur est important. Mais en raison du degré élevé d'incertitude qui accompagne les projections de serre Les changements climatiques induits tels que le modèle et les méthodes de réduction d'échelle MCGAO, les impacts spécifiques ne peut pas être prédit avec une grande précision et ne peut pas utiliser pour la planification et de gestion pour l'avenir.

Par conséquent, dans cette recherche pour l'examen de ces incertitudes, neuf CCSM3 nouveau modèle MCGAO-AR4, y compris, MCCG3, CSIRO Mk3, GFDL CM2.1, GISS ER, HadCM3, ECHAM5, Miroc-med, PCM (dans le scénario d'émissions A2) et deux downscaling y compris les méthodes; facteurs de changement et SDSM ont été utilisés pour évaluer l'impact du changement climatique sur la demande en eau agricole dans le réseau d'irrigation Qazvin pour 2010-2039 période.Les cultures ont été sélectionnées de blé, orge, betteraves à sucre et le maïs qui sont les principales cultures de la région. Tout d'abord, trois équations évapotranspiration de référence, y compris: Penman-Montith, Hargreaves-Samani, Jensen-Haize a été comparé pour la période de base, puis la meilleure équation a été choisi pour calculer l'évapotranspiration de référence.

Équation de Penman-Montith a été considérée comme un critère et deux autres équations ont été comparés avec elle. Grâce à une grande incertitude pour simuler des variables Penman-Montith à l'avenir, il n'a pas été utilisé pour le calcul de l'évapotranspiration.

Ensuite, les données des neuf sélectionnés modèles MCGAO-AR4 ont été extraites pour la région intéressée et à échelle réduite ont été pour la région.

A ce stade de l'examen d'incertitude et de l'analyse des risques, 2000 échantillons de maximum et minimum des séries chronologiques de température par la méthode de pondération PIMM ont été construits pour réduction d'échelle avec la méthode facteur de changement et 200 maximum et minimum des séries chronologiques de température a été construit avec la méthode SDSM.

Troisièmement, ces séries de températures maximales et minimales ont été introduits séparément dans les équations sélectionnées évapotranspiration de référence. En outre, la longueur croissante de chaque culture a été calculée à l'avenir en utilisant des températures maximales et minimales et l'équation GDD.

Basé sur l'augmentation de la température à l'avenir, de plus en plus la longueur de chaque culture a diminué en comparaison avec la période de base. Quatrième évapotranspiration des cultures, pour chaque culture au cours de différents stades de croissance a été déterminée en multipliant la valeur Kc et de l'évapotranspiration de référence.

En cela, les changements d'évapotranspiration du réseau d'irrigation au cours des périodes 2010-2039 dans le scénario A2 ont été déterminés. Sur la base des différents modèles *et méthodes de réduction d'échelle, une augmentation de la demande en eau du secteur agricole sera inévitable et les incertitudes et les risques seront impliqués.*

Pour chaque culture, les différences entre les cultures évapotranspiration la période de référence (1961-1990) et la période à venir (2010-2039) ont été montré que la fonction de distribution cumulative (CDF).Enfin, le volume croissant de demandes en eau pour toutes les cultures dans le réseau d'irrigation de la probabilité de 25%, 50% et 75%, due à chacun des méthode de réduction a été déterminée. Les résultats montrent qu'augmenter les besoins en eau des cultures par le changement de méthodes et de facteur de SDSM à une probabilité de 50% à 40% et 30% respectivement au cours de 2010-2039 périodes. D'autres mots, cette augmentation, sur la base des récoltes actuelles superficie cultivée, va augmenter le volume de la demande en eau des cultures de 173 à 188 MCM / an par SDSM et méthodes facteur de changement.

Mots clés : *Changement climatique, besoins en eau agricole, AOGCM, échelle réduite, Iran.*

(Traduction française telle que fournie par les auteurs)

1. INTRODUCTION

Change of climate ensues from the increase of greenhouse gases due to human activity and to the industrial development of countries, and leads to the increase of the Earth's temperature. Global warming affects different sections, among which the agricultural and water resources are the main (Purkey, et al, 2007). The average temperature of the surface of the earth is increasing due to the dissipation of the greenhouse gases, so that the recent IPCC[5] scenarios have estimated an average global temperature increase of 0.76^{0}C for the last century, and up to 6.4 degrees increase by the year 2100 (IPCC, 2007). Such changes or the global warming are considered as the most important manifestation of the change of climate in the present century and it is expected that this increase will lead to the increase of evaporation and transpiration, and will enable the atmosphere to displace higher amounts of water vapor (Alijani and Rahimi, 2005).

Since agriculture is the major water consumer in Iran, the investigation and evaluation of the effects of climate change on water demand in the future may help in building the nation's preparedness in mitigating the negative effects of this phenomenon. However, it should be noted that the estimation of the behavior of nature in the future is fraught with uncertainties (Wilby and Harris, 2006) due to unpredictability of the very nature, which some models try to rationalize. Nonetheless, the Atmosphere-Ocean General Circulation Model (AOGCM) and certain downscaling methods are relied upon and used these days for future atmospheric behaviour prediction. The present study investigats the effect of climate change on the water demand of the crops in the Qazvin Plain during the period 2010-2039; and presents the results in the form of probability graphs for each month by introducing the different sources of uncertainty into computations. These results, obtained by using the latest technology, may be useful for decision making with respect to water resources.

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2. MATERIALS AND METHODS

2.1 Study Area

The 5609 km^2 Qazvin Plain has semi-arid climate and is situated in the Salt Lake basin and Shur Sub basin, and is the largest of the plains in the basin. Among the main crops in this plain; wheat; barley; maize (fodder); and beet can be mentioned. The average annual precipitation in the Qazvin Plain is 250 mm. The meteorological stations in the region consist of the Bagh-e Kosar, Takestan, and Shahid Rejaee Power crop climatological stations, and the Qazvin Synoptic Station (Fig. 1).

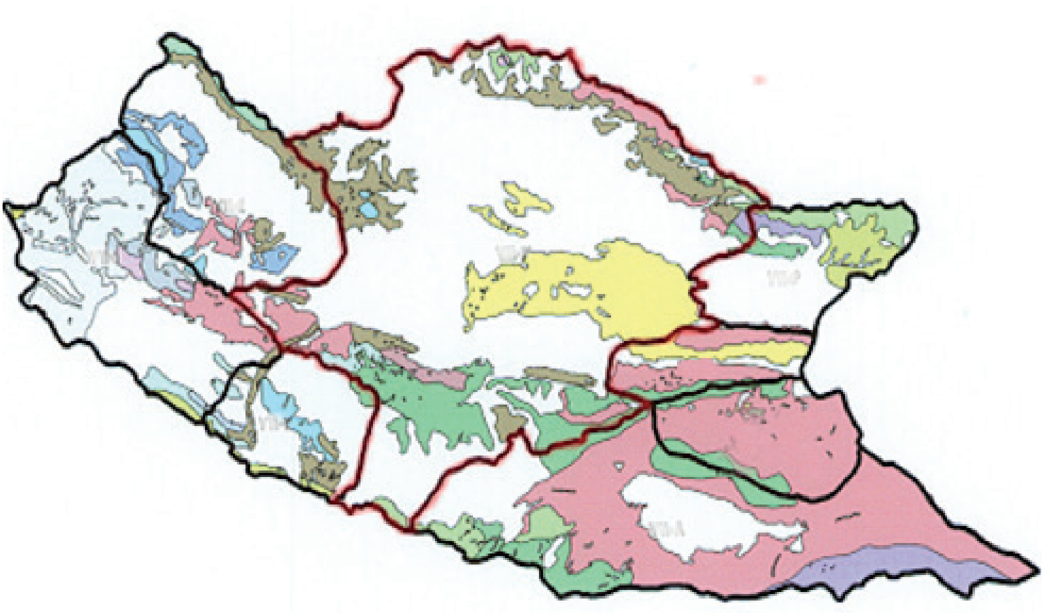

Fig. 1. Location of the Qazvin Plain in the Shur Sub basin (Situation de la Plaine dans le bassin de Shur Sous Qazvin)

2.2 Climatological Scenario

At present, the most reliable tool to produce climatological scenarios is the coupled three-dimensional atmosphere-ocean general circulation models (Massah Bavani, et al. 2006). These models are based on physical laws represented through mathematical relations, which are solved in a 3-D network at the Earth's surface. The AOGCMs used in this research are the subdivision of the fourth evaluation report, IPCC (AR4), published in 2007. Table 1 shows nine AOGCMs available at the IPCC-AR4 data base, whose outputs have been used in this research.

Table 1. Characteristics of nine AOGCMs available at the IPCC-AR4 data base whose outputs have been used in this research (Caractéristiques des modèles MCGAO neuf disponible à la base IPCC-AR4 données dont les sorties ont été utilisés dans cette recherche)

name of the model	the group compiling the model	simulation scenario	resolution power		Reference
			Atmospheric	Oceanic	
CCSM3	NCAR(USA)	A2,B1	1.4°. 1.4°	0.46°. 1.125°	Collins et al.(2006)
CGCM3	CCCMA(Canada)	A2,B1	3.75° .3.75°	1.875° .1.875°	Kim et al.(2002,2003)
CSIRO MK3	ABM(Australia)	A2,B1,A1F1	1.875° .1.875°	0.95°. 1.875°	Gordon et al.(2002)
GFDL CM2.1	NOAA/GFDL(USA)	A2,B1	2°. 2.5°	0.9°. 1.0°	Delworth et al.(2006)
GISS E-R	NASA/GISS(USA)	A2,B1,A1F1	4°. 5°	4°. 5°	Schmidt et al.(2006)
HADCM3	UKMO(UK)	A2,B1	2.5°. 3.75°	1.25°. 1.25°	Pope et al.(2000)
ECHAM5	MPI(Germany)	A2,B1	1.875° .1.875°	1°. 1°	Roeckner et al.(2003)
MIROC-MED	CCSR(Japan)	A2,B1	2.81°. 2.81°	0.9°. 1.4°	Hasumi and Emori(2004)
PCM	NCAR(USA)	A2,B1,A1F1	2.81°. 2.81°	1.0°. 1.0°	Washington et al.(2000)

2.3 Downscaling

The evaluation and determination of the effects of climate change (water resources, agricultural fields, energy, and transportation systems) necessitate high-resolution scenarios, whereas the AOGCMs compute with a resolution of several hundred kilometers. Due to this, there are different methods for the production of regional climatological scenarios from the AOGCMs. These methods are called downscaling methods. In this research, two downscaling methods; namely, the Proportional method and the Statistical method, have been used to investigate the effects of downscaling methods on the crop water requirements.

2.3.1. The Proportional Method

In this method, first the climate change for temperature is obtained through the following relation:

$$\Delta T_i = \bar{T}_{GCM,fut\ i} - \bar{T}_{GCM,base\ i} \qquad (1)$$

In which, ΔTi = climate change scenario relevant to temperature, for each month for the long-term average of 30 years ($12 \leq i \leq 1$),$T_{GCM,\ fut}$ = average temperature simulated through AOGCM model for 30 years, for each month of the future period, and $T_{GCM,\ base}$ is average temperature simulated through AOGCM model, for 30 years for each month of the base period.

Then, climate change scenarios are added, using the following relation, to the observed values, and the climatological scenario for the future is obtained, thus:

$$T = T_{obs} + \Delta T \quad (2)$$

In which, T_{obs} is temporal series of the observed temperature in the base period, T is temporal series obtained from the climatological scenario of temperature in the future period, and ΔT is downscaled climate change scenario

2.3.2. The Statistical Method

In this method, first the suitable statistical relation between predicting variables and predicted variables is developed, and then this relation is used to predict climatological variables in the future periods.

$$R=f(L) \quad (3)$$

In which, R is variable to be predicted (climatologically variable), L is predicting variables (a large-scale climatologically variable), and f is a function of L, and is computed with regard to observed data. In order to carry out statistical downscaling, the SDSM Software was used.

2.4 Estimation of Reference Crop Water Demand

In order to estimate the water demand of the reference crop, Modified Penman-Monteith, Hargreaves-Samani, and Modified Jensen-Haize equations were used.

2.4.1. Modified Penman-Monteith Equation

$$ETo = (0.408\Delta(Rn - G) + \gamma[890/((T + 273)U2(ea - ed)))/(\Delta + \gamma(1 + 0.34U2)) \quad (4)$$

$$\lambda = 2.501-(2.361 \times 10^{-3}) \times T \quad (5)$$

$$\gamma = 0.00163p/\lambda \quad (6)$$

$$\Delta = \frac{2504\exp\left[\frac{17.27T}{T+237.3}\right]}{(T+237.3)^2} \quad (7)$$

In these equations, ETo is the water demand, mm/day, of the reference crop; R_n, $MJm^{-2}\ d^{-1}$, is the net radiation at the surface of vegetation; T is the average temperature, °C, of the air at 2 m above the ground surface; U_2 is wind velocity at 2 m above the ground surface, ms-1; e_a-e_d, is vapor pressure deficit, Kpa, at 2 m above the ground surface, Δ slope of saturation vapor pressure curve at air temperature T [$kPa\ °C^{-1}$], γ is psychrometric constant ($kPa\ °C^{-1}$); G is the soil heat flux, $MJm^{-2}\ d^{-1}$, into the soil; λ is the latent heat of vaporization, ($MJkg^{-1}$); T is air temperature, °C, and p is atmospheric pressure, Kpa.

2.4.2. Hargreaves-Samani Equation

$$ETo = 0.0135\ k_T\ R_a\ TD\ (T+17.8) \quad (8)$$

$$K_T = 0.00185(TD)^2 - 0.0433\ TD + 0.4023 \quad (9)$$

In these relations, ETo is the water demand (mm/day) of the reference crop; T is the average daily temperature, (°C), and TD is the average difference between and Minimum temperatures in the intended period.

2.4.3. Modified Jensen-Haize Equation

$$ETo = C_T \times (T-T_X) \times K_T \times R_a \times TD^{0.5} \quad (10)$$

$$C_T = 1/(45- ((h/137)+(365/ (e_{sa,max} - e_{sa,min}))) \quad (11)$$

$$T_X = -2.5-0.14\ (e_{sa,max}-e_{sa,min}) - h/500 \quad (12)$$

$$S = (n/N) \times 100 \quad (14)$$

In these relations, ET_o is the water demand, mm/day, of the reference crop; h is the sea level elevation, m; $e_{sa,max}$ is the saturated vapor pressure (mbar) vis-à-vis air temperature in the warmest month of the year; $e_{sa,min}$ is the pressure of saturated vapor (mbar), vis-à-vis minimum air temperature in the warmest month of the year; T is daily average temperature, (°C); R_a is the extraterritorial radiation, in terms of mm water (see the Table); TD is the average difference of and minimum temperatures in the given period; S is the percentage of solar radiation in the area, and n is the real hours sunlight.

2.5 Estimation of the Crop Water Requirements

The crop water requirement is calculated through the following equation if crop coefficients are available:

$$ETc = K_c \times ETo \quad (15)$$

Here, ET_c is the water demand of the intended crop, and Kc, which is different for different stages of growth, is the crop coefficient of the crop.

Table 2. Crop coefficients for different growth stages of the crops being studied (Coefficients de la culture de différents stades de croissance des cultures à l'étude)

Crop	Crop coefficient (Mid-season)	Crop coefficient (Late- season)	Crop coefficient (Initial)
corn	1.32	0.84	0.6
sugar beet	1.31	0.83	0.3
wheat	1.15	0.3	0.7
barley	1.15	0.25	0.35

Table 3. Area under the different crops cultivation in the Qazvin Plain, Jamab Consultants, 1384 (L'aire sous la culture de différentes cultures dans la plaine de Qazvin (Conseillers Jamab, 1384))

Crop	Area under cultivation (ha)
corn	4565
sugar beet	1532
wheat	47160
barley	64194

Table 4. Date of cultivating different crops in the Qazvin Plain (Date de produire des cultures différentes dans la plaine de Qazvin)

Crop	Date of Cultivation
corn	13 May
sugar beet	1 April
wheat	13 October
barley	13 October

Table 5. Growth period length of the of crops(Durée de la période de croissance des cultures)

Length of the growth period in base period	crop
corn	150
sugar beet	176
wheat	241
barley	231

2.6 Length of the growth period

The length of the crop growth was calculated using the growing degree-day index as follow:

$$GDD = (T_{MAX}+T_{MIN})/2 \qquad (16)$$

$$IF\ T_{MIN} < T_{bas} \qquad T_{MIN} = T_{bas}$$

$$IF\ T_{MAX} = 30 \qquad T_{MAX} > 30$$

In Equation (16), T_{Max} and T_{Min} are daily and minimum temperatures, respectively; and T_{bas} is the necessary base temperature for the growth of the crop. This temperature is 5, 0, and 10 degrees Centigrade for wheat, barley, and beet, respectively.

Table 6. Total growing degree-day values needed by the crops of the Qazvin Plain (Total de plus en plus les valeurs de degrés-jours requis par les cultures de la plaine de Qazvin)

Crop	Sum of the Growing degree day
corn	1800
sugar beet	2700
wheat	22700
barley	2060

2.7 Weighting of AOGCMs through the MOTP Formula, and Creation of PDF

In order to consider the uncertainty of the AOGCM models, the temperature data obtained through these models for base period are weighted on the basis of the average standard deviation relative to the observed data. This weighting method is called 'mean observed temperature and precipitation method', and is based upon the following formula:

$$R_i = \frac{\frac{1}{B_{x,i}}}{\sum_{i=1}^{N} \frac{1}{B_{x,i}}} \quad (17)$$

In which, $B_{x,I}$ = standard deviation of the average temperature simulated through any of the AOGCM models for the base period for the month of (x) from the average of the observed data,N= number of the AOGCM models, and Ri= the weight given each of these models,

After this weighting monthly-temperature, PDF's (probability distribution function) were created for each of these models. In the next stage, 2000 samples of and minimum daily temperatures were produced.

These 2000 samples of Minimum and temperatures were put into the reference water demand equation and, as a result, 2000 series of daily reference water demand were obtained for each year in the future period. On the other hand, 200 series of minimum and temperatures were obtained for each year in the future period using the capability of the SDSM weather generator. Then, these were entered into the selected reference water demand equation and, as a result, 200 daily reference water demands were calculated for each year.

3. CONCLUSIONS AND DISCUSSION

3.1 Potential evaporation and transpiration simulation of the region in the past

Regarding the results given in Table 7, and as the ETo values obtained through the Hargreaves-Samani equation are closer to those of the Penman-Monteith equation than the values of the

Modified Jensen-Haize equation, and also as the variables available in the Penman-Monteith equation are numerous, and these variables cast much uncertainty on the estimation of ETo values in the future, so the Hargreaves-Smani equation, whose only variable is temperature has been used to estimate the potential evaporation and transpiration of the region with regard to climate change in the future.

Table 7. Correlation coefficients between Jensen-Haize and Hargreaves-Samani equations and Penman-Monteith equation (Les coefficients de corrélation entre Jensen-Haize et les équations Hargreaves-Samani et l'équation de Penman-Monteith)

MONTH / CORRELATION	JAN		FEB		MAR		APR		MAY		JUN	
	HARG	JAIN	HARG	JAIN	HARG	JAIN	HARG	JAIN	HARG	JAIN	HARG	JAIN
R^2	0.93	0.58	0.90	0.80	0.45	0.77	0.89	0.77	0.91	0.71	0.01	0.01
RMSE	0.23	0.26	0.13	0.18	0.27	0.26	0.66	3.10	1.51	3.96	3.50	5.38
MAE	0.22	0.21	0.12	0.16	0.24	0.23	0.66	1.22	1.51	1.91	3.50	2.88
MONTH / CORRELATION	JUL		AUG		SEP		OCT		NOV		DEC	
	HARG	JAIN	HARG	JAIN	HARG	JAIN	HARG	JAIN	HARG	JAIN	HARG	JAIN
R^2	0.20	0.06	0.39	0.32	0.07	0.06	0.81	0.79	0.57	0.37	0.68	0.64
RMSE	3.16	5.70	2.80	4.98	2.55	3.76	0.87	2.12	0.42	1.09	0.25	0.62
MAE	3.16	3.08	2.80	2.97	2.55	2.45	0.81	1.33	0.41	0.68	0.24	0.29

3.2 Combined investigation of the effect of uncertainties of the AOGCMs and of downscaling methods on the crop water requirements in the future period

As it was mentioned, this research is aimed at the estimation of the water demand on the crops in the region with regard to the uncertainties existing in the AOGCM models and in downscaling methods. Thus, in order to consider these uncertainties, cumulative distribution graph is used in this section to determine, with probability, the increase of the crop water requirements in each month of the growth period as compared to the demand in the base period (Figures 2 and 3). From all these graphs, the following are deduced:

1. The water demand values computed for the months of fall and winter through the Proportional and statistical methods are close to each other; these values get farther away from each other for the months of spring and summer, so that the values obtained through the Proportional downscaling show a considerable increase relative to those computed through the SDSM Method. The reason for this can be attributed to the Hargreaves-Samani reference water demand equation. As the difference of minimum and temperatures is effective in this equation, so according to Table 8, the results of the months, when the temperature difference between these two downscaling methods increases, get away from each other, and for the rest of the months, when there is not a considerable temperature difference, they come closer to each other.

2. There are usually negative values for the last month of the growth of each crop; the reason for this is clear with regard to the growth period becoming shorter in future. In other

words, although the crop water requirements increases due to temperature increase in the future, but as the growth period becomes shorter, this demand shows a decrease in the last month relative to the same month in the past period.

3. Usually the range of the changes of the water demand computed for the future period through the SDSM method is wider for the future period as compared to that for base period calculated through the Proportional method. This is due to the fact that the downscaled temperature data obtained for the future period are different from the observed ones with regard to the average, and to the daily oscillations as well, but in the proportional method, only the average of the downscaled data for the future are different from that of the observed data, and the oscillations of these data do not change.

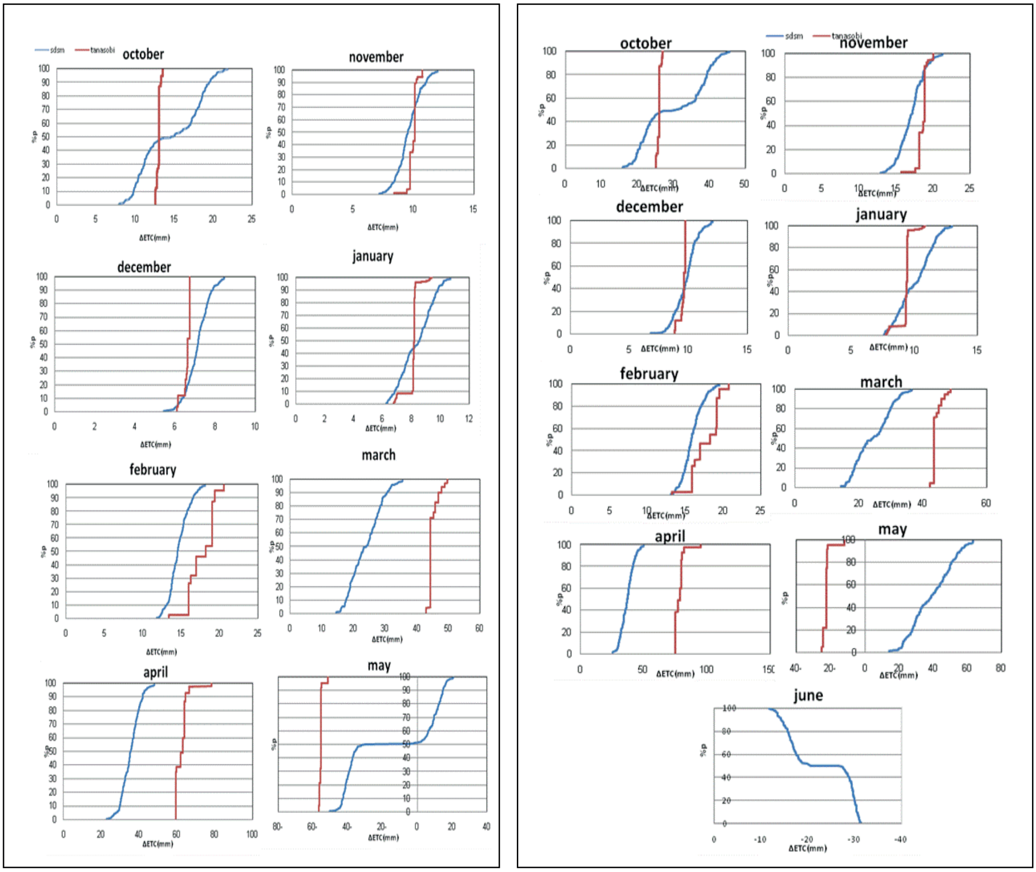

Fig. 2. Changes of water demand in the future, using the Proportional and SDSM methods. (Right: Wheat; Left: Barley(Les changements de la demande en eau au cours des mois de croissance dans la période à venir, en utilisant les méthodes et proportionnelle SDSM. Graphique de droite appartient au blé et à la gauche de l’orge)

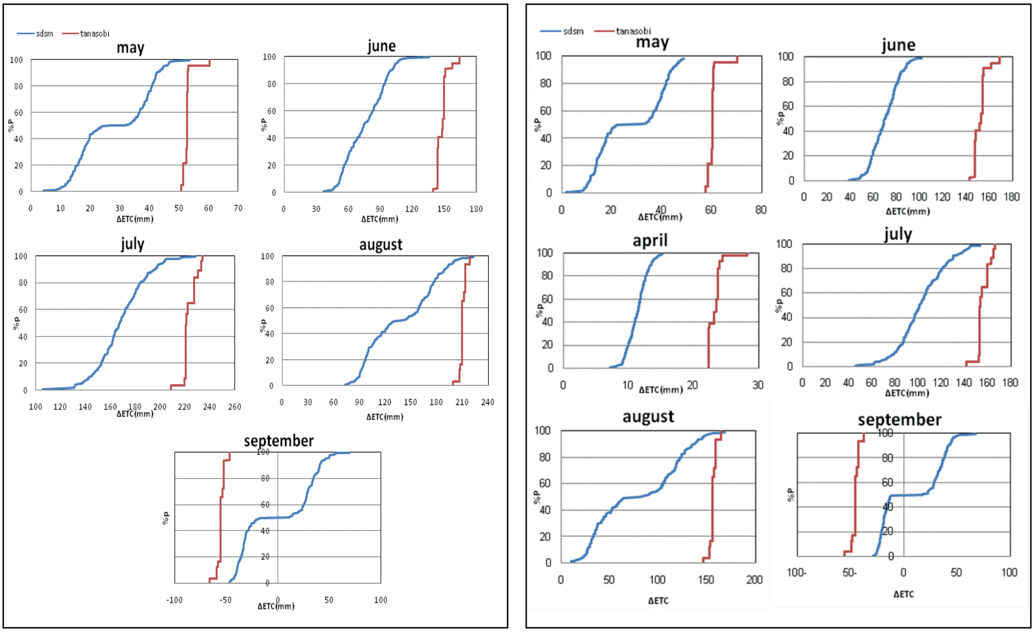

Fig. 3. Change in water demand in the future, using the proportional and SDSM methods. (Right: Beet and Left: Maize (La demande en eau dans les mois à la croissance dans la période à venir, en utilisant les méthodes et proportionnelle SDSM. Graphique de droite appartient à la betterave et la gauche au maïs)

The total increase in the water demand for the future period relative to the base period has been computed with the probabilities of 25%, 50%, and 75%, for both of the downscaling methods (Table 9). Also, the water demand increase has been shown, as percentages in Table 10, relative to base period.

Table 8. Difference of maximum and minimum temperatures simulated through two downscaling methods for the period 2010-2039 (Différence de températures maximales et minimales simulé par deux méthodes de réduction d'échelle pour la période 2010-2039)

month	proportional	statistical
JAN	11.08	11.13
FEB	11.65	11.42
MAR	13.10	12.06
APR	15.05	13.90
MAY	17.47	15.97
JUN	18.88	17.37
JUL	19.33	18.66
AUG	19.16	18.86
SEP	18.84	18.32
OCT	17.03	17.12
NOV	14.11	14.43
DEC	12.20	12.41

Table 9. Sum of the increase of the water demand for the four crops (mm) (Somme de l'augmentation de la demande en eau pour les quatre cultures (mm))

PROBABILITY(%) / METHOD OF DOWNSCALING	25%	50%	75%
SDSM	672.9	1018.4	1261.4
PROPERTIONAL	1334.5	1362.4	1399.3

Table 10. Percentage of the increase of the water demand relative to base period for the total four crops studied (Pourcentage de l'augmentation de la demande en eau par rapport à la période de base pour les quatre cultures étudiées total)

PROBABILITY(%) / METHOD OF DOWNSCALING	25%	50%	75%
SDSM	19.99	30.26	37.48
PROPERTIONAL	39.65	40.48	41.58

From the results, it can generally be stated that the water demand of the crops in the region will increase for the period 2010-2039. This increase will be 40%, using the Proportional method, and 30%, using the SDSM method, with 50% probability. This increase can lead, with the present area under cultivation, to the annual water demand of 173 MCM, according to the SDSM Method, and to 188 MCM, according to the Proportional method (Table 11).

Table 11. Sum of the water demands increase (CM per year) (Somme de l'eau exige l'augmentation (cm par an))

PROBABILITY(%) / METHOD OF DOWNSCALING	25%	50%	75%
SDSM	112915218.00	173920542.00	213215169.00
PROPERTIONAL	180642120.00	188978536.00	193381192.00

Based on Steinmann's (2006) findings, an increase above 10% is regarded as limit for confronting system with stress. By accepting this limit, under 50% probability, the system will face water stress during 2010-2039. This will require specific adaptation measures.

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