Assessment of inter-seasonal temperature and precipitation changes under global warming over Setif high plains region, vulnerability and adaptation

Tarek Bouregaa and Mohamed Fenni
Department of Agronomy, University Setif1, Setif, Algeria

Abstract

Purpose – The purpose of this paper is to assess the inter-seasonal temperature and precipitation changes in Setif high plains region under future greenhouse gas emissions, by using four general circulation models (GCMs) output data between three time slices of twenty-first century. The objective is to show the vulnerability of the region and the strategy of adaptation to these changes.

Design/methodology/approach – This study investigates likely changes in seasonal temperature and precipitation over Setif high plains region (North East of Algeria) between three time slices: 2025, 2050 and 2075. The projections are based on the SRES A2 and B2 scenarios. MAGICC-SCENGEN 5.3v.2 was used as a tool for downscaling the four selected GCMs output data. The vulnerability of the region, coupled with the possible impacts climate change, stresses the need for adaptive strategies in key sectors in the region for the long term sustainable development.

Findings – The results for change in seasonal temperature indicate a general warming under the two scenarios till the year 2075.The results of GFDLCM21 and GFDLCM20 show a general reduction of spring and autumn precipitations and an increase in winter and summer. BCCRBCM2 predicts a decrease in winter, spring and summer precipitations and an increase in autumn. Climate change, as well as increases in climate variability, will alter precipitation, temperature and evaporation regimes, and will increase the vulnerability of Setif high plains to changes in hydrological cycles. Climate and weather forecasting coupled with biotechnological advances in improving crop yields and tolerances to aridity, is likely to bring significant payoffs for strategy of adaptation in the field of agricultural water management.

Originality/value – This work is one of the first to study inter-seasonal temperature and precipitation changes under global warming over the region, and suggest some adaptive strategies to limit the effect of these changes.

Keywords GCMs, Vulnerability, Adaptation, Temperature, Precipitation, Setif high plains

Paper type Research paper

1. Introduction

Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since the eighteenth century and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. Climate change over the next century will affect rainfall patterns, river flows and sea levels all over the world. For many parts of the arid regions there is an expected precipitation decrease over the next century of 20 percent or more (Intergovernmental Panel on Climate Change (IPCC), 2007). Climate data gathered in North Africa during the twentieth century indicate heating, estimated at more than 1°C, with a pronounced trend in

World Journal of Science, Technology and Sustainable Development
Vol. 11 No. 4, 2014
pp. 304-314

2042-5945
DOI 10.1108/WJSTSD-05-2014-0005

the past 30 years. The data also shows a marked increase in the frequency of droughts and floods. The region experienced one drought every ten years at the beginning of the century, to a current state of five or six years of drought per ten years (Agoumi, 2003).

Future changes in mean seasonal rainfall in Africa are less well defined. Under the B1-low scenario, relatively few increase by 5 to 30 percent in DJF and decreases by 5 to 10 percent in JJA. Some areas of Sahelian West Africa and the Maghreb also experience "significant" rainfall decreases in JJA season under the B1-low scenario (Hulme *et al.*, 2000). According to the experts of the "Hydro-meteorological Institute for Training and Research," Algeria will experience a reduction in the rainy season and a rise in temperatures of around 1 to 3°C by 2020 and 2050, respectively, which would have fatal consequences for 30 percent of animal species. While the agricultural productivity can be increased under climate change conditions in Egypt, a decrease in productivity of almost 30 percent is projected for Algeria, even if the use of carbon fertilization is considered (Schilling *et al.*, 2011).

The first aim of this study is to assess the inter-seasonal temperature and precipitation changes in Setif high plains region under future greenhouse gas emissions, by using four general circulation models (GCMs) output data between three time slices of twenty-first century. The second objective is to show the vulnerability of the region and the strategy of adaptation to these changes.

2. Methodology

Area description

The Setif high plains region is located in the North East of Algeria. It is situated between 35°-36.5° N and 5°-6° E. The altitude varies from 900 to 1,300 m above sea level. The region has a semi-arid climate, characterized by rainy cold winters and dry hot summers and an annual mean rainfall of 400 mm, varying from 200 to 450 mm at south to north. The coldest month is January, with an average of minimum temperature of 1.6°C. The hottest month is July, with an average of maximum temperature of 33.6°C (Figure 1). The region is of agricultural importance for the country and hence irrigation and water demands drastically increase during summer months when precipitation is few (Figure 2). The soil of the region is calcareous earth classified as a steppic brown soil, with a pH around 8. Land in this region is used for farming mainly wheat and barley.

Model description

The MAGICC-SCENGEN 5.3 (version.2) software of Wigley (2008) was used to generate climate change scenarios on the Setif high plains region. It is a coupled gas-cycle/climate model (MAGICC) that drives a spatial climate-change scenario generator (SCENGEN). SCENGEN constructs climate change scenarios using results from MAGICC, and scales the results to predict regional climate changes in 2.5° latitude by 2.5° longitude cells (approximately 240 km on a side). Output from SCENGEN includes changes from historic averages in temperature and precipitation and changes in temperature and precipitation variation.

The SCENGEN grid boxes around the Setif high plains region are 35° to 37.5° N latitude and 5° to 7.5° E longitude. For impacts work, use of nine-box averages (7.5° × 7.5°) produces less spatially noisy results then using single grid boxes. The nine-cell area average is generally considered a more stable estimate of site

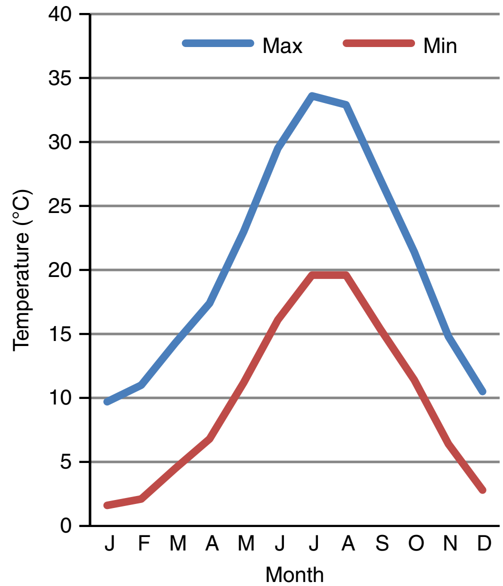

Figure 1.
Maximum and minimum monthly temperature

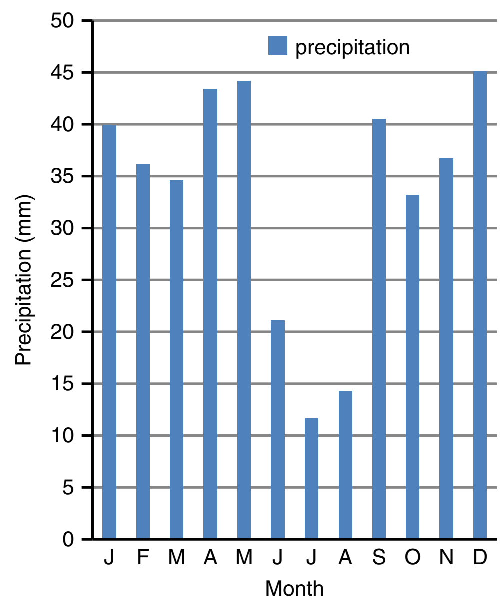

Figure 2.
Monthly precipitation at the Setif weather station from 1981 to 2012

changes since results for an individual grid cell are subject to more noise than a larger area surrounding the site (Wigley, 2008). The values for the grid cell containing the Setif high plains are calculated as the average of the cell and the eight surrounding cells.

Emission scenarios selection

In order to cover the influence of future greenhouse gas emissions and the corresponding socioeconomic development, a range of future greenhouse gas emission scenarios have been defined by International Panel on Climate Change (IPCC), in their Special Report on Emission Scenarios (SRES). The SRES scenarios are grouped into four scenarios families (A1, A2, B1 and B2) (Nakicenovic and Swart, 2000). Most of the recent climate change impact studies are focussing on the A2 and B2 storylines (Giannakopoulos *et al.*, 2005; Aksoy *et al.*, 2008; Githui *et al.*, 2009). This study also assumed the A2 and B2 storylines. The A2 scenario puts emphasis on self-reliance and preservation of local identities and economic development is primarily regionally oriented. The B2 scenario puts emphasis on local solutions to economic, social, and environmental sustainability (Nakicenovic and Swart, 2000).

Global climate model selection

Climate models used in this study were selected based on the validation results from MAGICC/SCENGEN between the observed and modeled variable. Two statistical metrics, correlation analysis and root mean square error, are used measure of model performance for Setif high plains region. The models that showed a pattern correlation coefficient of 1.0 indicates a perfect match between the observed and simulated spatial pattern, and a root mean square error of 0.0 indicates a perfect match between the observed and simulated magnitudes. Although its high resolution and good performance at regional scale, MIROC-HI was rejected from the list, because it appears to have a very high sensitivity (5.6°C), way higher than the 3° marked as best estimate in IPCC's AR4 (Wigley, 2008). Based on this, the four selected models were: GFDLCM21, GFDLCM20, BCCRBCM2 and MIROCMED (Table I).

We examined seasonal temperature and precipitation changes from MAGICC-SCENGEN using each of the four chosen GCMs independently, and used an average of output

Models	Correlation (*R*)	RMSE (mm/day)
BCCRBCM2	*0.831*	*0.479*
CCCMA-31	−0.903	0.358
CCSM-30	0.254	0.467
CNRM-CM3	0.556	0.108
CSIR0-30	0.533	0.339
ECHO-G	0.479	0.247
FGOALS1G	0.525	0.244
GFDLCM20	*0.988*	*0.177*
GFDLCM21	*1.000*	*0.177*
GISS-EH	−0.494	0.277
GISS-ER	−0.417	0.476
INMCM-30	0.703	0.554
IPSL_CM4	−0.825	0.633
MIROC-HI	0.983	0.900
MIROCMED	*0.768*	*0.044*
MPIECH-5	0.433	0.568
MRI-232A	0.759	0.398
NCARPCM1	0.657	0.351
UKHADCM3	0.711	0.286

Table I.
Regional performance of models

from the four GCMs to project climate change in Setif high plains region under A2 and B2 scenario.

3. Results

Projected changes in seasonal temperature

Under A2 and B2 scenarios, all models were consistent in terms of change in seasonal temperature. The average models prediction for warming show that temperature will increase under A2 scenario more than B2 scenario in the three time slices; according to these scenarios, more warming will be experienced in 2075 than in 2025 and 2050 periods.

As shown in Figure 3, the highest warming is seen in summer under the two scenarios, with values varying from 1.25 to 3.65°C under A2 and 1.19 to 3°C under B2 scenario. However, the lowest warming is expected in spring and winter under the two scenarios, respectively. Looking at the prediction of individual models, it appears that MIROCMED have the highest prediction of warming in summer season across the three periods with values ranging from 1.51 to 4.5°C under A2 scenario and 1.42 to 3.62°C under B2 scenario. This highest warming observed in summer is followed

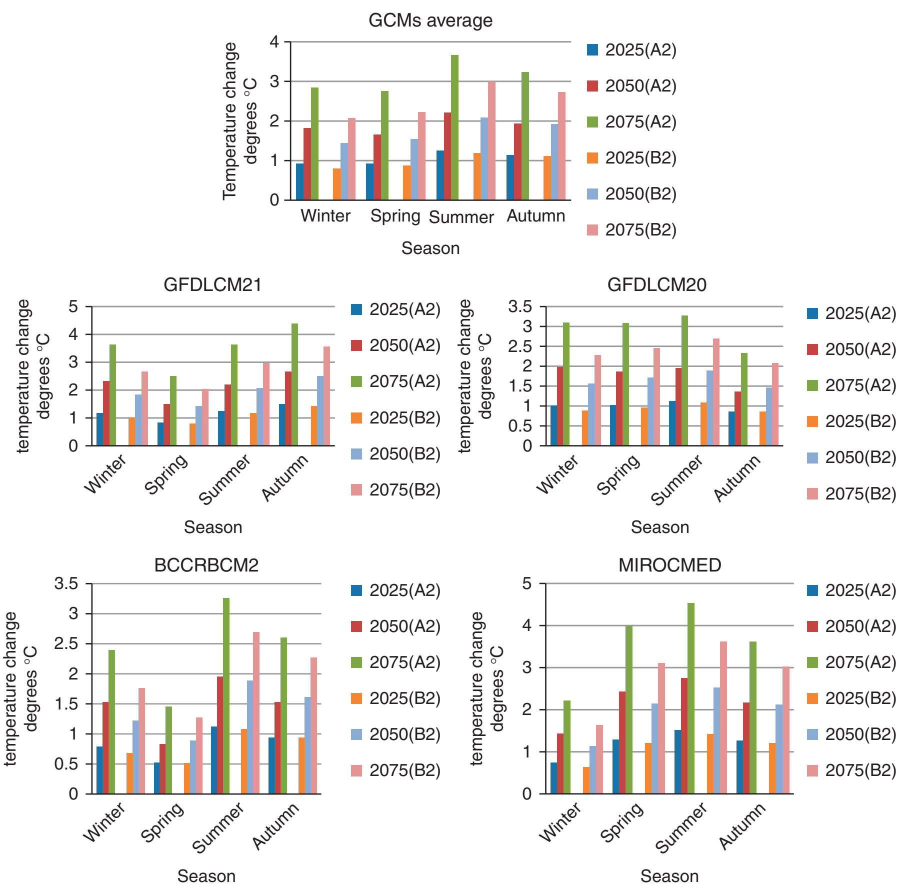

Figure 3.
Estimated changes in seasonal temperature for Setif high plains region in 2025, 2050 and 2075 (relative to 1990) under A2 and B2 emissions scenario with aerosol effects

by spring with increase in temperature varying from 1.29 to 3.98°C and 1.2 to 3.11°C under the two scenarios, respectively. Increase in temperature projected by GFDLCM21 was found to be lower than predicted by MIROCMED with increase in autumn temperature varying from 1.49 to 4.39°C under A2 scenario and 1.42 to 3.57°C under B2 scenario. The smallest warming is projected by BCCRBCM2 model in spring with values varying from 0.52 to 1.45°C under A2 and 0.51 to 1.27°C under B2 scenario. This lowest warming is followed by the projection of MIROCMED in winter with values ranging from 0.74 to 2.22°C and 0.64 to 1.63°C under the two scenarios, respectively.

Projected changes in seasonal precipitation

The results of average models for change in seasonal precipitation (Figure 4) indicate a general decrease in precipitation under the two scenarios and across the four seasons; except for winter season when an increase of 3.6, 8.2 and 13.5 percent can be observed under B2 scenario in 2025, 2050 and 2075, respectively, and an increase of 4.2 percent in 2075 under A2 scenario. The results of the four models show that the precipitation

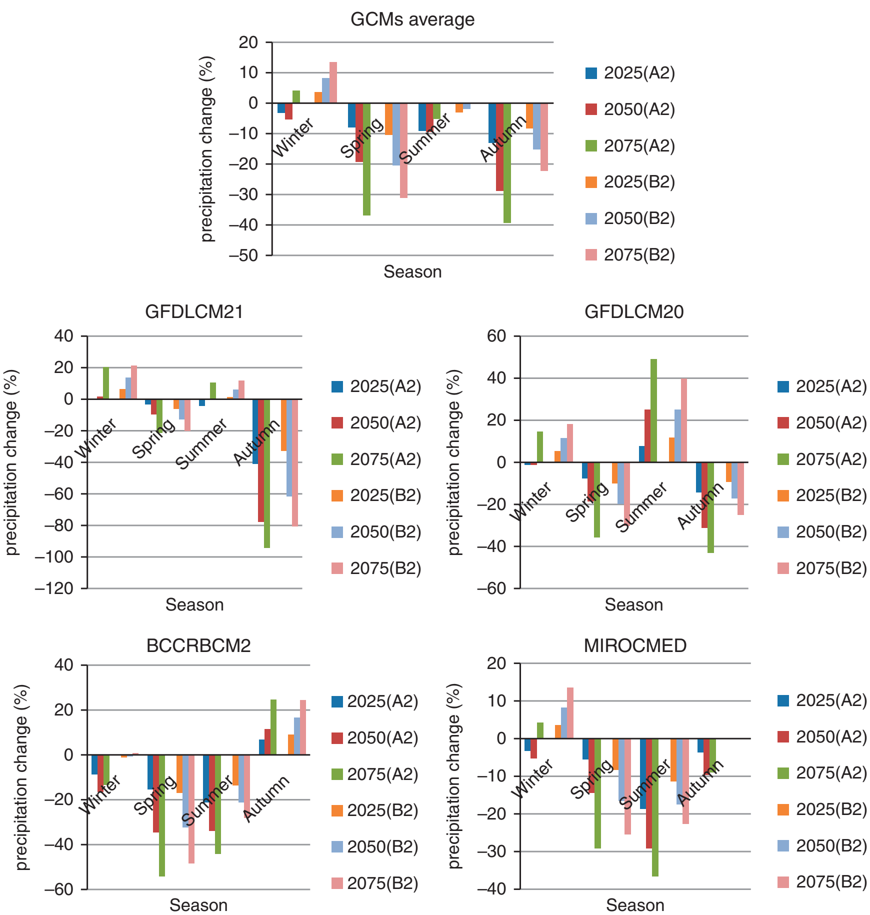

Figure 4.
Estimated changes in seasonal precipitation for Setif high plains region in 2025, 2050 and 2075 (relative to 1990) under A2 and B2 emissions scenario with aerosol effects

will decrease under A2 scenario more than B2 scenario in the three periods, according to these scenarios, more drying will be experienced in 2075 than in 2025 and 2050 periods. The highest decrease in precipitation is expected in autumn season with values ranging from −13 to −39.4 percent under A2 scenario and −8.3 to −22.2 percent under B2 scenario.

Looking at the results of individual models, and except of A2 scenario when GFDLCM21 and GFDLCM20 project a decrease in summer and winter precipitation (−4.2 percent in 2025, and −1.2 percent in 2025 and 2050, respectively), it appears that the two GCMs predict an increase in summer and winter precipitation and a decrease in spring and autumn precipitation; The highest decrease in precipitation is expected in autumn season (−41, −77.8 and −94.4 percent for 2025, 2050 and 2075, respectively), when projections are made by GFDLCM21. The projections of BCCRBCM2 indicate a decrease in winter, spring and summer precipitation and an increase in autumn, under the two scenarios; the values of change in winter precipitation lies in the range of −8.6 to −13.4 percent under A2 scenario and −1.2 to 0.7 percent under B2 scenario. The values of reduction in spring precipitation are more than observed in winter, it ranges from −15.4 to −54.1 percent and −16.9 to −48.4 percent under A2 and B2 scenarios, respectively, these values varying from −21.1 to −44.1 percent and −13.5 to −28.1 percent for summer, under the two scenarios, respectively. However, the values of change in autumn precipitation indicate a general increase with values ranging from 6.7 to 24.7 percent under A2 scenario and 9.1 to 24.5 percent under B2 scenario.

Except of 2075 winter, when precipitations are expected to rise at 4.3 percent, the projections of MIROCMED under A2 scenario indicate a general decrease in precipitation of all seasons. These values lies in the range of −3.2 to −5.3 percent for winter, −5.5 to −29.1 percent for spring, −18.7 to −36.6 percent for summer and −3.6 to −8.9 percent for autumn. Under B2 scenario, MIROCMED predicts a decrease in spring and summer precipitation and an increase in winter and autumn, with values ranging from −8.3 to −25.4 percent for spring, −11.4 to −22.6 percent for summer and 3.6 to 13.5 percent for winter. These changes range from 0 to 0.1 percent in autumn season.

4. Discussion

These results are generally consistent with previous studies. Giorgi and Lionello (2008) found that the Mediterranean region exhibits warming maximum in summer. In, spring, autumn and summer essentially the entire region and most of Western Europe show a pronounced decrease in precipitation. In Ergene (Turkey), the ECHAM4 Model show that the highest increase in temperature is seen in summer and the highest decrease in precipitation is observed in autumn. When HadCM2 model is used, both the highest increase in temperature and decrease in precipitation were projected in summer season (Aksoy *et al.*, 2008). According to Githui *et al.* (2009), temperature will increase in Kenya, with the 2050s experiencing much higher increases than the 2020s with a monthly temperature change range of 0-1.7°C. The analysis of regional climate (RegCM) simulations of the A2 and B2 scenario confirms the global MGME results and it shows wetter winter conditions at the northern boundary of the Mediterranean region and drier along the southern and eastern coast of the basin (Lionello and Giorgi, 2007).

The predictions of the four models used in the study of Jeganathan and Andimuthu (2013), show that the maximum rise in temperature of Tamil Nadu region (India) are expected in spring season, followed by winter, summer and autumn. Decreasing trends of precipitation are observed in winter and spring.

According to Schilling *et al.* (2011), projections of future climate change for Africa exhibit considerable uncertainties (including the possibility of the greening of the Sahara), both the risk and the duration of droughts are likely to increase in Northern Africa. The limitations of climate change scenarios for Africa arise because of the problem of small signal-to-noise ratios in some scenarios for precipitation and other variables, the inability of climate model predictions to account for the influence of land cover changes on future climate, and the relatively poor representation in many models of some aspects of climate variability that are important for Africa (e.g. ENSO) (Hulme *et al.*, 2000). Palmer (1999) and Palmer *et al.* (2005), indicate that the problem of predicting uncertainty can be posed in terms of the Liouville equation for the growth of initial uncertainty, or a form of Fokker-Planck equation if model uncertainties are also taken into account. However, in practice, the problem is approached using ensembles of integrations of comprehensive weather and climate prediction models, with explicit perturbations to both initial conditions and model formulation; the resulting ensemble of forecasts can be interpreted as a probabilistic prediction.

For these reasons, no single model is considered accurate, a GCM average pattern might be considered to give a better presentation of regional anthropogenic climate change than the pattern derived from any single model; it will help to reduce the uncertainties in future predictions (Hulme *et al.*, 2000; Shongwe *et al.*, 2009).

Vulnerability

Known for its semi-arid climate, Setif high plains region is highly vulnerable to climate change. Land used by agriculture, which occupy nearly 85 percent of the total land area, are estimated at 562,000 ha distributed as follows: 360,900 ha of agricultural area, 57,900 ha used as routes and pastureland, 41,200 ha of unproductive land, 102,000 ha of forests. Irrigated land accounts for 5 percent of the agricultural area; an area of 18,500 ha. The region therefore has only 3 percent of the total area as irrigated land. A fellow-winter cereals rotation occupy every year more than 80 percent of cultivated land. The grain yield average is >700 kg/ha. The region depends almost entirely on precipitation as the main water source for agriculture. The ratio "availability/capita" agricultural land is 0.24 ha/cap in 2010.

Water availability per capita is 144.5l /hab/day. Higher temperatures and less precipitation will likely decrease the overall availability. The analysis of the impact of climate change on water resources conducted in the region revealed the following risks: decrease in water flow, change in seasonal water recharging, with impact on the effectiveness of certain hydraulic and agricultural systems, increased evapotranspiration and, consequently, water salinity.

The impact of climate change on agriculture will have a dramatic effect on this sector: greater erosion and desertification (116,000 ha), leading to widespread soil degradation, deficient yields from rain-based agriculture of up to 50 percent during the 2000-2020 period, reduced crop growth period, risk of non-dormancy of some arboreal species, reduced agricultural production linked to higher water demand in this sector, combined with an anticipated decrease (Agoumi, 2003). The IPCC (2007) estimates that in North Africa climate change will cause a loss in agriculture of between 0.4 and 1.3 percent of GDP by 2100.

5. Strategy of adaptation

Although climate change is projected to have serious impacts on natural and human systems in the region, only modest efforts and steps are taken related to mitigation and adaptation. Nefzaoui *et al.* (2012) indicate that the adoption of the improved technologies and institutional innovations and of further upgrade thereof will enable the rural communities cope with climate change. Issues to be addressed include:

- modeling climate change effect on a local level to develop more accurate warning systems for better coping with and adaptation to climate change;
- selection of varieties and seeds adapted to the semi arid climate, like the new durum wheat (Boussellam variety);
- using new techniques to limit the effect of water shortage on crop production (direct seeding);
- due to the decreasing trend in precipitation for April and May, an emphasis on the traditionally used barley as dominant cereal can be recommended, since barley ripens faster than wheat;
- grow olives and fruit trees in mountain area;
- adapting agricultural calendars to climate change;
- reforestation, land consolidation and development of an agricultural map;
- water efficiency measures to reduce water demands;
- improve planning strategies and preparedness for droughts and severe floods;
- reduce water contamination from industrial, wastewater and other human sources;
- improve procedures for equitable distribution of water resources;
- accelerating the construction of dams, like the dams of Draà diss and Maouane;
- improve control dam operations: the volume of water supplied must correspond to real needs downstream, particularly for agriculture;
- inject surface water into groundwater;
- widespread development of efficient irrigation techniques (e.g. drip irrigation) (MATE, 2010);
- using non-conventional water sources: recycle water by industry, and use waste water;
- use industrial processes with low water consumption; and
- developing and promoting socially acceptable policies on insurance against climatic risks and on water pricing and property rights.

Algeria has implemented a strategy for adapting to climate and GHG mitigation. It covers all sectors, especially the energy sector which is responsible for the largest share of GHG emissions (74 percent). Much progress has been made in the mobilization of water resources for drinking and irrigation, and much remains to be done in agriculture (Sahnoune *et al.*, 2013).

6. Conclusion

The main conclusion that does emerge from this work is that the study region will be under the effect of increase in air temperature under the two scenarios and across the three periods of the twenty-first century. Different models project different seasonal changes and it might be seen that the predictions of the change in precipitation are more uncertain than predictions of the change in temperature. The results for change in seasonal temperature indicate a general warming under the two scenarios till the year 2075. The results of GFDLCM21 and GFDLCM20 show a general reduction of spring and autumn precipitations and an increase in winter and summer. BCCRBCM2 predicts a decrease in winter, spring and summer precipitations and an increase in autumn. The projections of MIROCMED indicate a general decrease in precipitation of all seasons, under A2 scenario. Under B2 scenario the model predicts a decrease in spring and summer precipitations and an increase in winter and autumn.

Climate change, as well as increases in climate variability, will alter precipitation, temperature and evaporation regimes, and will increase the vulnerability of Setif high plains to changes in hydrological cycles.

The impacts of climate change on crop production and food security could therefore be drastic. Climate and weather forecasting coupled with biotechnological advances in improving crop yields and tolerances to aridity, is likely to bring significant payoffs for strategy of adaptation in the field of agricultural water management.

References

Agoumi, A. (2003), "Vulnerability of North African countries to climatic changes", *International Institute for Sustainable Development*, pp. 1-10, available at: http//cckn.net//pdf/north africa. pdf (accessed April 4, 2013).

Aksoy, H., Unal, N.E., Alexandrov, V. and Dakova, S. (2008), "Hydrometeorological analysis of Northwestern Turkey with links to climate change", *International Journal of Climatology*, Vol. 28 No. 8, pp. 1047-1060.

Giannakopoulos, C., Bindi, M., Moriondo, M., Le Sager, P. and Tin T. (2005), "Climate change impacts in the Mediterranean resulting from a 2°C global temperature rise", WWF Report, pp. 1-66, available at: http//assets.panda.org/downloads/medreportfinal8july05.pdf (accessed December 22, 2012).

Giorgi, F. and Lionello, P. (2008), "Climate change projections for the Mediterranean region", *Global and Planetary Change*, Vol. 63 No. 2, pp. 90-104.

Githui, F., Wilson, G., Mutua, F. and Bauwens, W. (2009), "Climate change impact on SWAT simulated streamflow in Western Kenya", *International Journal of Climatology*, Vol. 29 No. 12, pp. 1823-1834.

Hulme, M., Wigley, T.M.L., Barrow, E.M., Raper, S.C.B., Centella, A., Smith, S. and Chipanshi, A.C. (2000), *Using a Climate Scenario Generator for Vulnerability and Adaptation Assessments: MAGICC and SCENGEN Version 2.4 Workbook*, Climate Research Unit, Norwich.

Intergovernmental Panel on Climate Change (IPCC) (2007), *Bilan 2007 des changements climatiques, Contribution des Groupes de travail I, II et III au quatrième rapport d'évaluation du Groupe d'experts intergouvernemental sur l'évolution du climat*, IPCC, Geneva.

Jeganathan, A. and Andimuthu, R. (2013), "Developing climate change scenarios for Tamil Nadu, India using MAGICC/ SCENGEN", *Theoretical and Applied Climatology*, Vol. 114 No. 3, pp. 705-714

Lionello, P. and Giorgi, F. (2007), "Winter precipitation and cyclones in the Mediterranean region: future climate scenarios in a regional simulation", *Advances in Geosciences*, Vol. 12, pp. 153-158.

MATE (2010), "Ministère de l'Aménagement du Territoire et de l'environnement (Ministry of Land Planning and Environment)", Seconde communication nationale de l'Algérie sur les changements climatiques à la CCNUCC, Algiers.

Nakićenović, N. and Swart, R. (2000), *Special Report on Emissions Scenarios*, Cambridge University Press, Cambridge.

Nefzaoui, A., Ketata, H. and El Mourid, M. (2012), "Agricultural technological and institutional innovations for enhanced adaptation to environmental change in North Africa", available at: www.intechopen.com/books/international-perspectives-on-global-environmental-change/agriculturaltechnological-and-institutional-innovations-for-enhanced-adaptation-to-environmental-ch (accessed July 12, 2012).

Palmer, T.N. (1999), "Predicting uncertainty in forecasts of weather and climate", *ECMWF Technical Memorandum*, Vol. 294 No. 2, pp. 1-51.

Palmer, T.N., Shutts, G.J., Hagedorn, R., Doblas-Reyes, F.J., Jung, T. and Leutbecher, M., (2005), "Representing model uncertainty in weather and climate prediction", *Annu. Rev. Earth Planet. Sci*, Vol. 33, pp. 163-193.

Sahnoune, F., Belhamel, M., Zelmat, M. and Kerbachi, R. (2013), "Climate change in Algeria: vulnerability and strategy of mitigation and adaptation", *Energy Procedia*, Vol. 36, pp. 1286-1294.

Schilling, J., Freier, K., Hertig, E. and Scheffran, J. (2011), "Climate change, vulnerability and adaptation in North Africa with focus on Morocco", Working Paper No. CLISEC-13, Research Group Climate Change and Security, University of Hamburg, Hamburg.

Shongwe, M.E., Van Oldenborgh, G.J., Van Den Hurk, B.J.J.M., De Boer, B., Coelho, C.A.S. and Van Aalst, M.K. (2009), "Projected changes in mean and extreme precipitation in Africa under global warming. Part I: Southern Africa", *Journal of Climate*, Vol. 22 No. 13, pp. 3819-3834.

Wigley, T.M.L. (2008), "MAGICC/SCENGEN 5.3: user manual (version 2)", available at: www.cgd.ucar.edu/ cas/wigley/magicc/ (accessed December 28, 2012).

Corresponding author
Tarek Bouregaa can be contacted at: ibnziad_1983@hotmail.com