INVESTIGATION OF AOGCM MODELS AND SRES- SCENARIOS UNCERTAINTY IMPACT ON THE GHARANGHU BASIN RUNOFF

ETUDE DES MODELES AOGCM ET SRES – IMPACT DE L'INCERTITUDE SUR L'ECOULEMENT DU BASSIN GHARANGHU

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ABSTRACT

This research investigates the runoff changes vis-à-vis the uncertainties of AOGCMs and SRES emission scenarios; in Gharanghu basin in north-west of Iran. At first, Monthly temperature and precipitation change scenarios of basin were constructed from 7 AOGCM models using baseline period (1971-2000) data and future period 2010-2039 under the A2 and B2 SRES-emission scenarios. These climate change scenarios were downscaled to the basin using original grid box information of each AOGCM. Results displayed a temperature increase and varying of precipitation in 2020s relative to the baseline period. Monthly probability distribution functions (pdf) of temperature and precipitation change scenarios in 2020s were constructed by a weighting method. A monthly rainfall-runoff conceptual model (IHACRES) was calibrated for the basin. Carrying out the Monte-Carlo method, 2000 samples of temperature and precipitation were taken from corresponding pdfs. Then 2000 temperature and precipitation time series for 2020s were constructed using change factor method. These time series were introduced to IHACRES. By this, 2000 30-year time series of monthly runoff were simulated in 2020s and then 2000 30-year average of monthly runoff time series for future period were compared with monthly runoff average for baseline period. Results indicated that climate change will affect the runoff of the basin. The mean annual runoff for 2010- 2039 period increase by 1.73 m^3/s in A2 and 0.44 m^3/s in B2, relative to 1971- 2000 period.

Key words: *Climate models, Green house gases, Monte-Carlo, Runoff changes.*

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RÉSUMÉ ET CONCLUSIONS

Il est de notoriété publique que l'activité humaine et de la population croissante ont modifié le climat et la biosphère terrestre. La tendance linéaire de ce réchauffement au cours des 50 dernières années (0,13 ° C [0,10 ° C à 0,16 ° C] par décennie) est presque deux fois plus que pendant les 100 dernières années. D'autres paramètres climatologiques montrent des tendances très variable sur les deux échelles mondiale et régionale. Le changement climatique anthropique a non seulement eu une incidence sur les variables climatiques, mais aussi les ressources en eau. Important sur les eaux de ruissellement et les inondations, les tendances dans les inondations fluviales sont plus difficiles à détecter, comme les changements dans les facteurs tels que l'utilisation des terres, des réservoirs, de drainage ou de régimes de lutte contre les inondations auront un impact sur les eaux de ruissellement, en plus de changements en raison du climat. Pour évaluer l'ampleur probable des changements climatiques dans l'avenir et ses retombées sur le ruissellement, les scientifiques s'appuient sur des simulations de modèles de circulation générale (MCG), entraîné par des scénarios plausibles des futures émissions provenant des activités humaines.

Le principal objectif de cette étude est d'évaluer l'impact du changement climatique et pondérée SRES-scénarios (A2 et B2) sur le ruissellement Gharanghu. Dans cette étude, les scénarios de changement climatique qui comprenait des scénarios A2 et B2 ont été générés à partir de 7-TAR MCG à échelle réduite et à une échelle appropriée Gharanghu bassin hydrographique. Ces données pondérées et a servi de base à un modèle hydrologique de générer des eaux de ruissellement climatique impact d'un bassin d'étude. Ils ont ensuite été utilisés dans un modèle de simulation des bassins hydrographiques statistiques pour étudier la sensibilité d'un système de réservoir pour le changement climatique pour le risque de ruissellement.

Afin d'évaluer l'impact des incertitudes liées au changement climatique sur le ruissellement, sept grandes étapes ont été suivies.

- *Une relation conceptuelle entre les précipitations et le ruissellement a été déterminé (pour la période de référence).*
- *Scénarios de changements climatiques ont été construites pour le bassin Gharanghu en 2010-2039 en utilisant les résultats de sept modèles de circulation générale dans les scénarios A2 et B2.*
- *Pdfs température discrets et les précipitations ont été construits en utilisant une méthode MCG-pondération.*
- *Méthode de Monte-Carlo a été effectuée pour l'échantillon de l'pdfs.*
- *Les échantillons scénarios de changement climatique ont été appliquées au modèle pluie-débit, afin de déterminer l'ampleur des changements d'écoulement à la station hydrométrique Mianeh.*
- *Les 30 - année moyenne écoulement mensuel a été simulé dans 2010-2039 selon les scénarios A2 et B2, en comparant les résultats de référence.*
- *Étapes quatrième-sixième ont été réitéré 2000 fois.*

Pour évaluer les eaux de ruissellement du bassin à l'avenir, discrète pdfs mensuelles de

température et les précipitations dans les scénarios de changement 2010-2039 ont été construits sous les scénarios A2 et B2 en utilisant chaque poids GCM. Ensuite, méthode de Monte Carlo a été réalisée pour simuler 2000 échantillons de chaque pdf mois. Ensuite, chaque ensemble de la température et les séries chronologiques des précipitations de 2010-2039 période introduits individuellement à la IHACRES et toute l'année 2000-30 écoulement mensuel de la rivière Gharanghu ont été simulées. Ensuite, la moyenne 2000 - les eaux de ruissellement 30 années de temps mensuel pour la période à venir ont été comparées à l'écoulement mensuel moyen pour la période observée pour deux scénarios. Les résultats montrent que, l'écoulement annuel moyen pour 2010 - 2039 majoration de la période 1,73 m^3 / s dans la cellule A2 et 0,44 m^3 / s en B2 par rapport à 1971 à 2000 période et l'augmentation du ruissellement de A2 est plus que B2. En outre, le coefficient de variation de baisse de décharge pour la période future. Comme, la diminution de celui de 2010 - 2039 par rapport à la période période observée pour la catégorie A2 et B2 est de 26,8 et 28,1%, respectivement.

On peut conclure de cette étude que les scénarios d'émission de trop compter sur un seul des scénarios ou très peu le climat MCG et aussi différentes risquerait d'entraîner un ruissellement inapproprié. Par conséquent, pour fournir des conseils à base scientifique aux décideurs, il est essentiel que les études d'impact sur le changement climatique envisager un éventail de scénarios climatiques pondérée des différents MCG.

Mots clés : *Modèles du climat, gaz contribuant à l'effet de serre, méthode de Monte-Carlo, changement d'écoulement.*

(Traduction française telle que fournie par les auteurs)

1. INTRODUCTION

It is believed that growing population, intensified human activity and greenhouse gas emissions in many regions in the world would cause a significant increases in mean annual temperature (i.e. >20 C) by the end of the present century (IPCC, 2007). The linear warming trend over the last 50 years (0.13°C per decade) is nearly twice that for the last 100 years. Other climatological parameters, such as precipitation, cloudiness and evaporation have shown strongly varying trends on both global and regional scales. Climate change has been affecting extreme events (e.g. drought, flood, etc.) although it is not widely recognized (Robson 2003). Several studies (Whitfield and Cannon, 2000; Muzik, 2001 and Boyer et al., 2010, among others) have shown that small perturbations in precipitation frequency and/or quantity can result in significant impacts on the mean annual discharge. Moreover, Christensen et al., 2004 mentioned that modest changes in natural inflows result in larger changes in reservoir storage. Any changes in the hydrologic cycle will affect energy production and flood control efforts (Xu and Singh, 2004) to such an extent that water management adaptation measures will very likely be brought in.

At present, most forecasts for the effect of climate change on runoff are largely based on general circulation models (GCMs). Depending on the scenario for greenhouse gas emissions assumed for the model (Carter 2007), the GCM outputs scenarios for temperature and precipitation, the latter of which is far more uncertain than the former. These uncertainties are then propagated into the hydrologic model used to predict runoff. The hydrologic model in turn requires calibration and validation against historical climatic and discharge data before it can be used to forecast runoff under a particular GCM scenario (Jiang et al., 2007).

So, water management and design practices will face new challenges, which will require a better quantitative understanding of potential changes. This understanding of the impacts of climate change is complicated by several sources of uncertainty linked to climate change. The uncertainty depends on both climate data and simulated hydrologic regimes (Prudhomme et al., 2003). Climatic uncertainty is linked to greenhouse gas emission scenarios (GHGES) and especially to general circulation models (GCMs), whose representation of topography and climate processes is imperfect due to computational limitations. The future climate uncertainty has recently been introduced into hydrology impact studies by using more than one climate projection obtained from the combination of GCM and GHGES. Downscaling methods also add uncertainty to climate data due to the limitations that are inherent in each technique. Hydrologic uncertainty results from the transfer of hydrological models to a future climate, and particularly with respect to model calibration. Considering all these sources of uncertainty, future hydrologic conditions can only be described by taking into account as much of this uncertainty as possible. As such, a precise deterministic prediction is not possible.

A broad range of literature exists regarding managing uncertainty in climate change impact assessments, often using Monte-Carlo approach (New and Hulme 2000; Katz 2002; Prudhomme et al. 2003). Such studies have not generally weight GCMs, and have imagined the uniform prior distribution for all GCMs. This can affect the final results of impact assessment studies.

This study demonstrates one attempt to introduce a procedure to assess the impact of climate change on runoff using a weighting method and under SRES- emission scenarios. Section 2 of this paper, describes the characteristic of the study area. In section 3 the methodology of the research includes rainfall runoff, emission scenarios, GCM-Weighting method and runoff analysis will be presented. This is followed by an examination of the weighted scenarios on the runoff (Section 4). We conclude in section 5 with a discussion of the advantages of this approach and the implications for climate change impact.

2. STUDY AREA AND DATA SETS

The 120 km kong Gharanghu River is the largest river in the Gharanghu Basin (drainage area - 3590 km2: Fig. 1). It originates in the north- west of Iran and flows eastward. The hydrometer gauging station Tunel 7, considered in this study, is located in the eastern end of the Gharanghu basin. The mean discharge at this gauging station and the mean yearly precipitation is 250.4 MCM/year and 403.7 mm, respectively. The monthly precipitation (from 12 stations), temperature (from 2 stations) and monthly discharge (from hydrometer gauging station Tunel 7) are available for the baseline period 1971–2000. These data were obtained from the Meteorological Institute and Ministry of Energy of Iran.

Seven GCM configurations are considered in this study; CCSR: Japanese Centre for Climate Research Studies model, CGCM2: Canadian Centre for Climate Modeling and Analysis GCM, CSIRO-Mk2: Australian Commonwealth Scientific and Industrial Research Organization, ECHAM4 – OPYC3: German Climate Research Centre, European Centre/Hamburg, GFDL-R30 : US Geophysical Fluid Dynamics Laboratory, HadCM3: UK Hadley Centre for Climate Prediction and Research Coupled and NCAR-DOE–PCM: US National Centre for Atmospheric Research model, DOE version (Carter 2007). For each configuration two runs were considered, one for the control period 1971–2000 and one for the period 2010-2039, based on the SRES-scenarios A2 and B2.

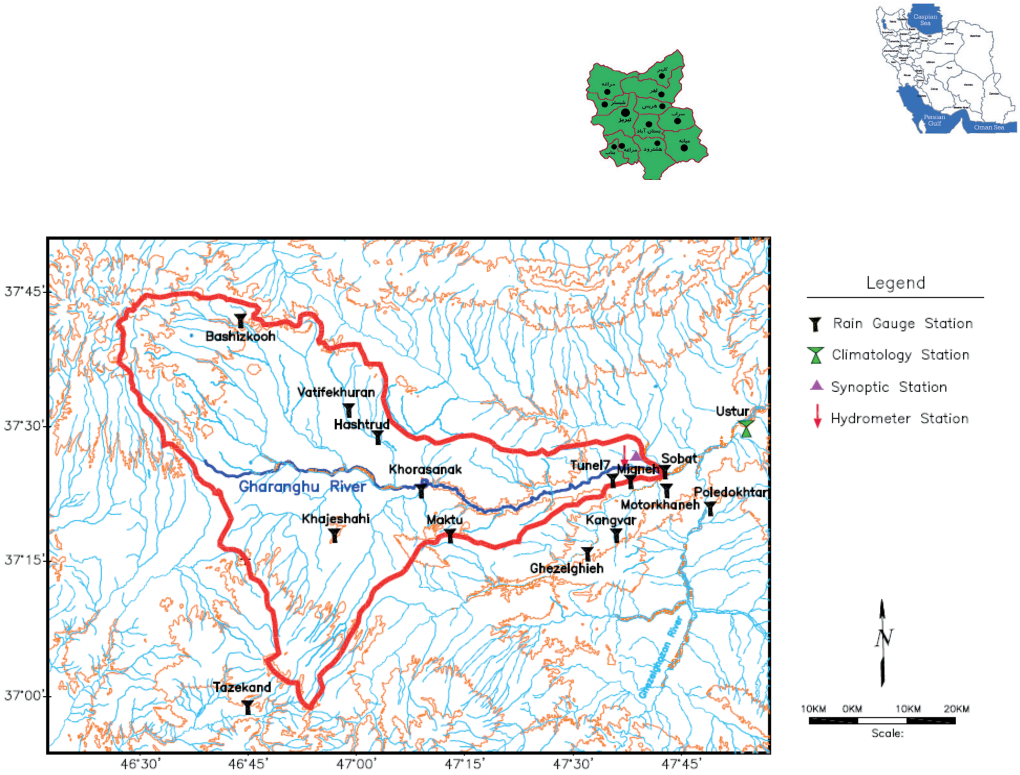


Fig. 1. Location of study catchment and stations (Localisation du bassin versant de l'étude et des stations)

3. METHODOLOGY

In order to assess the impact of climate change uncertainties on runoff, seven major steps were followed:

- A conceptual relationship between rainfall and runoff was determined (for the baseline period).
- Climate change scenarios were constructed for the Gharanghu basin in 2010-2039 using the results of seven GCMs under A2 and B2 scenarios.
- Discrete temperature and precipitation pdfs were constructed using a GCM- weighting method.
- Monte Carlo method was carried out to sample from the pdfs.

- The climate change scenario samples were applied to rainfall-runoff model in order to determine the changes in runoff at the Tunel 7 gauging station.
- The 30- year monthly runoff time series were simulated in 2010- 2039 under A2 and B2 scenarios, comparing the baseline results.
- Steps fourth to sixth were iterated 2000 times.

In the following the methodology of each steps are described.

3.1 Rainfall-runoff model description

The IHACRES module structure consists of a non-linear loss module, which converts observed rainfall to effective rainfall or rainfall excess, and a linear streamflow routing module, which extends the concept from unit hydrograph theory that the relationship between rainfall excess and total streamflow is conservative and linear (Jakeman and Hornberger 1993).

The non-linear loss module allows one to account for the effect of antecedent weather conditions on the current status of soil wetness index s_k and vegetation conditions, and evapotranspiration effects. Here the effective rainfall u_k is calculated from the measured precipitation r_k and temperature t_k by the recursive relations:

$$s_k = \frac{r_k}{c} + (1 - \frac{1}{\tau_w(t_k)})s_{k-1} \tag{1}$$

$$u_k = r_k(s_k + s_{k-1})/2 \tag{2}$$

$$\tau_w(t_k) = \tau_w \exp(20f - t_k f) \tag{3}$$

The constant c is calculated so that the volume of excess rainfall is equal to that of the total stream flow for the period over which the model is calibrated, τ_w and f are parameters which should be optimized, τ_w is a time constant reflecting the rate of drying (in months) of the catchment at 25°C and f is a factor which modulates this rate as temperature varies.

The linear module allows any configuration of stores in parallel or series. In the two-store configuration, at time step k, quick flow, $x_k^{(q)}$, and slow flow, $x_k^{(s)}$, combine additively to yield streamflow (discharge), qk:

$$q_k = x_k^{(q)} + x_k^{(s)} \tag{4}$$

With

$$x_k^q = -\alpha_q x_{k-1}^{(q)} + \beta_q u_k \tag{5}$$

$$x_k^s = -\alpha_q x_{k-1}^{(s)} + \beta_s u_k \tag{6}$$

Where, U_k is the effective rainfall. The parameters α_q and α_s can be expressed as time constants for the quick and slow flow stores, respectively:

$$\tau_q = -\Delta / \ln(-\alpha_q) \tag{7}$$

$$\tau_s = -\Delta / \ln(-\alpha_s) \tag{8}$$

Where, Δ is the time step (monthly here). In catchments which are modeled with only one store, only Equations (2) and (4) are relevant.

Model calibration was performed in the basin with monthly area averaged precipitation, temperature and runoff time series during the period of observation, 1971-2000.

3.2 SRES- scenarios

In 1996, a new set of emission scenarios that called Special Report on Emission Scenario (SRES) was presented by IPCC (Intergovernmental Panel of Climate Change). Each one sub-scenarios of SRES, is belong to one of A1, A2, B1 and B2 families.

The A2 storyline and scenario family describes a heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge slowly, which results in continuously increasing global population. Economic development is regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines.

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

In this research, because of more production of CO_2 gas in A2 and B2 scenarios, we used these scenarios.

3.3 Construction of climate change scenarios

A simple downscaling approach, the ‘change fields’ procedure was applied to derive the monthly climate change scenarios for the basin. The climate change scenarios were obtained by computing the differences (or ratio) between the averages of the AOGCMs dataset for the future periods (2010-2039) and the corresponding averages of the models simulated for the baseline period (here, 1971-2000). The changes for temperature are usually presented based on the differences (e.g. 2010- 2039 minus 1971-2000), while for precipitation change, ratios are commonly used (e.g. 2010-2039 divided by 1971-2000: Carter 2007; Diaz-Nieto and Wilby and Harris 2006).

3.4 Weighting GCMs

Single forecasts of the climate response to increasing greenhouse gas levels, are far more useful to policy makers when they are accompanied by some measure of the associated uncertainty (Schneider, 2001). In ensemble forecasting, it is customary to take the arithmetic ensemble mean as a prediction quantity and in most cases this already provides a better skill than any of the ensemble members alone. The term “Multi-model ensemble” indicates a set of simulations from various climate models with different structures. The use of such ensembles allows assessing the structural uncertainty included in model output. The simplest way of presenting climate change scenarios from different GCMs is with no weighting estimates. On the other hand by this approach all models assume the same weights and cannot explain the differences in GCM model performance. Ensemble weights are calculated by comparing model output for the present month with observed data. Accordingly we will evaluate the sensitivity of the expose unit to a multi-model probabilistic prediction by using the following equation:

$$R_i = \frac{\frac{1}{B_{x,i}}}{\sum_{i=1}^{N} \frac{1}{B_{x,i}}} \qquad (9)$$

Where R_i is a measure of the model reliability in terms of the model bias in simulating present month temperature/precipitation and $B_{x,j}$ is the model bias, defined as the difference between simulated and observed monthly mean temperature/ precipitation for the baseline period (here 1971-2000). It is obvious that the higher is the bias, the lower will be the model reliability. On the other hand, models with more ability are assigned higher weights and hence given more emphasis.

4. RESULTS

To assess the impact of uncertainties due to climate change on runoff of Gharanghu basin, we at first calibrated the IHACRES model. For this, the area-averaged monthly temperature and precipitation data of the basin and the Tunel 7 monthly runoff data over 1971-2000 were used. Different calibration and verification periods were tested using three criteria; correlation coefficient (r), Root Mean Square Error (RMSE) and Mean Absolutely Error (MAE). Figure 2 shows the best result obtained from calibration and verification of IHACRES. As shown in the figure, the performance of the model in simulating the monthly runoff of the river is desirable. Finally, as we needed a model that can be iterated a lot of times; we developed a FORTRAN code using equation 1 to 5 with calibrated coefficient from IHACRES.

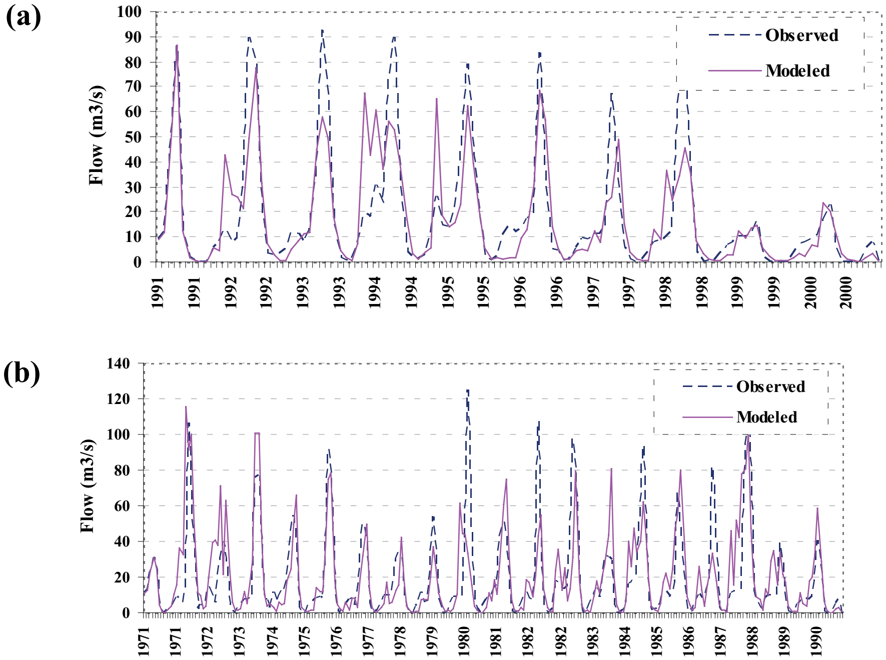


Fig. 2. Observed and modeled runoff for (a) calibration period (r=0.83, RMSE=13.07, MAE=7.59) and (b) verification period (r=0.72, RMSE=17.71, MAE=10.28) (Ruissellement observées et modélisées pour (a) période d'étalonnage (r = 0,83, RMSE = 13,07, MAE = 7.59) et la période de vérification (b) (r = 0,72, RMSE = 17,71, MAE = 10.28)

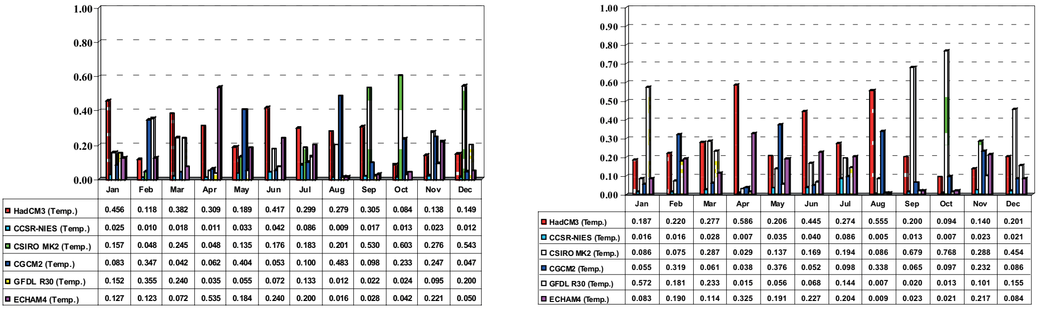
To simulate the runoff of the Gharanghu basin in the future, three steps were followed. Constructing climate change scenarios of the basin, constructing pdfs of climate change scenarios, sampling from pdfs, and introducing samples to IHACRES. Accordingly monthly temperature and precipitation change scenarios of the basin were constructed for the period 2010-2039 from 7 AOGCM models under A2 and B2 scenarios. Results showed that (not shown here) there is good agreement between AOGCMs in simulating the temperature, since all models estimate 0.2 to 3°C and 0.3 to 4°C temperature increase in the future relative to the baseline under A2 and B2 Scenario, respectively. For precipitation this agreement was poor and both decrease and increase changes relative to the baseline were simulated by the models. On the other hand most of the models show increase in precipitation for the autumn season and decrease for summer (should be noted that the pattern of the precipitation of the basin in the baseline is winterly).

To construct the monthly pdfs of climate change scenarios of the basin, at first monthly temperature and precipitation data of 7 GCMs over the period 1971-2000 were downscaled to the study area using the information of the main grid box of each model. Then 30-year mean monthly modeled data were compared with observed area averaged temperature and precipitation data of the basin in same period. The performance of each GCM in simulating the temperature and precipitation of the basin was evaluated using correlation coefficient (r), Root Mean Square Error (RMSE) and Mean Absolutely Error (MAE) (Table 1). As shown, the ability of GCMs to simulate the temperature is better than precipitation. On the other hand

NCAR DOE PCM has very low performance in simulating the precipitation and so was omitted for the next analyses. Using equation 9, the monthly weights of each GCM were calculated in simulating temperature and precipitation of basin under A2 and B2 (Fig. 3 and Fig. 4). As shown in Figures 3 and 4, each model takes into account different weights in each month. For example, HadCM3 takes into account the highest weight in simulating temperature in April and January (February and May for precipitation) for A2 and B2 Scenario, respectively, while in October (for both A2 and B2) it is one of the lowest (August and January for precipitation) for A2 and B2 scenario, respectively.

Table 1. Performance of GCMs in simulating observed climate variable of the basin (Performance des MCG à simuler variable climatique observé du bassin)

Climate Variable	Precipitation			Tmperature		
Model / Performance	MAE (mm)	RMSE (mm)	r (%)	MAE (°C)	RMSE (°C)	r (%)
HadCM3	7.16	9.43	90.0	0.82	0.99	99.5
CCSR-NIES	15.02	20.16	70.0	8.30	8.40	99.0
CSIRO MK2	11.90	15.30	80.0	1.22	1.50	98.9
CGCM2	35.29	51.69	77.0	2.04	2.63	96.8
GFDL R30	11.66	13.82	96.0	3.43	4.23	98.9
NCAR DOE PCM	24.75	32.86	18.0	3.56	3.93	98.5
ECHAM4-OPYC3	16.01	19.39	89.0	2.23	2.83	98.5



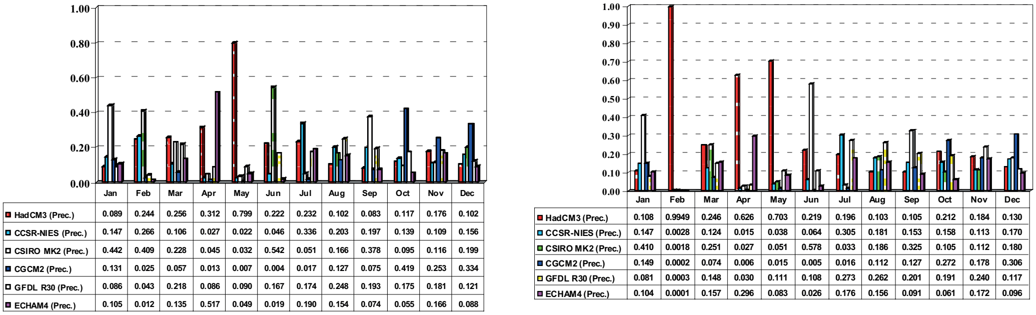
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟥 HadCM3 (Temp.)	0.456	0.118	0.382	0.309	0.189	0.417	0.299	0.279	0.305	0.084	0.138	0.149
🟦 CCSR-NIES (Temp.)	0.025	0.010	0.018	0.011	0.033	0.042	0.086	0.009	0.017	0.013	0.023	0.012
🟩 CSIRO MK2 (Temp.)	0.157	0.048	0.245	0.048	0.135	0.176	0.183	0.201	0.530	0.603	0.276	0.543
🟦 CGCM2 (Temp.)	0.083	0.347	0.042	0.062	0.404	0.053	0.100	0.483	0.098	0.233	0.247	0.047
🟨 GFDL R30 (Temp.)	0.152	0.355	0.240	0.035	0.055	0.072	0.133	0.012	0.022	0.024	0.095	0.200
🟪 ECHAM4 (Temp.)	0.127	0.123	0.072	0.535	0.184	0.240	0.200	0.016	0.028	0.042	0.221	0.050

(b)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟥 HadCM3 (Temp.)	0.187	0.220	0.277	0.586	0.206	0.445	0.274	0.555	0.200	0.094	0.140	0.201
🟦 CCSR-NIES (Temp.)	0.016	0.016	0.028	0.007	0.035	0.040	0.086	0.005	0.013	0.007	0.023	0.021
☐ CSIRO MK2 (Temp.)	0.086	0.075	0.287	0.029	0.137	0.169	0.194	0.086	0.679	0.768	0.288	0.454
🟦 CGCM2 (Temp.)	0.055	0.319	0.061	0.038	0.376	0.052	0.098	0.338	0.065	0.097	0.232	0.086
☐ GFDL R30 (Temp.)	0.572	0.181	0.233	0.015	0.056	0.068	0.144	0.007	0.020	0.013	0.101	0.155
🟪 ECHAM4 (Temp.)	0.083	0.190	0.114	0.325	0.191	0.227	0.204	0.009	0.023	0.021	0.217	0.084

(a)

Fig. 3. Monthly weights of GCMs in simulating temperature (a) A2 scenario and (b) B2 scenario of Gharanghu basin (Poids mensuel des MCG à simuler la température (a) scénario A2 et (b) le scénario B2 du bassin Gharanghu)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
HadCM3 (Prec.)	0.089	0.244	0.256	0.312	0.799	0.222	0.232	0.102	0.083	0.117	0.176	0.102
CCSR-NIES (Prec.)	0.147	0.266	0.106	0.027	0.022	0.046	0.336	0.203	0.197	0.139	0.109	0.156
CSIRO MK2 (Prec.)	0.442	0.409	0.228	0.045	0.032	0.542	0.051	0.166	0.378	0.095	0.116	0.199
CGCM2 (Prec.)	0.131	0.025	0.057	0.013	0.007	0.004	0.017	0.127	0.075	0.419	0.253	0.334
GFDL R30 (Prec.)	0.086	0.043	0.218	0.086	0.090	0.167	0.174	0.248	0.193	0.175	0.181	0.121
ECHAM4 (Prec.)	0.105	0.012	0.135	0.517	0.049	0.019	0.190	0.154	0.074	0.055	0.166	0.088

(b)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
HadCM3 (Prec.)	0.108	0.9949	0.246	0.626	0.703	0.219	0.196	0.103	0.105	0.212	0.184	0.130
CCSR-NIES (Prec.)	0.147	0.0028	0.124	0.015	0.038	0.064	0.305	0.181	0.153	0.158	0.113	0.170
CSIRO MK2 (Prec.)	0.410	0.0018	0.251	0.027	0.051	0.578	0.033	0.186	0.325	0.105	0.112	0.180
CGCM2 (Prec.)	0.149	0.0002	0.074	0.006	0.015	0.005	0.016	0.112	0.127	0.272	0.178	0.306
GFDL R30 (Prec.)	0.081	0.0003	0.148	0.030	0.111	0.108	0.273	0.262	0.201	0.191	0.240	0.117
ECHAM4 (Prec.)	0.104	0.0001	0.157	0.296	0.083	0.026	0.176	0.156	0.091	0.061	0.172	0.096

(a)

Fig. 4. Monthly weights of GCMs in simulating precipitation (a) A2 scenario and (b) B2 scenario of Gharanghu basin (Poids mensuelle de MCG dans la simulation des précipitations (a) scénario A2 et (b) le scénario B2 du bassin Gharanghu)

To assess the runoff of the Gharanghu basin in 2010-2039, discrete monthly pdfs of temperature and precipitation change scenarios of the basin in 2010-2039 were constructed under A2 and B2 scenarios using each GCM weights. Then Monte Carlo method was carried out to simulate 2000 samples from each monthly pdf. Finally each monthly sample added to the observed monthly temperature and precipitation time series to produce 2010- 2039 monthly time series of desired variables. Then each set of temperature and precipitation time series of period 2010-2039 individually introduced to the IHACRES and 2000 monthly time series of runoff of the Gharanghu River were simulated.

Then, 2000- 30 year average of monthly runoff time series for the future period (under A2 and B2 scenario) were compared to monthly runoff average for baseline period that results have been presented in figure 5. As shown, the mean 30- year of monthly runoff for 2010- 2039 period increase 1.73 m^3/s in A2 and 0.44 m^3/s in B2 relative to 1971- 2000 period and the runoff increase for A2 is more than B2 (Table 2). Also, results show that variation coefficient of discharge decrease for future period relative to baseline period. As, decreasing in 2010- 2039 period relative to baseline period for A2 and B2 scenarios is 26.8 and 28.1%, respectively.

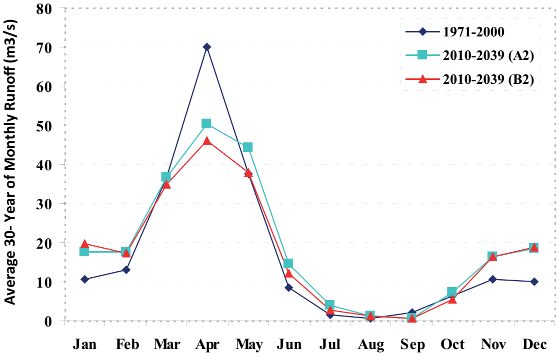


Fig. 5. Average 30- year of monthly runoff in future (A2 and B2 scenarios) and baseline period (Moyenne des 30 - année de l'écoulement mensuel à l'avenir (scénarios A2 et B2) et la période de reference)

Table 2. Statistical parameters of yearly discharge under A2 and B2 scenarios (Les paramètres statistiques de la décharge annuellement en vertu des scénarios A2 et B2)

Discharge (m^3/s)	Discharge (m^3/s)	Statistical Parameter	Period
17.32	17.32	Average	1971- 2000
19.57	19.57	Standard Derivation	
112.99	112.99	Coefficient of Variation	
B2	A2	Scenario	
17.76	19.05	Average	2010- 2039
14.42	15.75	Standard Derivation	
81.19	82.68	Coefficient of Variation	

5. CONCLUSIONS

In this study, climate change scenarios that included SRES emission scenario (A2 and B2) were generated from 7-TAR GCM and downscaled to an appropriate river basin scale. These data weighted and served as input to a hydrologic model to generate climate impacted runoff for a study basin. These were then used in a statistical river basin simulation model to investigate the sensitivity of a reservoir system to climate change for runoff. It can be concluded that over-reliance on a single or very few GCMs climate scenarios and not considering to different emission scenarios could lead to inappropriate runoff. Therefore for providing scientifically based advice to decision makers it is essential that climate change impact studies consider a range of weighted climate scenarios derived from different GCMs and considering to different emission scenarios. The methodology and the final results of this research can play the base role for other disciplines such as adaptation policies that are greatly affected by changes in runoff. It should be noted that, although applying the uncertainties due to GCM simulation in impact assessment studies can improve the final results, one should use the methodology that applies other uncertainties due to downscaling methods, rainfall-runoff modeling and weighting method in the analyses.

REFERENCES

Boyer, C., Chaumont, D., Chartier, I and G. Roy, A. (2010), Impact of climate change on the hydrology of St. Lawrence tributaries. Journal of Hydrology, 384: 65- 83

Carter, T.R. (2007), General guideline on the use of scenario data for climate impact and adaptation assessment, Finnish Environment Institute, Helsinki, Finland

Christensen, N.S., Wood, A.W., Voisin, N., Lettenmaier, D.P. and Palmer, R.N. (2004), the effects of climate change on the hydrology and water resources of the Colorado River basin, Climatic Change 62, pp. 337–363.

Diaz-Nieto, J. and Wilby, R.L. (2005), a comparison of statistical and climate change factor methods: impacts on low flows in the river Thames, United Kingdom. Jouornal of Climatic Change, 69: 245–268

IPCC 2007, Summary for Policymarkers, in: Climate Change 2007, Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.) (2007) Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 1-18

Jakeman, A. J. and Hornberger, G. M. (1993), How Much Complexity is Warranted in a Rainfall-Runoff Model? Water Resour. Res. 29: 2637–2649.

Jiang, T., Chen, Y.D., Xu, C., Chen, X. and Singh, V.P. (2007), Comparison of hydrological impacts of climate change simulated by six hydrological models in the Dongjiang Basin, South China, Journal of Hydrology 336, pp. 316–333.

Katz, R.W. 2002. Techniques for estimating uncertainty in climate change scenarios and impact studies. Climate research, 20(2):167-185.

Muzik, I. (2001), Sensitivity of hydrologic systems to climate change, Canadian Water Resources Journal 26 (2), pp. 233–253.

New, M. and Hulme, M. (2000), Representing uncertainty in climate change scenario: a Monte-Carlo approach. Integrated Assessment. 1: 203-213

Prudhomme, Ch., Jakob, D. and Svensson, C. (2003), Uncertainty and climate change impact on the flood regime of small UK catchments. Journal of Hydrology. 277: 1-23

Robson, A.J. (2003), Evidence for trends in UK flooding. In Proc. Flood risk in a changing climate Statistical Royal Society, 21-22 Nov 2001, London.

Whitfield, P.H. and Cannon, A.J. (2000), recent variation in climate and hydrology in Canada, Canadian Water Resources Journal 25 (1), pp. 19–65.

Wilby, R. L., and I. Harris (2006), A framework for assessing uncertainties in climate change impacts: Low-flow scenarios for the River Thames, UK, Water Resource. Res., 42.

Xu, Ch.Y. and Singh, V.P. (2004), Review on regional water resources assessment models under stationary and changing climate, Water Resources Management 18, pp. 591–612.