Evaluating the effects of climate change on groundwater level in the Varamin plain

Hamidreza Azizi, Hossein Ebrahimi, Hossein Mohammad Vali Samani and Vida Khaki

ABSTRACT

In this research, a number of paired three-dimensional Atmosphere-Ocean General Circulation Model (AOGCM) from CMIP (Climate Model Inter Comparison Project) 5 group with the base period of 1989–2005 have been evaluated and the output of these models was micro-scaled and calibrated by LARS-WG software. The appropriate model was selected to simulate temperature and rainfall data under the emission scenarios of RCP (Representative Concentration Pathway) 2.6, RCP4.5 and RCP8.5 for the future period of 2020–2050, and then to model the groundwater level of the region, GMS software for both stable and transient states for one water year was calibrated and then was validated by observation data. The results in the future periods showed an increase of 1–1.5 degrees in temperature and an increase in rainfall in the early months of the year to late spring season and a decrease in rainfall in autumn season. Generally, the RCP4.5 scenario showed slightly more annual rainfall increase over the next 30 years compared to the base period than the other two scenarios. The time series investigation of the average of groundwater level shows that the implementation of RCP 2.6, RCP 4.5 and RCP 8.5 scenarios respectively leads to an average monthly increase of 4.2, 4.3 and 4.6 cm of the groundwater level.

Key words | aquifer simulation, climate change, GMS, groundwater, LARS-WG

HIGHLIGHTS

- Using the models and scenarios of the fifth IPCC report in Varamin and Tehran plains to study the trend of climate change.
- Using a step-by-step approach to investigate the effect of climate change on groundwater level in Varamin plain.
- A view of the future of the Varamin plain aquifer under different climate change scenarios for groundwater resources management.
GRAPHICAL ABSTRACT

NOMENCLATURE

\[ Q_{in} \] the sum of the effective factors
\[ Q_{out} \] the sum of the effective factors
\[ \Delta V \] changes in the volume of water storage
\[ A \] area of the balance extent in terms of square kilometers
\[ \Delta h \] average annual changes in groundwater level in the balance period in terms of meter
\[ S_y \] the average storage coefficient of the balance area
\[ k \] the hydraulic conductivity
\[ \sigma \] the standard deviation of the data
\[ h \] the potential load
\[ w \] indicates the volume flux per unit volume
\[ s_s \] the specific storage for porous materials
\[ t \] time

INTRODUCTION

In recent years, climate changes have engaged all regions of the world with their issues and crises. According to the fifth evaluation report of the Intergovernmental Panel on Climate Change (IPCC), global temperatures have risen by 0.85 °C from 1880 to 2012, and if global greenhouse gas emission is not reduced, the average global temperature can rise by 1.1–4.6 ratio by 2100 (IPCC 2013).

Global temperature changes and its rising trend are known as climate change regarding the average weather conditions around the world. Climate change has a considerable impact on surface and groundwater resources (Hashmi et al. 2014). Considering that the impact of climate changes on groundwater resources is indirect and slower than surface water resources, monitoring the status of these resources and maintaining their sustainability under the influence of these changes is of great importance (Shakiba & Cheshmi 2013).

The first step in investigating the effects of climate changes is to examine the impact of this phenomenon on climate parameters. Therefore, in order to investigate the effects of climate change in future periods, the amount of climate variables in the future must first be simulated (Node Farahani et al. 2011). One of the most reliable tools for investigating the effects of climate change is the use of climatic variables simulated by the downscaling models of climatic parameters such as LARS-W that can predict climatic parameters in local scale. In this regard, numerous studies have been conducted, that are mentioned in the following.

Crosbie et al. (2013) examined the effects of climate changes on feeding aquifer groundwater in the highland plains of the United States. Groundwater feeding was modeled for different types of soil and vegetation using soil, vegetation, atmosphere and WAVES transfer model. The results of investigations showed that feeding the northern highland plains increased by 8%, the central highland plain decreased by 3% and the southern highland plains
decreased by 10%. Ahmadebrahimpour et al. (2019) investigated future drought conditions under a changing climate. The results of SPI analyses revealed that under RCP 2.6 the frequency of droughts is almost constant while under RCP 8.5 drought frequency increased especially in the period 2071–2100.

Shrestha et al. (2016) investigated runoff and sediment uncertainty in the future for the time periods of 2030 and 2060 under the impact of climate change in the Mekong Basin using the LARS-WG and SWAT 2060 under the GCM model. Their results showed that sediment load and runoff will respectively increase and decrease in the future. Nistor et al. (2016) using the new NISTOR-CEGW method, considering the effective rainfall and De Martonne drought coefficient in the Carpathians, investigated the intensity of the effect of climate change on groundwater resources. The results showed that the intensity of the effect of climate changes on groundwater resources in the region under study was low.

Shahvari et al. (2019) investigated the effects of climate change on water resources in the Varamin plain basin using the Soil and Water Assessment Tool (SWAT) model. Their results showed that the ratio of runoff in the period of 2011–2030 under all three scenarios will increase in spring and summer seasons and decrease in autumn and winter seasons. This seasonal shift in runoff is due to the effects of climate change in the form of rising temperature, changing rainfall pattern, and so on. Klaas et al. (2020) investigated the effect of climate change on groundwater level in the Karst region under the HadCM3 model. Their results showed a reduction in the amount of feeding and the storage of groundwater resources. Haidu & Nistor (2020) using the NISTOR index, investigated the intensity of the effect of climate change on a spatial scale in eastern France. Their results showed that the intensity of the effect of climate change on groundwater resources is moderate and low.

With regard to the importance of the effects of climate change on water resources, especially valuable groundwater resources, research in this field is necessary. The present research with the aim of investigating climate change and its effects on groundwater level due to rainfall and temperature has been conducted in a case study in the semi-arid climate region of Iran. Regarding the position of the region, increasing removals for agricultural water consumption has caused a drop in water level in the plain, that by conducting this research and determining the status of the aquifer under climate change scenarios in the future period, a principled planning to control removal and aquifer development plans in the region can be presented.

MATERIALS AND METHODS

Study area

Varamin plain, a strategic region in terms of agriculture, has been located at distance of 40–45 km south to southeast of Tehran province. The climatic situation of this plain is in many ways similar to the climate of the central plateau of Iran and is located in arid to semi-arid climate. Varamin plain catchment basin with an area of 1,720 square kilometers is one of the sub-basins of Namak Lake, which has been located in the geographical area of 35° 0’ 0” to 36° 0’ 0” N latitude and 51° 0’ 0” to 52° 0’ 0” E longitude (Figure 1). The Jajrood, Kondrood, Galandûak and Dama-vand Rivers have been located in the study catchment basin, the most important of which is the Jajrood River, on which the Latian Dam has been constructed in the upstream. Latian Dam is one of the factors in the hydrological cycle of the basin and also downstream agriculture development itself has a great network.

Hydroclimatology studies

Meteorological information including pluviometry, thermometry and climatology (relative humidity, frosty days, sunny hours, wind, evaporation and transpiration) have been collected from Varamin Synoptic Station, which is the plain station representation. The average annual temperature in this basin is 16.9 °C and the warmest month of the year is July with an average temperature of 29.5 °C and the coldest month of the year is January with an average temperature of 3.3 °C; also the average annual rainfall is 156 mm in the year. The driest month of the year is August, with an average of 0 mm rainfall and the highest rainfall is related to March with 35 mm ratio.

Hydrological information including hydrometric network and water flow calculation has been obtained from
hydrometric stations in the aquifer area. Hydrogeological characteristics of the aquifer are obtained by preparing a single hydrograph, groundwater average level map and hydraulic conduction map, so that having monthly statistics of 48 observation well rings in the plain surface, a groundwater average level map is drawn for the water year of 2014–2015, and having a map of transfer capability obtained from (T pumping test) and the layer thickness of the output of GIS software, the k hydraulic conduction map is obtained.

**Groundwater balance in the study area**

The general equation of groundwater balance is presented as Equation (1):

\[
\Delta V = Q_{in} - Q_{out} \tag{1}
\]

where \(Q_{in}\) is the sum of the effective factors in feeding and \(Q_{out}\) is the sum of the effective factors in discharging the aquifer and \(\Delta V\) is the changes in the volume of water storage in the aquifer during the balance period. On the other hand, the amount of changes in groundwater reservoir volume is calculated by Equation (2):

\[
\Delta V = S_y \times \Delta h \times A \tag{2}
\]

The changes in the storage volume of the balance area in terms of million cubic meters is \(\Delta V\), the area of the balance extent in terms of square kilometers is \(A\), the average annual changes in groundwater level in the balance period in terms of meter is \(\Delta h\) and the average storage coefficient of the balance area is \(S_y\) that based on making the amount of feeding and discharging balance, using Equations (1) and (2), has been determined equal to 6%.

The ratio of groundwater inflow and outflow after determining the inflow and outflow sections has been determined using the average level map of the water year of 2014–2015 and the map of the ability to transfer and the measurement of the length of each one of the sections and hydraulic gradient and Darcy equation (Figure 2).

Also, the presence of hydraulic conductivity information, aquifer floor rock level, and average groundwater level in the water year of 2014–2015 along with the aquifer
position to determine the ratio of groundwater inflow and outflow from the groundwater aquifer is essential.

Also based on the results obtained from water balance parameters Underground in Varamin aquifer, The groundwater balance for 2014–2015 of Varamin aquifer is presented in Table 1.

As it is clear from the groundwater balance sheet table of the study area, the changes in inflow and outflow in the target year are negative, which can be a sign of uncontrolled extraction from exploitation wells. Therefore, the study of the effects of climate change on groundwater changes in the study area will be more important than ever.

**Groundwater modeling by GMS software**

In this research, GMS10.3 software was used to establish a relationship between GIS software and MODFLOW code (McDonald & Harbaugh 1988) to construct a conceptual and numerical model of the aquifer. The MODFLOW numerical model is based on solving the groundwater motion equation so that the three-dimensional motion of groundwater with constant density is solved by the partial differential equation, Equation (3), using the finite difference method and based on the continuity equation.

\[
\begin{align*}
\left( k_{xx} \frac{\partial h}{\partial x} \right) + \left( k_{yy} \frac{\partial h}{\partial y} \right) + \left( k_{zz} \frac{\partial h}{\partial z} \right) - w &= \left( s_s \frac{\partial h}{\partial t} \right)
\end{align*}
\]

which \( k \) is the hydraulic conductivity, \( h \) is the potential load, \( w \) indicates the volume flux per unit volume, which shows the feeding and discharge, \( s_s \) is the specific storage for porous materials, and \( t \) is the time.

**Conceptual and numerical model of varamin aquifer**

The conceptual model of the aquifer is a three-dimensional view of structural, hydraulic, hydrodynamic, and so on characteristics, which has been obtained based on the analysis of the discharge data of exploitation wells and their return water ratio, observation wells, aqueducts and springs, the ratio of surface feeding (rainfall and runoff) to the aquifer, temperature and evapotranspiration potential and boundary conditions of the aquifer (Figure 3). The more data is obtained from the aquifer, the closer the conceptual model is to the real conditions. In general, in Varamin plain, there is practically a main free aquifer corresponding to the groundwater balance area between the clay layers in its southern parts, and the wells are also located in this main layer. The highest aquifer thickness is in the north of the plain with 280 meters and the lowest alluvial thickness is in the southwest of the region with 150 meters. The bedrock of the main aquifer has generally been composed of clay sediments, marl, congenital Miocene and myopliocene

![Figure 2 | Underground Inlet and Outlet Sections of Plain Aquifer Area Varamin.](http://iwaponline.com/ws/article-pdf/doi/10.2166/ws.2021.007/831248/ws2021007.pdf)

**Table 1 | Varamin plain aquifer balance for 2014–2015 (MCM)**

| Drainage | Recharge | Balance component |
|----------|----------|-------------------|
| 116/07   | Inlet flow from the aquifer border |
| 12/66    | Recharge of rainfall |
| 30/81    | Infiltration of surface currents |
| 187/14   | Agriculture Water returned from |
| 48/1     | Drinking and industry |
| 41/43    | Outlet flow from the aquifer boundary |
| 0        | Evaporation rate from the aquifer |
| 389/94   | Harvesting from wells |
| 3        | Drainage from the river |
| 434/37   | Total |
| 394/78   | Tank volume changes |
with low permeability. The main sources of feeding the Varamin plain are rainfall, main waterways, wastewater treatment plant in the south of Tehran and subsurface feeding. Groundwater depth in the main aquifer is between 30 and 170 meters below ground surface that the general direction of groundwater flow in the region is from northwest to southeast.

Creating and preparing varamin aquifer flow model

Necessary stages to set up the model in GMS10.3 software include networking the case study area, determining the model area, spatial and temporal division, defining the model boundaries and how to assign the values of the initial parameters to various nodes of the model. It is necessary to mention that in the modeling stage, it has been tried as much as possible that the groundwater model area correspond to the balance area.

Calibration and validation stage of GMS software

The purpose of this stage is calibration of various parameters of the model and to minimize the error in successive time steps. In this study, the model was calibrated and validated with different time steps (Figure 4) according to the existence of observation well information under stable and transient conditions. In this study, the maximum acceptable error ratio between the observed static level and the simulated observation wells has been considered ±2 m.

AOGCM climate models and climate data extraction

Currently, the most reliable tool for generating climate scenarios are the paired three-dimensional Atmosphere-Ocean General Circulation Model, abbreviated as AOGCM (Wilby & Harris 2006). According to the purpose of this part of the research, which investigates the effects of climate change using the Climate Model Inter Comparison Project (CMIP5) group models under Representative Concentration Pathway (RCP) emission scenarios on groundwater level in Varamin plain basin, considering the satellite conditions of the models and the climatic conditions of the case study area, among 61 paired three dimensional Atmosphere-Ocean models of the fifth report of the Intergovernmental Panel on Climate Change (IPCC), named as CMIP5, 10 models were selected and evaluated. To investigate the performance of these models in simulating the temperature and rainfall variables of the region, the average monthly amounts of temperature and rainfall simulated by this model in the base period of 1989–2005 were compared with the corresponding observation amounts of the station under study in the same period. To investigate the performance of the models, four criteria of Determination Coefficient \( R^2 \), Correlation Coefficient \( \rho \), Root Mean Square Error (RMSE) and Bias Error Criterion were used.

Downscaling

Due to the low resolution power of AOGCM models, it is necessary and essential to make them micro scale. In this research, in order to downscale the data to generate climate change scenarios, the LARS-WG stochastic climate
generator was used to simulate atmospheric data (Racsko et al. 1991; Semenov & Brooks 1999).

**Calibration of LARS-WG model in the case study area**

Initially, the specification of station name, geographical latitude and longitude, height from sea level and 16-year observation data from 1989 to 2005 including minimum temperature, maximum temperature and rainfall were entered into the model. During calibration operations, the model using input files and the analysis of station data determines the characteristics of the statistical parameters of the observed data and uses them in the validation stage and time series generation.

**Meteorological data production**

This stage includes simulating meteorological data (minimum temperature, maximum temperature and rainfall) for any number of arbitrary years according to the considered climate change scenario (Semenov & Stratonovitch 2010).

At this stage, the data of monthly changes of minimum temperature, maximum temperature and rainfall simulated by the appropriate model of the region under the three emission scenarios of RCP2.6, RCP4.5 and RCP8.5, in the period of 2020–2050 are generated and are investigated with observation values in the base period in the study area.

**Investigating the effects of climate change using a calibrated GMS model**

Based on the proposed approach prepared (Figure 5), to investigate the quantitative behavior of the groundwater aquifer under the generated CMIP5 emission scenarios, it is necessary to simulate the GMS simulation model whose parameters have already been calibrated according to the climate parameters of temperature and rainfall under the scenarios of (RCP2.6, RCP4.5, RCP8.5) for a period of 30 years.

Due to changes occurring in climatic parameters of temperature and rainfall under various RCP scenarios, the quantitative behavior of aquifer will also have fluctuations. Based on these changes and comparing it with the existing conditions, the effects due to climate change of the region on groundwater can be realized.

![Figure 5](http://iwaponline.com/ws/article-pdf/doi/10.2166/ws.2021.007/831248/ws2021007.pdf)
RESULTS AND DISCUSSION

Calibration results of GMS model

In order to calibrate the aquifer of Varamin plain under stable and transient conditions, groundwater level associated with 48 observation wells was used. In the stable state, the hydraulic conductivity parameter and in the transient state, the specific water flow parameter was calibrated and the final simulation error values were obtained at the location of each of the piezometers.

The scatter diagram of points between observation and calculation groundwater level values has been shown in the observation wells of Varamin plain aquifer in a stable state (Figure 6). According to Figure 6, the correlation coefficient between the calculated and observed values is equal to $R^2 = 0.9932$. It should be mentioned that the Root Mean Square Error value between the observation and calculation level values is equal to 3.71, which indicates a very proper agreement between the results of the calibrated simulation model and the real values.

In order to calibrate the model in the transient conditions, calibration operations were performed on specific water flow parameters and feeding amounts to the aquifer. Based on the results of the calibrated simulation model, it can be realized that the parameter of aquifer storage coefficient varies in the range between 0.001% and 0.154%.

Now, according to the calibrated model, the quantitative behavior of the aquifer can be simulated for a short time period. In fact, based on calibrated parameters, it is possible to predict the groundwater level in the future conditions. For this purpose, the calibrated model was simulated for a period of 30 months after the calibration period (according to the existence of observation well information) and its results were analyzed in the form of a groundwater level hydrograph for each piezometer. According to these results and considering the error of 2 meters it can be realized that the simulated model, despite the shortage of available information, was able to predict the quantitative behavior of the groundwater reservoir well. In fact, this model can be used to investigate the effects of various hydrological and meteorological parameters on the groundwater level.

Evaluating AOGCM models

The performance of AOGCM models in the base period of 1989–2005 was evaluated with observation data of the case study area. According to the results of Table 2, the EC-EARTH model has shown a high correlation coefficient in simulating temperature and rainfall compared to other models. The value of correlation coefficient ($\rho$), represents the linear relationship between the simulated data and the observations, the value of which is between zero and one. So the closer the value of $\rho$ is to one, the stronger the linear relationship between the two values. So the EC-EARTH model was acceptable and was selected for further study.
temperatures and maximum temperature and daily radiation variables in the future period.

Investigating temperature and rainfall changes under CMIP5-AR5 emission scenarios in the future period compared to the base period in varamin synoptic station

According to Figure 7, the trend of annual temperature increase by ECEARTH model under all the three emission scenarios of RCP8.5, RCP4.5, and RCP2.6 until 2050 is evident. Scenario RCP8.5 shows a greater temperature increase than the other two scenarios in the next 30 years compared to the base period in the study area.

According to Figure 8, uniform changes in annual rainfall under all three RCP emission scenarios are not observed in the future period compared to the observation period. Generally, the RCP4.5 scenario shows a slight increase in annual rainfall over the next 30 years compared to the other two scenarios.

Fluctuation of groundwater level in the future period

Due to changes occurring in rainfall and temperature ratio under various scenarios, the quantitative behavior of the aquifer will also have fluctuations. Based on these changes and comparing them with the existing conditions, the effects due to climate changes in the region on groundwater can be realized.

By implementing the proposed approach for each of the defined scenarios, the predicted groundwater level time series was determined. To better show the various sections

| Model       | Rainfall Bias (mm) | RMSE (mm) | ρ (%) | R² (%) | Temperature Bias (oC) | RMSE (oC) | ρ (%) | R² (%) |
|-------------|-------------------|-----------|-------|-------|------------------------|-----------|-------|-------|
| EC-EARTH   | 8.3               | 10.8      | 84    | 72    | – 7.8                  | 7.8       | 99    | 99    |
| CAN ESM2   | –2.5              | 6.7       | 72    | 53    | – 5                    | 7.8       | 83    | 70    |
| CCSM4      | 15.7              | 19        | 77    | 59    | – 5.4                  | 7.5       | 86    | 75    |
| GFDL-CM    | –9.4              | 10.5      | 88    | 62    | 31.3                   | 36.7      | 79    | 77    |
| GFDL-ESM2G | 20.3              | 23.9      | 74    | 55    | – 4.6                  | 6.9       | 99    | 72    |
| GFDL-ESM2M | 16                | 19.3      | 75    | 56    | – 4.6                  | 6.9       | 85    | 72    |
| MIROC5     | 37                | 43.6      | 79    | 61    | – 3.3                  | 5.7       | 88    | 77    |
| HADGEM2    | 13.8              | 16.9      | 54    | 30    | – 6.5                  | 9.1       | 77    | 59    |
| BCC-CSM1.1 | 18.5              | 13.7      | 60    | 36    | – 60.08                | 7.9       | 85    | 73    |
| GISS-E2-H  | 20.09             | 21.4      | 68    | 46    | – 5.4                  | 6.2       | 99    | 99    |

Figure 7 | Comparison of the Average Annual Temperature Simulated Using the ECEARTH Model under the Emission Scenarios of RCP8.5, RCP4.5, and RCP2.6 in the Period of 2020–2050 Compared to the Base Period of the Studied Station.
of the aquifer in terms of groundwater level changes, and considering that 48 piezometers cover the entire surface of the plain and the aquifer can be divided into 4 different areas, aquifer behavior for the northern, southern, eastern and western sections (Figure 9) under various scenarios was examined separately, and extracted and presented comparatively (Figure 10).

As shown in Figure 10, the yellow graph shows the fluctuation of the water table in each area according to the continuation of the existing conditions, also the other 3 graphs show the fluctuation of the water level in each area under 3 climate change scenarios. Investigating the predicted groundwater level situation shows that in all aquifer sections, the effects of climate directly affect the quantitative situation of aquifer and has led to an increase in groundwater level, which corresponds with the result (Shahvari et al. 2019) regarding the increase of runoff in Varamin plain. This trend has emerged as a positive effect except in the southern parts of the aquifer, which is the groundwater outlet, and prevents the ascending decline of the aquifer in the eastern parts of the plain, which is very sensitive to removal as the floor level balance is high. It should also be
noted that in all zones, the increase in groundwater level in the next three decades under the RCP8.5 scenario is more than the other two scenarios. Also as mentioned before, Varamin plain is a strategic region in terms of agriculture, so there are many exploitation wells in the plain. About 2054 active wells. So, these overdrafts from exploitation wells have made it impossible to compensate for the lack of groundwater balance every year. It should also be

Figure 10 | Groundwater Level Time Series Predicted under Various Scenarios in Northern, Southern, Eastern and Western Areas.
considered that the density of exploitation wells and the amount of harvest varies according to the type of agricultural area in the plain. So, it can be seen that in areas where the yellow graph is far from other graphs, the amount of recharge due to rainfall can not compensate for the decline in water table due to increasing overdraft from wells in that area. But, if we consider the hydrograph of the whole aquifer, it will be different. So by Examination of the average time series of groundwater level under the studied scenarios shows that the implementation of RCP 2.6, RCP 4.5 and RCP 8.5 scenarios on average monthly leads to 4.2, 4.3 and 4.6 cm increase respectively in groundwater level and thus improving the saturation thickness of the aquifer.
It should be mentioned that this level increase ratio can cause water storage of 25.8, 26.22 and 28 million cubic meters per year respectively in the three scenarios investigated in the aquifer.

CONCLUSION

Regarding the increasing growth of water consumption and considering that the focus of much consumption is based on groundwater extraction, therefore the topic of investigating the impact of climate change scenarios in long-term horizon on groundwater resources is very important. In this regard, using a step-by-step approach of modeling and simulation, this effect on the level of the aquifer in the region in the future was investigated. In this regard, in the present research, RCP2.6, RCP4.5 and RCP8.5 climate change scenarios were generated for two important variables of temperature and rainfall in Varamin plain area in Tehran province, and finally changes in groundwater level in all three scenarios were analyzed. It should be mentioned that the effects of climate change typically occur on a large scale, and investigating it for a study area with limited extent will not certainly be free of errors and mistakes. However, this investigation can provide an overview of the situation of the aquifer in the future to provide more appropriate management plans for the users and managers of water systems.

The results show the temperature increase by 1–1.5 degrees and in general a relative increase in the average annual rainfall in the next 30 years as well as an increase in the groundwater level compared to the base period in the region. It can be concluded that if the amount of harvesting from exploitation wells is controlled, the condition of the aquifer can be improved in the future. Otherwise, the thickness of the aquifer will deteriorate. Due to the strategic location of Varamin plain in terms of agriculture in Tehran province and the necessity to maintain the aquifer, principled planning to control the removal and to cure the aquifer, including projects such as underground dam, artificial recharge, managing well harvesting and using smart controllers, modifying the cropping pattern and so on are necessary and essential. The results of this research can be further analyzed for sensitivity and evaluation in the form of other climatic scenarios as well as downscaling models and other rainfall-runoff analysis.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

REFERENCES

Ahmadebrahimpour, E., Aminnejad, B. & Khalili, K. 2019
Assessing future drought conditions under a changing climate: a case study of the Lake Urmia basin in Iran. Water Supply 19 (6), 1851–1861.

Crosbie, R. S., Scanlon, B. R., Mpelasoka, F. S., Reedy, R. C., Gates, J. B. & Zhang, L. 2015
Potential climate change effects on groundwater recharge in the High Plains Aquifer. USA Water Resources Research 49 (7), 3936–3951.

Haidu, I. & Nistor, M.-M. 2020
Long-term effect of climate change on groundwater recharge in the Grand Est region of France. Meteorological Applications 27 (1), e1796.

Hashmi, M. Z., Shamseldin, A. Y. & Melville, B. W. 2011
Comparison of SDSM and LARS-WG for simulation and downscaling of extreme precipitation events in a watershed stochastic. Environmental Research and Risk Assessment 25 (4), 475–484.

IPCC 2013 Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Klaas, D. K. S. Y., Imteaz, M. A., Sudiayem, I., Klaas, E. M. E. & Klaas, E. C. M. 2020
Assessing climate changes impacts on tropical karst catchment: implications on groundwater resource sustainability and management strategies. Journal of Hydrology 582, 124426.

Mcdonald, M. G. & Harbaugh, A. W. 1988
A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model. Techniques of Water-Resources Investigations.

Nistor, M.-M., Dezsi, Ş., Cheval, S. & Baciu, M. 2016
Climate change effects on groundwater resources: a new assessment method through climate indices and effective precipitation in Beliş district. Western Carpathians Meteorological Applications 23 (3), 554–561.

Node Farahani, M. A., Rasekhi, A., Parmas, B. & Keshvari, A. 2018
The effects of climate change on temperature, precipitation and drought in the the future Shadegan basin. Journal of Iran-Water Resources Research 14 (3), 125–139.

Racska, P., Szeidl, L. & Semenov, M. 1991
A serial approach to local stochastic weather models. Ecological Modelling 57 (1), 27–41.
Semenov, M. & Brooks, R. 1999 Spatial interpolation of the LARS-WG weather generator in Great Britain. *Climate Research* – *CLIMATE RES* 11, 137–148.

Semenov, M. & Stratonovitch, P. 2010 Use of multi-model ensembles from global climate models for assessment of climate change impacts. *Climate Research* – *CLIMATE RES* 41, 1–14.

Shahvari, N., Khalilian, S., Mosavi, S. H. & Mortazavi, S. A. 2019 Assessing climate change impacts on water resources and crop yield: a case study of Varamin plain basin. *Iran Environmental Monitoring and Assessment* 191 (3), 134.

Shahiba, A. R. & Cheshmi, A. 2013 Evaluation of the effect of climate change on groundwater resources of Ramhormoz plain using NARX neural network. *Journal of Researches in Earth Sciences* 2 (5), 46–57.

Shrestha, B., Cochrane, T. A., Caruso, B. S., Arias, M. E. & Piman, T. 2016 Uncertainty in flow and sediment projections due to future climate scenarios for the 3S Rivers in the Mekong Basin. *Journal of Hydrology* 540, 1088–1104.

Wilby, R. L. & Harris, I. 2006 A framework for assessing uncertainties in climate change impacts: low-flow scenarios for the River Thames. *UK Water Resources Research* 42 (2).

First received 21 August 2020; accepted in revised form 23 December 2020. Available online 7 January 2021