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Study of Climate Change Impact on Water Resources Allocation in Maragheh Plain Using WEAP Model

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Abstract

The appropriate water resources planning and management is very important due to the critical status of water all around the world and the ever-increasing need for water in each country. Over the past few decades, due to the climate changes and the weakness of integrated water resources management and neglecting the country's sustainable development, the water resources in Iran has been faced great challenges. The main purpose of this study is to examine the impact of climate changes on supply to demands in various sectors of agriculture, urban, and industry in four regions downstream of the ALAVIAN dam, Maragheh, Iran. For this purpose, the LARS-WG model was calibrated to create the future data for the Maragheh synoptic station. Then, among the 14 GCM models in the LARS-WG model, the IPSLCM 4 model under the A1B scenario was selected as the most suitable model for the climate simulation of the study area by using R^2, MAE and RMSE indices. In the next step, WEAP model was run for producing a reference scenario and providing information on climate changes in the future. The maximum and minimum annual temperatures during the years 2020-2040 is accompanied by an increase of about 1 ^{o}C. In other words, the region climate is moving towards increasing in the temperature. The changes in monthly precipitation did not show a general increasing or decreasing trend. The results of this study also showed that the negative effects of climate change may intensify the tensions and water scarcity with an increase in exploitation of groundwater resources. The results showed as the water resources in the study area is assigned to the urban, industrial and agricultural sectors, the needs for the urban and industrial sectors at the future are completely met and water resource indices did not change under the effect of climate change. While the agricultural sector may encounter to water scarcity and may be damaged by climate changes, as compared with urban and industrial sectors.

Keywords: Climate Change, Integrated Water Resources Management.

1. Introduction

Water is a major contributor to the complex global developments and sustainable development of each country. In a report on the water security challenges in the 21th century, the importance of water security has been emphasized on various parts of the world, including socio-economic and environmental issues (Grey and Garrick, 2012). Pressure on the water resources is continuously increased due to growth of the population and socio-economic developments, as well as the climate changes (Vörösmarty et al, 2010). The distribution of water resources and hydrological cycle are largely affected by the increase in greenhouse gases of the atmosphere and the global warming (Hagemann et al, 2013). The climate change may increase the temperature and reduce the precipitation in many regions, especially in warm and dry areas. Nowadays, the agricultural sector is the main consumer of the water resources and more than 70 percent of the total waters are generally allocated to the agricultural sector (UN-Water, 2014). Therefore, the first sector facing the water scarcity is the agricultural sector (UN-Water, 2006). In addition, the water scarcity may affect all socio-economic sectors and threatens the sustainability of the natural resources. Furthermore, many researchers believe that the climate changes will increase the water scarcity at the future periods (Lobell et al, 2008).

The study of the affecting factors on the water scarcity and the resulting problems require an interdisciplinary and multidisciplinary management approach for the water resources; an approach that ensures the water management and other related resources, in order to maximize the socio-economic welfare level. The integrated modeling and assessment of the water resources in the mid-1980s were outlined as a link between various sciences and complex environmental issues, such as climate changes. (Akhtar et al, 2013). Planning, development, and management of the water resources should include all socio-economic relations, such as inappropriate education and poverty (Loucks and Van Beek, 2005). There are various ways to simulate and evaluate the water resources, which is proportional to the user’s purposes. Velazquez et al. (2011) studied the effects of climate changes on the river flows in one of the watersheds of Spain and provided some approaches to adapt to future changes in water resources at the catchment area. In their study, the greatest decrease was observed in the average river flow in August. Due to the low flow rates in this month, the status of water resources will be critical (Velazquez et al. 2011).

Appropriate management of water resources, due to the complex nature of water issues, rapid population growth, water demand for various uses and limited water resources, requires new methods, on which, the technical, economic, environmental, social, and logic viewpoints are gathered in an integrated framework. This is the concept of integrated water resource management (IWRM), which is one of the principal methods for achieving the sustainable water resources at national and international levels. Since the early 1980s, along with the advances in technology in various sciences, modeling of water resource allocation has been paid more attention. Water allocation is a combination of the activities that enable consumers to use water for useful purposes, in accordance with the adopted laws and regulations in the region. Among the various simulation models presented in the field of water allocation, the WEAP, RIBASIM, MODSIM, WBALMO, and MIKE BASIN software are of the important models and their applications can be found in Hagan (2007), Leemhuis et al. (2009), Chen et al. (2010), Chen and Wei, 2014) and Shourian and Mousavi (2005). Among the existing models, the WEAP model has been selected, due to its ability to combine important processes affecting the natural and human systems of water resource management at the river basin level and its comprehensive application to solve similar problems in different parts of the world. The WEAP model is developed by the Stockholm Environmental Institute (SEI). The WEAP model is based on the water balance equations and it has the ability to simulate-optimize water right by the allocation priorities.

Booij et al. (2011) evaluated the effects of climate change on river flows in the Nile Basin. For this purpose, precipitation-runoff model (HBV) was combined with water allocation and distribution model (RIBASIM) for upstream of Nile basin (NHSM). In this study, in order to simulate the future climate, the simulated series by three general circulation models (GCMs) have been used under two SRES emission scenarios. Finally, the GCM-NHSM simulation under two SRES emission scenarios for description of the hydrologic-climatic conditions for the years 2046-2065 and 2081-2100 showed that the difference between the predicts for the future discharges based on the GCM-NHSM simulation are very large. These differences are due to the high water tension in Egypt.

To this end, many studies have been conducted to investigate the effects of climate change on water resources systems. Some investigated the impact of climate change on the characteristics of meteorological (e.g. Kamal and Masah Bavani, 2010; Mathukumalli et al, 2016; Alexander and Arblaster, 2017; Ishida et al, 2017; Peng et al, 2017; Danandeh Mehr et al, 2020), or hydrological (e.g. Kumar et al, 2020; Todd et al, 2011; Ahmadzadeh et al, 2022; Tavakoli et al, 2018; Bharati et al, 2019; Shrestha and Shrestha, 2019) variables that affect the water resources system. Thus, studies such as those conducted by Ardestani and Ghahfarrokhi (2021), Li et al. (2015), and Zeinadini et al. (2019) are suggested for further investigation when the performance of water resources systems under climate change is on the interest.

Therefore, on the basis of the above-mentioned studies, the main purpose of this study was to simulate the effects of climate change in Maragheh plain on climatology parameters, precipitation and surface flow in the Sufichai River, and to apply a general sensitivity analysis according to the changes in runoff and existing consumptions. The effects of these changes on the allocations at the consumption points and the amount of reservoir's storage in the ALAVIAN Dam basin was evaluated, as well.

2. Materials and Methods

2.1. Study Area

Maragheh plain is located at northwest of Iran and the southern slopes of Sahand and southeast of Urmia Lake, between 46° 09' to 46° 11' eastern longitude and 37° 11' to 37° 28' north latitude. Sufichai is the main water resource of Maragheh plain. In the months of the year with high volume of water, the river flow is used to irrigate the agricultural lands and gardens of the region. In the warm months of the year, when the river flow decreases, the main river flow is captured by the farmers in upstream areas, and the downstream areas are facing water scarcity; therefore, the farmers exploit groundwater to supply water demand for agriculture. In order to solve the above problem and prevent damages to the aquifer of Maragheh plain, ALAVIAN reservoir dam with a useful capacity of 57 Mm^3 was constructed on the Sufichai River near the village of ALAVIAN located at 3.5 miles north of Maragheh in 1995. The location of the ALAVIAN Dam in the Maragheh plain is shown in Figure 1.

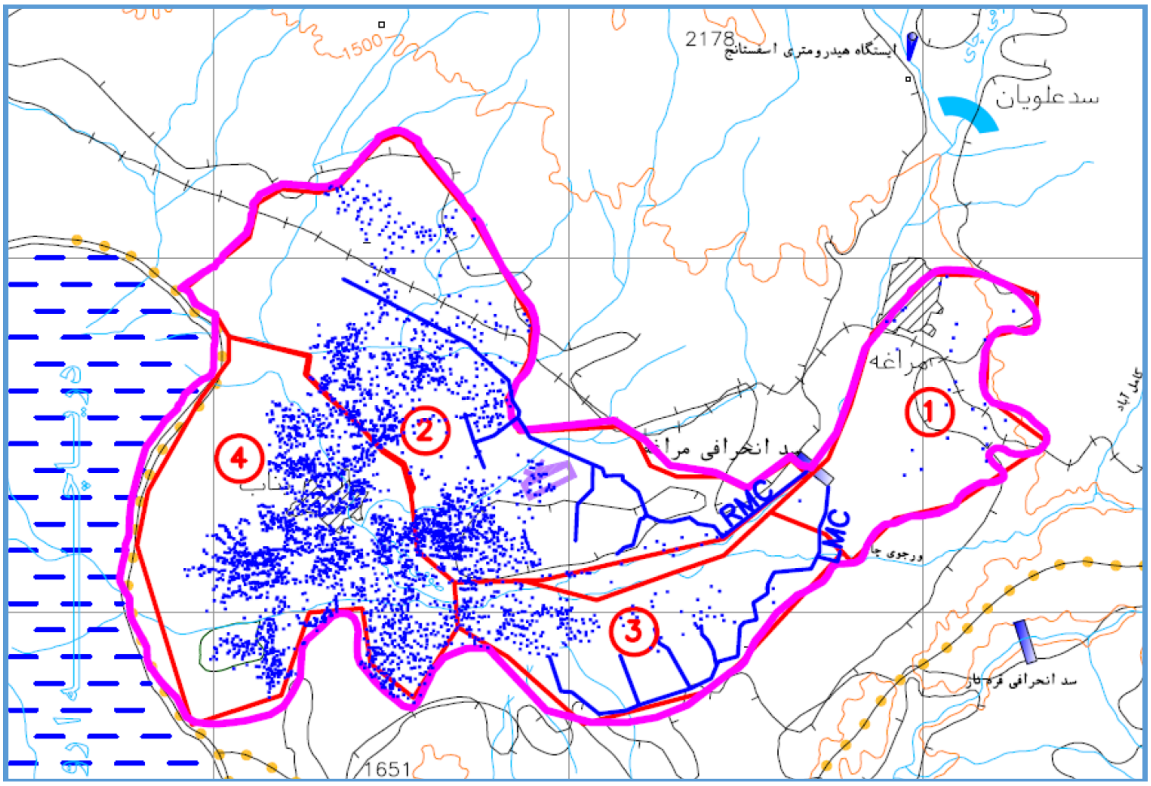


Fig.1. Geographic location of Alavian Dam in Maragheh Plain.

2.2. Sources of Data

Different datasets were used to establish the WEAP hydrological model for the study basin (Table 1). These data include the Digital Elevation Model (DEM) of the Sufichai River Basin, hydrological, climate, and water consumptions.

All the necessary data for this work were provided after quality control. The stations were also selected based on completeness of the data during the study periods. Previous studies also obtained the raw data from the same place for their research works.

Table 1. Input datasets of the water evaluation and planning (WEAP) modeling in the Sufichai River Basin

Data Item	Description	Sources
Meteorological data (1984–2017)	Precipitation, temperature	National Meteorological Agency of Iran
Hydrological data (1984–2017)	Reservoirs, data of Gauging stations	Department of water resources and hydrology of Iran
Water demand data	✓ Water use rate ✓ Population number ✓ Water consumption ✓ Agricultural sector ✓ Urban sector ✓ Land use data	Ministry of water resources and energy of Iran

The climatic data such as precipitation, temperature, wind speed, and humidity were collected from the Iranian National Meteorological Agency (INMA). The stream flow/discharge data was acquired from the department of water resources and hydrology, which was used for calibration and validation of the basin. Water use, population, and other data were collected from various socioeconomic surveys and the statistical agency of Iran, which are essential to analyze the water demand, water coverage, and unmet demand of water in the basin. The irrigation water demand of irrigated sites was also obtained from the basin authority office, as well as literature to compute the water requirement and water scarcity.

2.3. Production of climate scenarios

There are several ways to simulate climate parameters in the future years. At present, the most valid tool for producing the climate scenarios is the 3D Atmosphere-Ocean General Circulation Model (AOGCM) (Wibly and Harris, 2006). Then, among 14 AOGCM models under different scenarios, the IPSLCM4 model was selected under the A1B scenario as the best model by using R^2, MAE and RMSE indices for validation analysis as shown in Table 2.

2.4. Downscaling

One of the most important problems when working with general circulation models is their small spatial resolution. The raw output of these models is not recommended for regional applications. Converting the large-scale data of the general circulation models to the regional, local or station data is defined as downscaling. Nowadays, there are two different classes for downscaling. Dynamic methods including explicit solution of the systems based on their physical-dynamic processes and statistical methods with the aim of developing relationships between large-scale climatic parameters and regional climatic variables and identifying relationships between systems using observational data. In this research, an exponential method was applied using the LARS-WG model. This model as one of the most widely used tool was employed for the randomly generating of climatic data in order to produce maximum and minimum air temperatures and daily precipitation at the Maragheh Synoptic Station during the years 1984-2017 under climate change conditions.

2.5. Integrated Modeling in WEAP

The water planning and evaluation system in WEAP has been developed with the aim of an integrated assessment of demand, supply and water quality, as a practical tool for water resources planning. WEAP has been developed for involving consumption, quality, environmental protection and ecosystems in a tool for water resource planning. The main advantage of this software is the integrated approach to simulate water systems and its orientation in line with the policies. WEAP has the ability to simulate the effects of the implementation of development plans, including water transmission plans on existing water resources. Using the WEAP capability with the MODFLOW groundwater simulation model, the positive and negative impacts of the water development and transmission plans on groundwater and aquifer status were evaluated. We used observed and measured input and release of the ALAVIAN dam operation to evaluate WEAP model in simulation period.

2.6. Entered runoff into the dam in the future

Amini Rakan (2012) presented the following equation for calculating the output monthly runoff from the ALAVIAN dam basin using the Gene Expression Programming Method. In this research, the following equation was used to calculate the amount of entered runoff into the dam in the future.

$$Q_t = (R_{t-5} R_{t-1} R_{t-3}^{1/3})^{1/3} + (R_t R_{t-4})^{1/4} + (((R_{t-1}^{R_{t-5}} R_t)^{1/2})^{1/9})^{1/9} \qquad (1)$$

where, R_t is the precipitation in time step t, and R_{t-1} to R_{t-5}, are the precipitation in time steps of t-1 to t-5.

2.7. Estimation of actual evapotranspiration in the future

Dinpashoh (2006) studied the values of ET_o in Iran based on the drought index by three methods of Hargreaves-Samani, Linaka, and modified Trent-White. The Hargreaves-Samani's method was proposed for the west and northwest of the country, the Trent White method was proposed for the north and northeast, and in the center and south-east of the country, the Linaka's method was proposed. In this study, the Hargreaves-Samani's formula was used to calculate the reference evapotranspiration, as follows:

$$ET_o = 0.0135(KT)Ra(TD)^{0.5}(T + 17.8) \qquad (2)$$

$$KT = 0.00185(TD)^2 - 0.0433(TD) + 0.4023 \qquad (3)$$

$$TD = T_{max} - T_{min} \qquad (4)$$

where, ET_o is the reference evapotranspiration (mm/day), T is the average monthly temperature, T_{min} and T_{max}, respectively, are the minimum and maximum temperatures (°C), and R_a is the extraterrestrial radiation (MJ/day), which is determined based on latitude for each month.

3. Results and Discussions

The analysis of the results of this research was carried out in four steps. In the first step, among 14 GCM models in the LARS-WG model, the IPSLCM4 model under the A1B scenario was chosen as the most suitable model for simulating the climate of the study area according to the values of MOTP. The statistical indices of R^2, RMSE, MAE were employed in the LARS-WG model. In Table 2, GCM models for the temperature and precipitation are presented. According to the above calculations, IPSLCM4 model was selected under scenario A1B for temperature variables and MIRO model for precipitation with the lowest values of MAE and RMSE and the highest value of R^2.

Table. 2. Statistical Indices (MSE, MAE, and R^2) of GCM Models for Temperature and Precipitation.

Parameter	**Index**	**BCM**	**CGCM**	**CNR3**	**HADC**	**FGO**	**GFD**	**GISS**	**HADG**	**INM**	**IPS**	**MIRO**	**NCRC**	**NCAR**	**CSR**
Temp.	**MAE**	5.50	5.66	4.15	3.90	2.56	4.22	4.11	4.77	4.86	**2.25**	2.97	2.63	3.57	5.63
	RMSE	5.98	6.35	4.99	4.49	3.19	4.86	4.68	5.33	5.44	**2.96**	3.61	3.12	4.10	5.93
	R^2	0.97	0.97	0.96	0.95	0.97	0.96	0.96	0.96	0.96	**0.98**	0.97	0.98	0.97	0.94
Precipitation	**MAE**	40.01	20.23	27.76	18.26	20.69	22.84	47.82	41.17	26.3	25.29	**16.13**	37.02	19.28	22.16
	RMSE	60.18	29.43	37.77	26.7	26.85	34.42	61.51	56.85	37.94	33.13	**24.2**	50.8	26.01	29.36
	R^2	0.15	0.41	0.21	0.53	0.47	0.48	0.61	0.49	0.44	0.04	**0.57**	0.48	0.44	0.32

In the next step, the LARS-WG model was calibrated and temperature and precipitation data were generated in the future years 2020-2040. The comparison of changes in the monthly average of the minimum and maximum temperature and precipitation from the baseline condition of the LARS-WG model in the observation years 1984-2017 is presented in the Figures 2 to 4 and Table 3, which indicates that one can use the LARS-WG model to generate precipitation and temperature data in the future years. Moreover, Figures 5 to 7 and Table 4 shows the variation in precipitation, the average monthly maximum temperature for the years 2020-2040 compared to the observation years 1984-2017. It should be noted that the negative values in the above tables indicate a decrease and positive values indicate an increase. With regard to the fact that the output runoff from the dam is formed by precipitation in upstream basin, and considering the direct relationship between evaporation and temperature, the temperature and precipitation during the years 2020-2040 were used as the input for the runoff-precipitation model in the upstream reaches of the ALAVIAN dam in order to predict the inflow hydrograph to the dam reservoir (Amini Rakan, 2012). Figure 8 show the time series and the average monthly inflow and outflow of the ALAVIAN Dam reservoir during the years 2020-2040 used in the WEAP model. This diagram shows the large changes in runoff to the reservoir of ALAVIAN Dam in the forecast period.

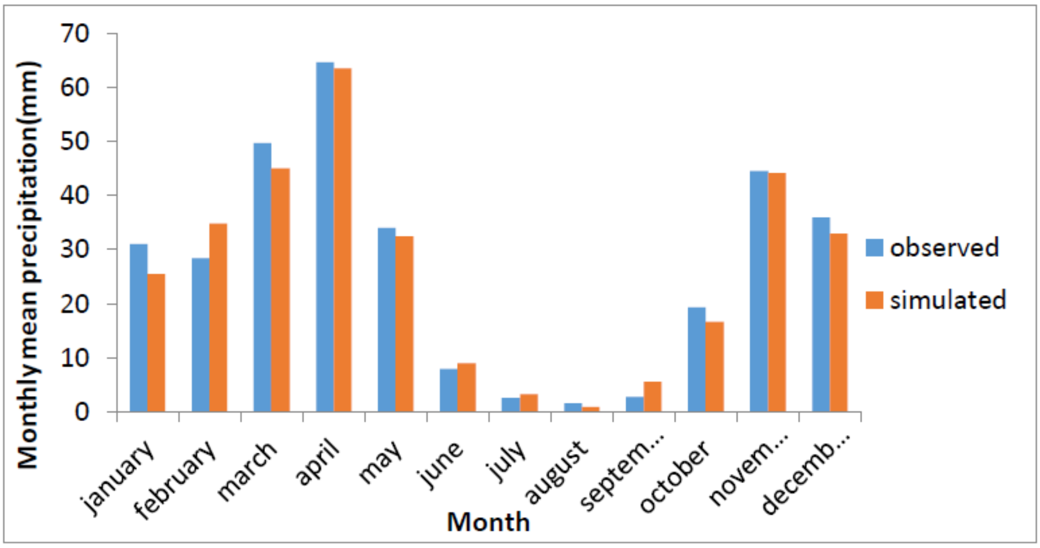
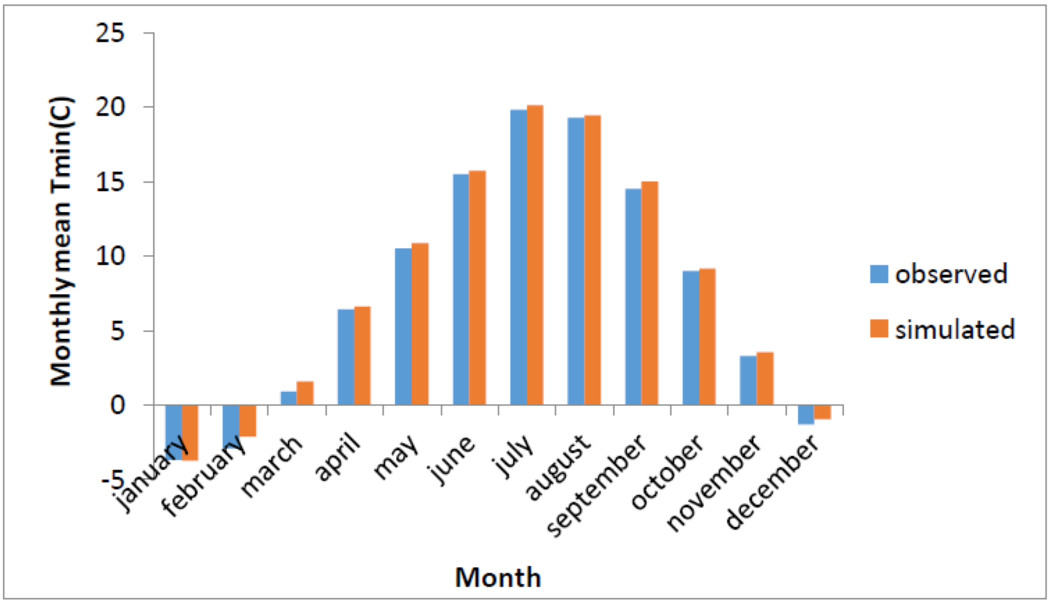


Fig .2. Comparison of monthly precipitation changes from the baseline condition of the LARS-WG model during the observational years 1984-2017 at the Maragheh synoptic station.



3. Comparison of changes in the monthly average of the minimum temperature obtained from the line condition of the LARS-WG model during the observational years 1984-2017 at the Maragheh synoptic station.

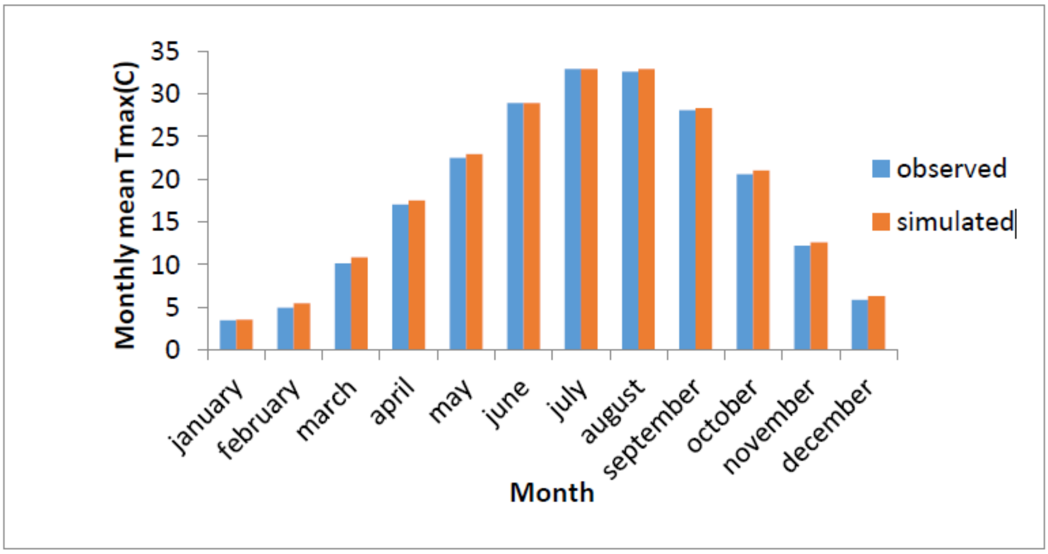


Fig.4. Comparison of changes in the monthly average of maximum temperature obtained from the LARS-WG baseline condition during the observational years 1984-2017 at the Maragheh synoptic station.

Table. 3. LARS-WG validation results for monthly precipitation, minimum and maximum temperature in the observational years 1984 to 2017.

Month	**Minimum Temperature**				**Maximum Temperature**				**Precipitation**			
	K_s	**P-value**	**t**	**P-value**	**K_s**	**P-value**	**t**	**P-value**	**K_s**	**P-value**	**t**	**P-value**
January	0.21	0.63	1.04	0.30	0.16	0.91	0.57	0.58	0.10	1.00	0.62	0.54
February	0.11	1.00	0.15	0.88	0.11	1.00	0.70	0.49	0.04	1.00	1.06	0.30
March	0.11	1.00	0.67	0.50	0.11	1.00	0.78	0.44	0.14	0.98	1.16	0.26
April	0.11	1.00	0.11	0.92	0.05	1.00	-0.61	0.55	0.07	1.00	-0.09	0.93
May	0.11	1.00	-0.46	0.65	0.11	1.00	-0.58	0.56	0.16	0.89	0.69	0.49
June	0.11	1.00	0.37	0.71	0.16	0.91	0.51	0.62	0.17	0.88	-0.70	0.49
July	0.11	1.00	0.46	0.65	0.11	1.00	-0.35	0.73	0.13	0.98	-0.96	0.34
August	0.11	1.00	0.63	0.54	0.16	0.91	0.67	0.51	0.31	0.19	-0.33	0.75
September	0.05	1.00	-0.20	0.85	0.11	1.00	0.38	0.70	0.17	0.84	-1.26	0.21
October	0.05	1.00	0.42	0.68	0.05	1.00	-0.65	0.52	0.07	1.00	-0.66	0.52
November	0.11	1.00	0.12	0.91	0.05	1.00	-1.00	0.32	0.05	1.00	0.25	0.80
December	0.11	1.00	-0.24	0.81	0.11	1.00	0.03	0.97	0.04	1.00	-0.37	0.71

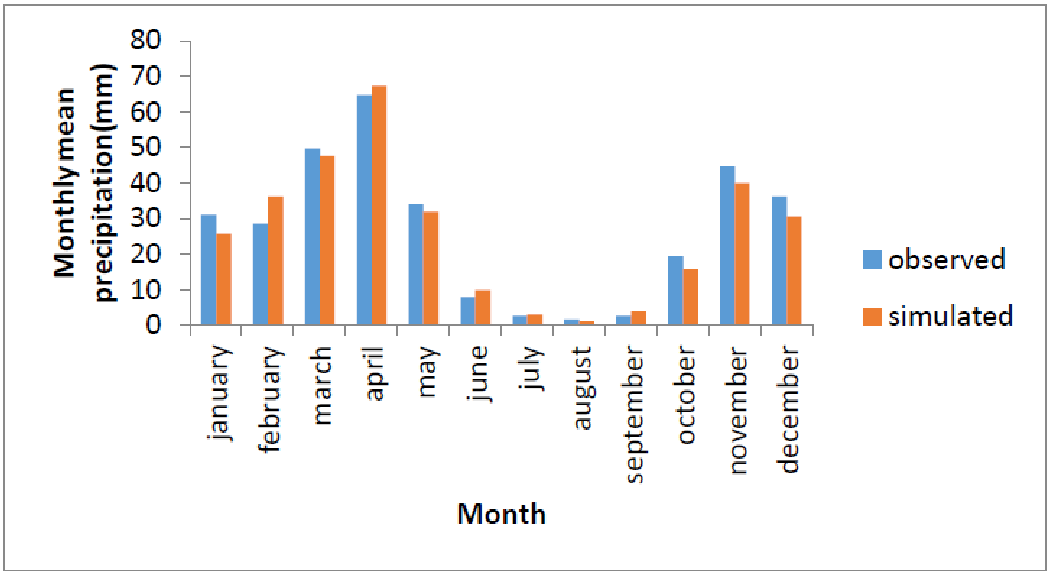


Fig.5. Comparison of monthly precipitation changes from the IPSLCM 4 model under the A1B scenario in the future years 2020-2040 compared to the observational years 1988-2017 at the Maragheh synoptic station.

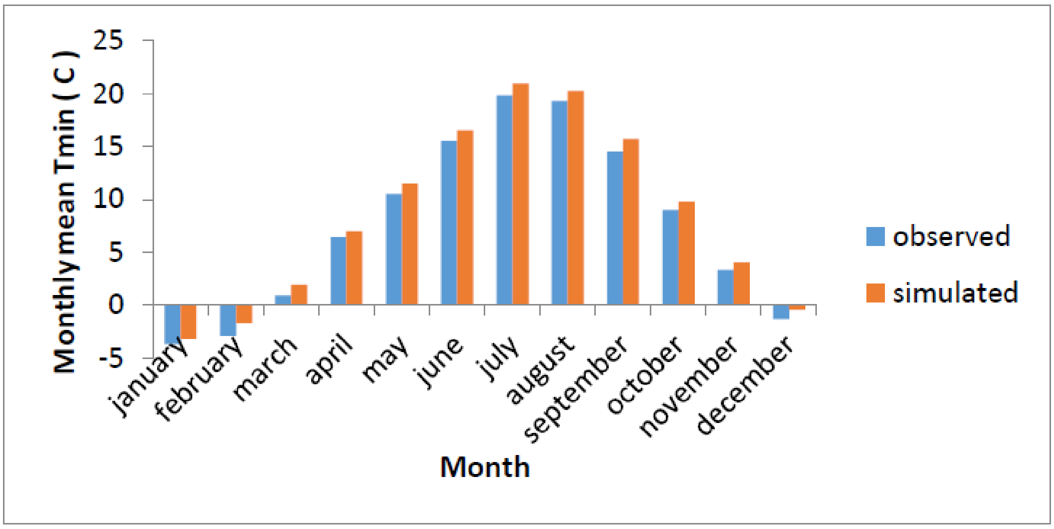


Fig.6. Comparison of the monthly average changes in the minimum temperature obtained from the IPSLCM 4 model under the A1B scenario the future years 2020-2040 compared to the observational years 1988-2017 at the Maragheh synoptic station.

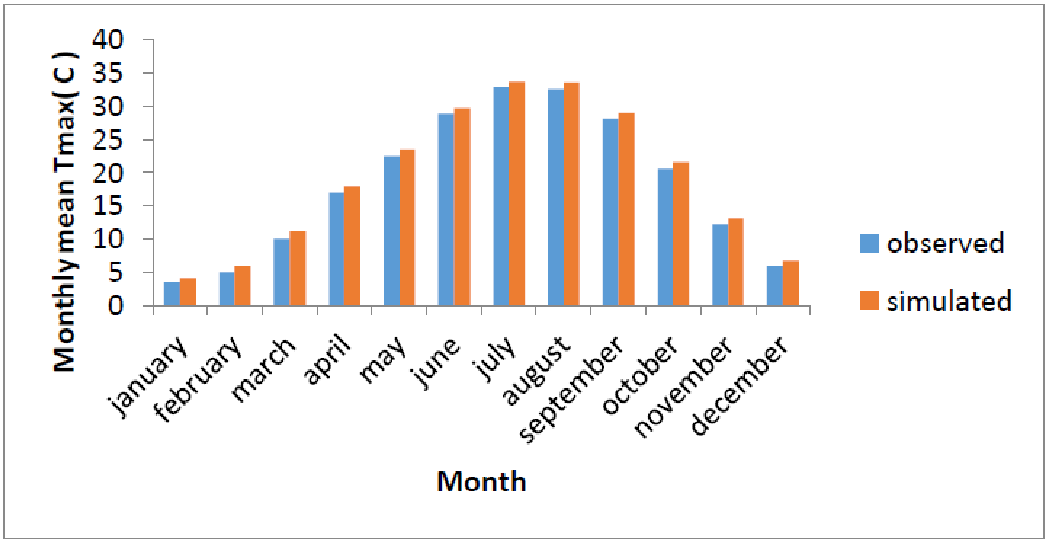


Fig.7. Comparison of the monthly average changes in the maximum temperature obtained from the IPSLCM 4 model under the A1B scenario over the coming 2020-2040 compared to the observational years 1988-2017 at the Maragheh synoptic station.

Table. 4. Precipitation variations, average monthly maximum temperature in the years 2020-2040 compared to the observational years 1984-2017

Month	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Annual**
Precipitation	-5.21	7.62	-2.22	2.63	-2.15	1.83	0.48	-0.47	1.14	-3.6	-4.66	-5.49	-10.11
T_{min}	0.51	1.22	0.98	0.58	0.99	1.00	1.09	0.91	1.19	0.73	0.70	0.79	0.89
T_{max}	0.60	0.96	1.09	0.94	1.04	0.77	0.77	1.03	0.98	0.98	0.90	0.83	0.91

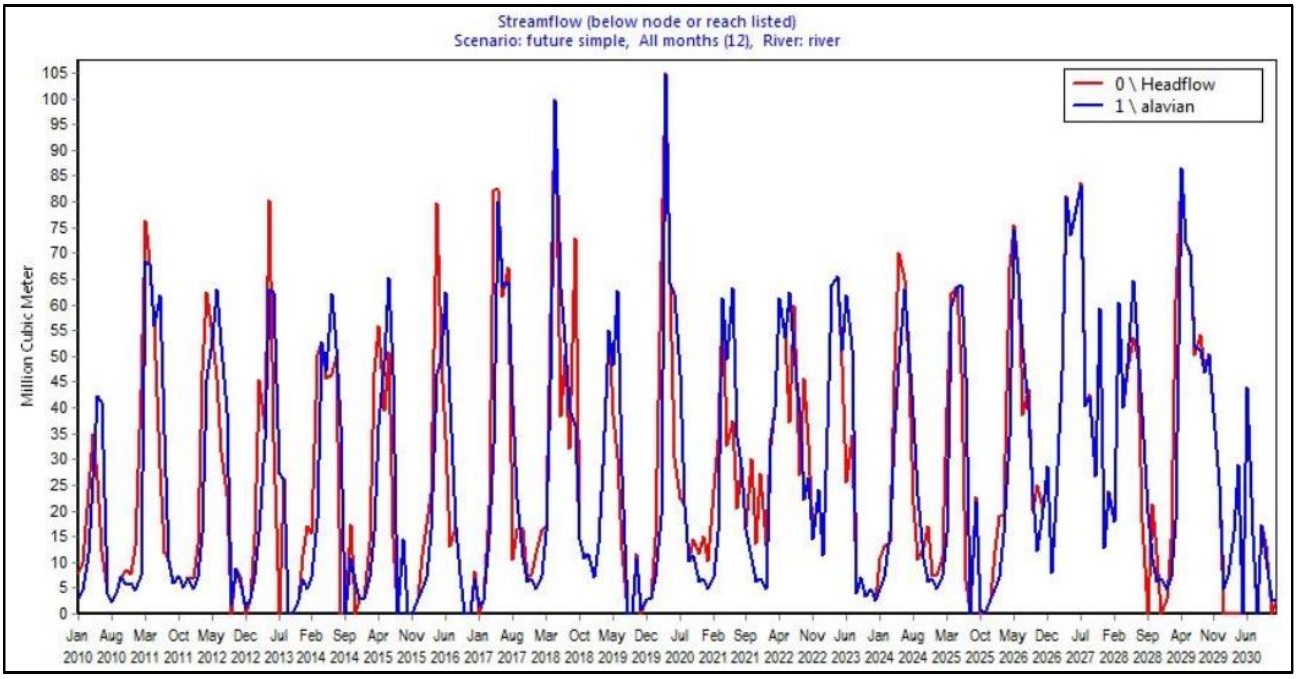


Fig.8. Time series of input and output flows of the Alawian Dam reservoir during the years 2020-2040 used in WEAP model

In the third step, the WEAP model was run after considering the year 2020 as the base year for producing the reference scenario and providing information for future climate change, and the effect of climate change was examined on the supply to demands in various sectors of agriculture, urban, and industry, and amounts of water resources at the future periods. Changes in inflow discharge and water harvesting from the dam reservoir during each time period will result in changing the volume of water in the reservoir during that period. The average monthly water volume of the ALAVIAN Dam reservoir for the years 2020-2040 is shown in Figure 9. Accordingly, the volume of water in the reservoir of the ALAVIAN dam is in the allowable range. The average monthly demand for agricultural sector, average monthly unmet agricultural needs, and average monthly non-supply needs of urban and industry in the years 2020-2040 are shown in the Figures 10 to 12.

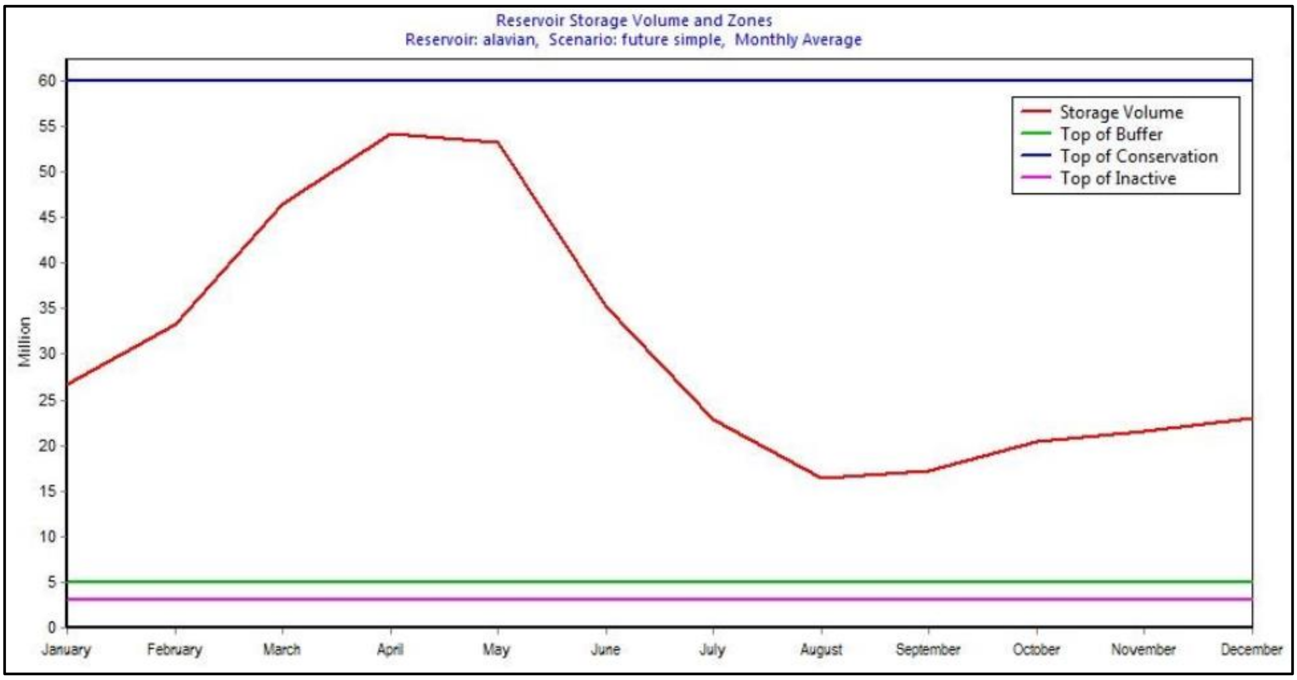


Fig.9. Average monthly volume of water in the reservoir of Alavian dam during the years 2020-2040

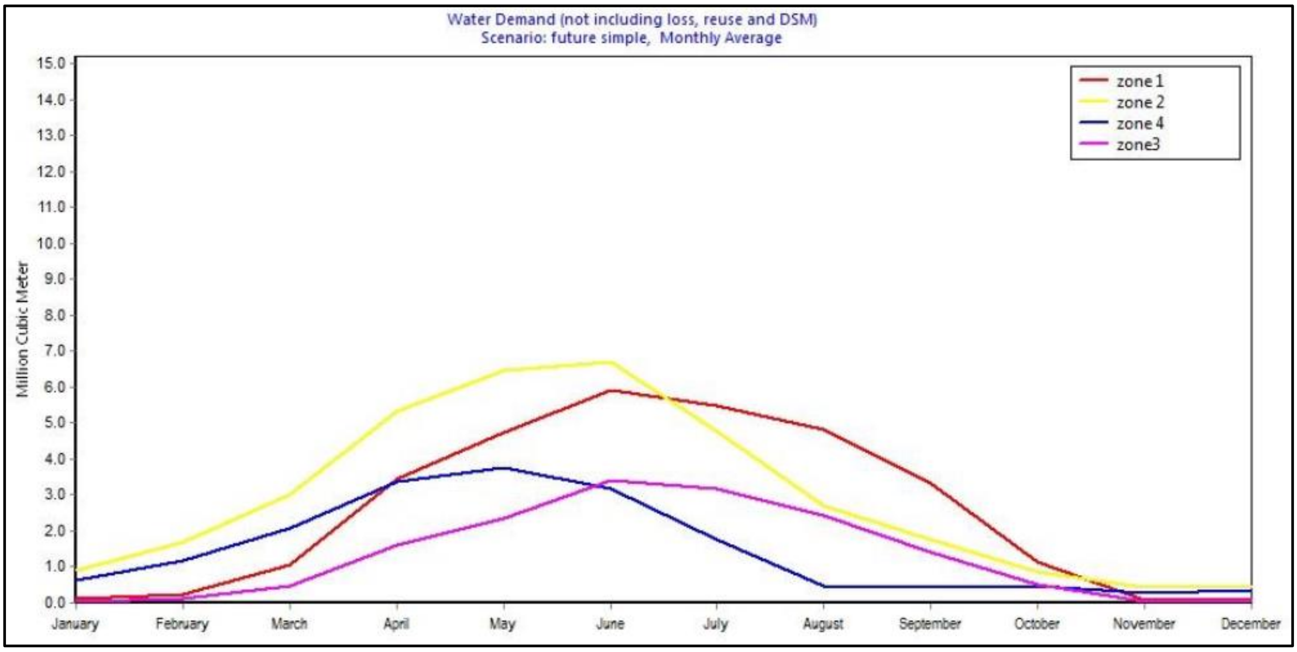


Fig.10. The average monthly demand for agricultural sector during the years 2020-2040

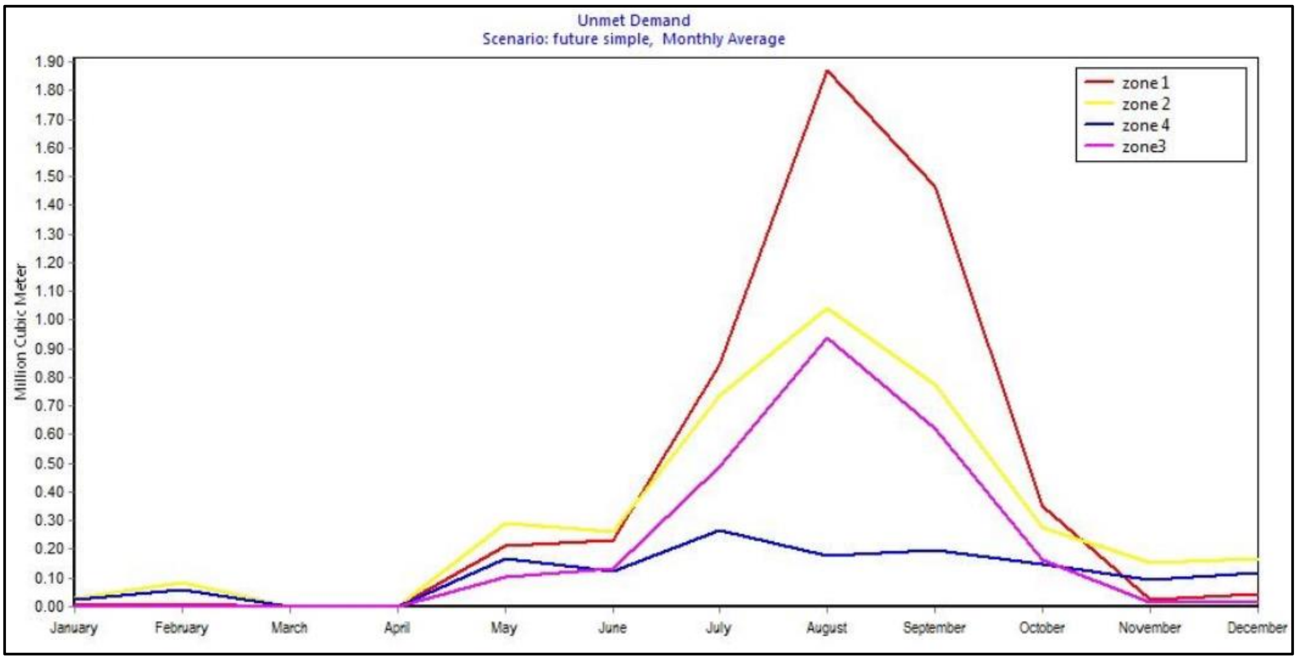


Fig.11. Average monthly unmet agricultural needs during the years 2020-2040

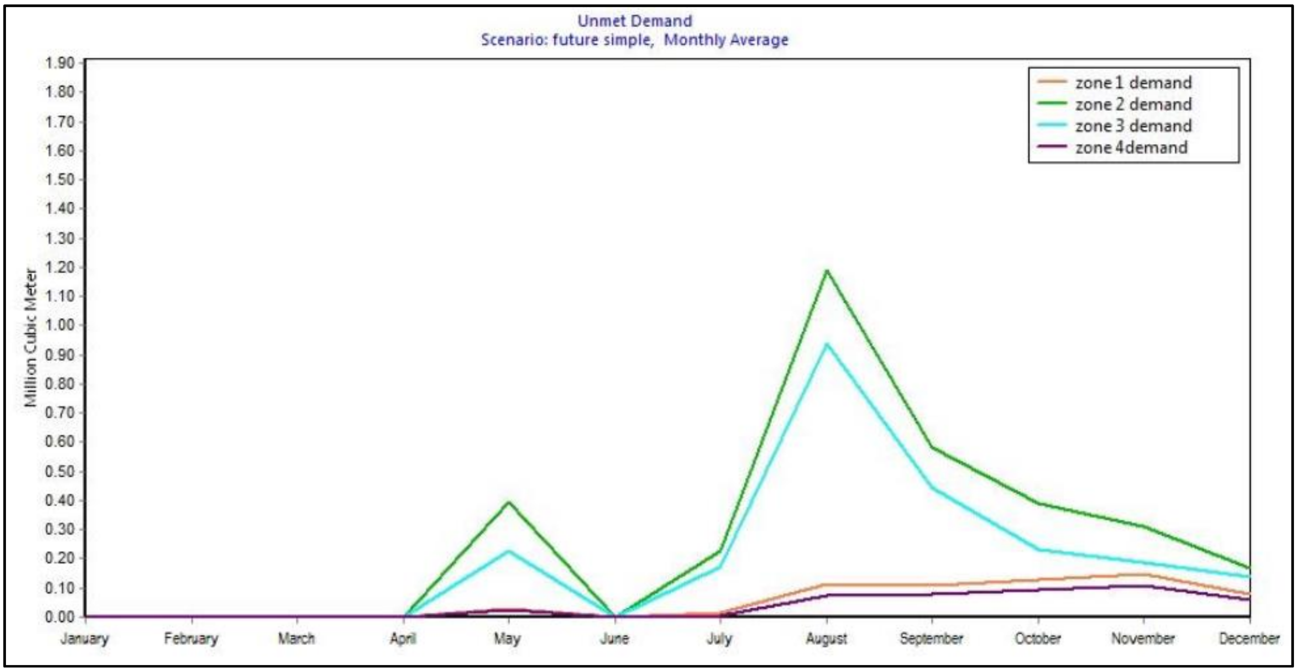


Fig.12. Average monthly non-supply needs of urban and industry during the years 2020-2040

Figure 10 shows the changes in agricultural needs in the four areas of the Maragheh plain, with the highest agricultural needs in zone-2 and the lowest in zone-3. Also, the maximum monthly agricultural needs in the four zones are not matched, which can be considered a positive point in terms of water resources management. Figure 11 shows the changes in the amount of unmet agricultural needs in the four areas in the Maragheh plain, with the highest shortage in Zone 1 in August and the lowest shortage in Zone 4. Also, in all four zones, the biggest shortage is seen in August. Figure 12 shows the changes in the amount of unmet drinking and industry needs in the four areas of the Maragheh plain, with the highest shortages in zones 2 and 3 in August and the lowest shortages in zones 1 and 4. Moreover, in all four zones, the biggest shortage is seen in August.

4. Conclusion

The main aim of this study was to evaluate the integrated effects of climate change on the water resource systems and demands at the downstream of Alavian dam (Zanjan Province, Iran). The IPSLCM 4 climate model under the A1B scenario was used to study the effects of climate change on the water resource systems and demands in the study area. The statistical downscaling showed that the temperature of the region increased in most months of the year, and this increase alters in different months of the year. The maximum and minimum annual temperatures during the years 2020-2040 are accompanied by an increment of about 1 ^{o}C. In other words, the climate of the study area is moving towards increasing temperature. Monthly precipitation changes did not show a general increasing or decreasing trend. The results of this study showed that the negative effects of the climate change may result in the tensions and water scarcity, and an increase in the withdrawal of groundwater resources. In addition, the results showed that water supplies in the study area are allocated to the urban, industrial and agricultural sectors, respectively. The water demand for the urban and industrial sectors will be completely provided in the future periods, and the water resource indices did not change by the climate change. While, the agriculture sector faces water scarcity, resulted from climate change, compared with two other sectors.

5. Conflicts of Interest

No potential conflict of interest was reported by the authors

6. References

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