THE MODELING OF EFFECTS OF CLIMATE CHANGE ON OPEN WATER EVAPORATION

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Abstract

The aim of this article is modeling the effects of climate change on open water evaporation. To this end, SDSM model was used. Data related to base period for the evaporation modeling was from 1983 to 2005 and the maximum and minimum evaporation values were simulated for the next two periods of 2030-2050 and 2080-2100. The results showed that sea-level pressure, wind speed, geopotential height and surface temperature has the greatest effect on evaporation. Also, the results of evaporation modeling showed that the range of evaporation would be decreased for both time periods and under all scenarios. Increasing the concentration of greenhouse gases with its positive and negative feedbacks reduced the intensity of maximum evaporation and consequently increased the minimum amount of daily evaporation. The highest decrease in the maximum evaporation amounts and the highest increase in the minimum evaporation amounts would occur in the cold months of the year and in the warm months of the year, respectively.

Keywords: Climate Change, Wind speed, Surface temperature, Evaporation, SDSM Model

I. Introduction

Climate change is a result of the variability of climate systems and external factors. The 20th century was the hottest century and the 1990s to 2000s were the hottest decades of the last thousand years [XV]. The conducted investigations exhibited that since the beginning of the 20th century the average of earth’s temperature increased about 0.6°C. The fourth IPCC report indicated that the increase in greenhouse gas emissions over the past century led to an increase in the
average temperature of global air about 0.4 to 0.8°C Van Vliet [XXVIII]. Increasing greenhouse gases in the recent decades disturbed the global climate balance, which is called climate change phenomenon. The most significant consequences of climate change were increasing the average temperature of earth, increasing the limit phenomenon of climate, such as heavy floods, destructive storms, heat waves, and sudden and weird frosts, heavy and unexpected snowfall and extensive droughts. Therefore, due to global warming and socio-economic effects on macroplanning and microplanning, it became the subject of the attention of the most scientific community over the last few decades. Moreover, global warming revealed the need of country planners for climate assessment and predicting different economic and social sectors as well as their need for climate predicting and predicting in the coming decades for strategic planning in different sectors including water resources, agriculture, health, environment, the need to study the impacts of climate change in different sectors Abbasnia et al. [XVII] Factors such as increasing the air temperature, decreasing rainfall, severe groundwater drop in many plains, drying up of wetlands, reducing river runoff, etc. caused difficult conditions and it was expected to appear more challenges in the future time with respect to population growth, upgrades The level of health, the concentration of the population in the big cities, and some factors like these. Climate change on different parts of water resources such as evapotranspiration in different regions had different effects on nature and intensity and affected water resources and soil resources thorough different ways Deryng et al. [IV]. The outputs of general circulation models (GCM) of atmosphere under different scenarios of carbon dioxide emissions were used in most of the researches related to the prediction of future climate conditions. Although there are many uncertainties in GCM models, they are currently regarded as the best ways to reach the future climate Chu J et al. [X]. GCM did not allow the use of them at smaller scales. Then, the conditions were appeared, in regional climate models which had been highly considered. Regional climate models simplify the contents and algorithm of a planetary model in order to display features of boundary conditions better Wang et al. [XXXI]. Regional models simulated the effect of micro-scale forces and prepared the desired information of regional scale. Nowadays, the use of the outputs of GCM of atmosphere is inevitable after scaling it to small size by regional models in order to investigate the effects of climate change in different researches around the world. Since Sistan plain is located in an arid region, the evaporation from Class "A" Pan is 5000 mm annually. With regard to low rainfall (about 60 mm) and water resources limitation, there is a high potential for water deficit tensions in the region. So, the SDSM model was used in this study with the purpose of investigating the evaporation fluctuations and variations of evaporation. So, the minimum and maximum evaporation values for the next two time periods are simulated under different scenarios.

In relation to water resources modeling, several studies have been conducted which some of them are: Loukas et al. [II] on the effect of climate change on southern Taiwan water resources, Lenters and Kratz [V] on evaporation from the surface level of Sparkling Lake in northern Wisconsin in the United States, on the evaporation of the Tana basin in northern Finland and Norway, on the water resources of the Tarim river basin in northwest China. The results would indicate an increase in these
climatic parameters in the future climate. Gianniou and Antonopoulus [XXV] used two methods of water balance and energy balance along with one-dimensional model to distribute the daily temperature and ultimately concluded that evaporation rate was low in spring and high in summer, depending on the stored energy in the reservoir. In the study of evaporation range from Dickey Lake in Ontario Canada, Fowler and Wilby [VII] induced that the best method in cold seasons and in the shorter periods (weekly or monthly) were water balance method and Debrine-Kajiman method, respectively. Donohue et al. [XI] evaluated 5 formulas for estimating potential evaporation under climate change condition. In this study, the Penman formula presented the best potential evaporation rate compared to other methods. Consequently, with respect to climate change, it was cleared that the temperature rate and the evaporation rate under climate change conditions were increasing. Solomon [XXVII] found that the average temperature of the rivers of the America, Europe, East China, part of South Africa and Australia were increased during the period of 2100-2071 compared to the base period of 1971-2000. Song and Zhang [XII] simulated the flow of the Beijing river basin with the SWAT model and analyzed the hydrological response of the basin under climate change. The results showed that if the rainfall did not change and the temperature was increased, then the mean of annual evaporation increased and the water productivity decreased. Provided that the temperature does not change and the rainfall increases, the evaporation and water productivity will increase. Helffer et al. [VI] examined the effect of climate change on temperature and evaporation from the surface of the large reservoir of Vionehole in Australia. The results exhibited that the evaporation rate of the reservoir would increase by a maximum of 15%. Benzaghta et al. [XVIII] estimated the results of three models of Penman, Priestley-Taylor, and Linniker for evaluating evaporation from Libya water reservoirs in terms of significance statistic. Having investigating the temperature and evaporation changes at 54 meteorological stations in China, revealed that evaporation rate was increased by 1.8% and temperature was also increased to the amount of 0.27 on average per decade. By examining the effects of different climate change scenarios on the Euphrate basin, Bozkurt and LutfiSen [III] understood that annual surface temperatures were increased with a specific scenario (A1F1) of winter within the basin at their maximum value of 6.1º C in mountainous regions. Tabari et al. [VIII] examined the amount of evapotranspiration of reference plant in various climates of Iran. The results cleared that evapotranspiration variations of the reference plant in arid regions were more than in wet regions. Tanasijevic et al. [XIII, XVI] studied the impact of climate change on changes in evapotranspiration of olive plants in the Mediterranean region. They applied the A1B scenario and the ECHAM5 model to study climate change, and used 56 FAO to evaluate plant evapotranspiration. The results indicated 8% increase in evapotranspiration by the year 2065. Tao et al. [XXIX] investigated the impact of climate change on evapotranspiration of reference plant in the Kiang Jiang river basin in China under RCP scenarios with SDSM model for downscaling. It became clear that evapotranspiration of reference plant will increase under all scenarios in future periods.

One of the studies in Iran was conducted by Jahantigh et al. [XX], modeling the impacts of climate change on water resources in Sistan from the outputs of the
IPSIL-CM4 model by the year 2050. The results of the comparison of Helmand River in three scenarios with reconstructed historic values indicated a 5% to 22% decrease from Afghanistan. Goodarzi and Soltani [XIX] studied the impacts of climate change phenomenon on the temperature and catchment basin precipitation of Iskandari in Isfahan province. Findings illustrated 7.2% increase in annual precipitation and 1°C increase in mean annual temperature. Dinpajou et al. [XXX] examined the long-term effects of climate change on temperature and precipitation in Zabol city with the use of the LARS-WG model. It was clear that the LARS-WG model had high ability in estimating the meteorological parameters. Abedi, E. Mazaheri [IX] applied the LARS-WG model with the aim of evaluating the effects of climate change on temperature and evaporation from free reservoirs in Isfahan. Obviously, the annual temperature and solar radiation were increased. examined the effect of climate change on potential evapotranspiration of Shahroud city using LARS-WG model. The findings exhibited that the ETO average would increase about 4.5% in the first period under both emission scenarios and it would increase about 15% and 8% in the second period for the A2 and B1 scenarios, respectively. It was also clear that the amount of ETO in warm months had been determined to increase more in comparison to cold months of year. Ahmadabadi made use of SDSM and SWAT models in order to study the effect of climate change on Can catchment basin cycle [I]. The findings of this study revealed that in future climate conditions for the period 2016-2045 would decrease rainfall, increase temperature and reduce real evapotranspiration, confirming the efficiency of both SDSM models in climate prediction and SWAT model in hydrological simulations. Based on RCP emission scenarios, Heidari and Khoshkhoo [XXVI] examined the effects of climate change on reference evapotranspiration on selected stations in western Iran in the future three time periods 2011-2040, 2041-2070 and 2071-2100 compared to the base period of 1970-1999. The results showed that the highest increase rate of evapotranspiration of future periods would take place with comparison to base period on all seasonal and annual scales and in the whole region under the RCP8.5 scenario in the period 2071-2100. Comparison of reference evapotranspiration rates between various seasonal and annual scales also indicated that the rate of reference evapotranspiration was increased in western Iran in autumn and winter seasons were much more dramatic than other temporal scales.

II. Method

Study Area

Sistan is an arid plain in the north of Sistan and Baluchestan province of Iran which has a common border with South Khorasan Province and Afghanistan. Chahnimeh reservoirs located in vicinity of this city are large water storage reservoirs which have a significant role in supplying domestic and agricultural water in the region. These four natural impoundments are 50 km far from Zabol city and 5 km from Zahak City. The excess water from the Hirmand River is conveyed to them by a channel. The location of the reservoirs are showed in (Figure 1).
is called downscaling Fowler and Wilby [VII] and Dankers and Christensen [XXII].

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Donohue et al. [XIV]. Therefore, downscaling techniques make an increase in the

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value of data obtained from paired oceanic-atmosphere models. Indeed, for evaluating the effects of the climatic changes and addressing the lack of low spatial resolution, the outputs of GCMs of atmosphere and converting those to local scales in different studies, it is needed to do correction on the output averages of atmospheric parameters to have the minimum possible error with observational data. This method is called downscaling Fowler and Wilby [VII] and Dankers and Christensen [XXII].

Fig. 1: The location of Chahnimeh reservoirs on map of Iran

Data

The data applied for this study was daily evaporation data from Half Well’s
dam station and CanESM2 network data from CMPI5 center. The statistical period of
the evaporation data is from 1983 to 2005. Statistical deficits were resorted with the
use of climatic data of adjacent stations and linear regression model. At the end, evaporation modeling was carried out for two periods of 2030-2050 and 2080-2100
under three RCP scenarios. The variations of evaporation range in different scenarios in future climate were analyzed, investigating the statistical parameters of minimum and maximum evaporation.

Climatic and Downscaling Models

Today, most researches related to future climate prediction use GCM of
atmosphere under different scenarios of carbon dioxide emissions. Although there are
many uncertainties in GCM models, they are currently regarded as the best way to
reach the future climate Fowler and Wilby [VII]. Global climate models (GCMs) were incomplete for describing and simulating the regional and local procedures. So they applied regional models (RCMs) to improve climate change prediction Chu J et al. [X]. There are several methods to produce regional climatic scenarios (RCMs) from climatic scenarios of AOGCMs models, which are considered as downscaling Wilby and Harris [XXIII]. Downscaling is a method for assessing the climatic data or high-resolution climate change from planetary models with low resolving power (Figure 2). On the one hand, many atmospheric phenomena require information at a
resolution of 50 kilometers or less, and on the other hand there is some
incompatibility between the existing climatic data scale and the scale used by
Donohue et al. [XIV]. Therefore, downscaling techniques make an increase in the
value of data obtained from paired oceanic-atmosphere models. Indeed, for evaluating the effects of the climatic changes and addressing the lack of low spatial resolution, the outputs of GCMs of atmosphere and converting those to local scales in different studies, it is needed to do correction on the output averages of atmospheric parameters to have the minimum possible error with observational data. This method is called downscaling Fowler and Wilby [VII] and Dankers and Christensen [XXII].
Downscaling can be grouped into four categories with respect to climate change approaches: dynamic (envelopment), statistical, the use of base cell or proportional method and determination of synoptic condition Semenov [XXI]. In general, in most studies related to climate change and investigating its effects, two methods of dynamic or statistics or combinations of them are used for downscaling the climatic data and several models are developed based on them. The SDSM model was used in this study to simulate the range of evaporation changes. SDSM model was presented on 2002 entitled SDSM2.1. Since then, this model has been reviewed for several times. This model was first introduced by Wilby and Harris [XXIII] in UK. This model provided more insight into the application of large scale atmospheric variables in the investigating and evaluating the local climate fluctuations. The SDSM model uses statistical regression methods for downscaling operations. In this model, the relationships of predictors (outputs of GCM) and under prediction (historical data of weather station) were analyzed and the experimental relations between them were determined and declared to the user. The main objective of this part was contributing to the user in selecting the effective predictor variables to downscale the outputs of the GCM. This is the most challenging step in the promotion of any statistical downscaling model due to the profound effect of predictor variable selection on the characteristics of downscaled climate scenarios. In this stage, one of the necessary factors for proper correction of predictor variables is the user’s experience. Among the factors which present its models to the user are correlation, variance, standard deviation, and standard error. The user should select predictor variables for the model with respect to his experience and the comparison provided by the model. Then, the selected variables were calibrated by the user. After verification of calibrated model and the production of historical data, they would compare to observed data and the model would produce the climate data for future in case of calibration Wilby and Dawson [XXIV].

![Fig. 2: Description of general scheme for downscaling method](image)

Emission scenario is one of the most noticeable scenarios in climatic studies. The latest family of emission scenarios published based on the fifth assessment report
of the intergovernmental panel on climate change. Non-adoption of greenhouse gas mitigation policies and confronting with its climate consequences will lead the global climate into the trajectory of RCP8.5 emission scenario. In the RCP 8.5 scenario, the amount of CO2 concentration will be reached to 1370 ppm by the year 2100, estimating the effects of greenhouse gases on radiation emissions to 8.5 W/m². In RCP 4.5 scenario, the amount of CO2 concentration will increase to 650 ppm by the year 2100, estimating the effects of greenhouse gases on radiation emissions to 4.5 W/m². In the RCP2.6 scenario, the amount of CO2 concentration is estimated to be 490 ppm by the year 2100 and the effect of greenhouse gases on radiation emissions will be to 2.6 W/m².

III. Results and Discussions

Strengthening of the Tested Beams
The relationship of 26 CanESM2 data with evaporation from the half well station was investigated with the purpose of investigating the effect of climate change on the range of evaporation variations. Seven selected variables were identified with respect to correlation values of these variables with evaporation data. The relationship of these variables with evaporation is exhibited in (Figure 3).

Table 1. The most important variables affecting evaporation from Chahnimeh reservoirs of Sistan plain

| Correlation | Variable | Correlation | Variable |
|-------------|----------|-------------|----------|
| -0.594      | MV850hPa | -0.734      | SLP      |
| -0.604      | HGT850hPa| -0.637      | SMV      |
| 0.797       | MT       | 0.710       | HGT500hPa|
| -0.459      | ZV500hPa | \text{Surface meridional velocity 850 hPa} |
|             |          | \text{Mean Temperature at 2m} |
|             |          | \text{Height Geopotential 500 hpa} |
|             |          | \text{Height Geopotential 850 hpa} |
The Results of Maximum and Minimum Evaporation Modeling under RCP 2.6 Scenario for Time Periods 2080-2100 and 2030-2050

Simulation of maximum evaporation for both time periods under RCP 2.6 scenario cleared that the maximum evaporation would be reduced relative to the base period in all months of the year except June and July. The maximum reduction of the maximum evaporation will occur in the cold months of the year. The minimum amount of evaporation under this scenario for both time periods relative to the base period showed that the highest increase would occur in the warm months of the year. Comparison of simulated values of future maximum and minimum evaporation revealed that the range of evaporation variations would decrease relative to the base period and the maximum reduction of the range of evaporation variations would occur in cold months of year (Figure 4).

Fig. 3: The relationship of different variables with evaporation from Chahnimeh reservoirs in Sistan plain (1983-2005)

Fig. 4: Variation of Evaporation from Chahnimeh reservoirs in Sistan Plain under RCP 2.6 Scenario for the Periods of 2030-2050 and 2050-2100
The Results of Maximum and Minimum Evaporation Modeling Under RCP 4.5 Scenario for Time Periods 2080-2100 and 2030-2050

The maximum values of evaporation under RCP 4.5 scenario would increase relative to the base period only in July and the evaporation showed lower values relative to the base period in colder months of the year. Moreover, the maximum amount of evaporation in the time period of 2080-2100 would be lower than the previous periods. The minimum amount of evaporation related to this scenario exhibited an increase in minimum values of evaporation compared to the base period. Increasing the minimum evaporation under this scenario would be more occurred during the warm period of the year. The range of evaporation changes in this scenario would also be decreased compared to the base period, which the decrease in the change ranges between 2080-2100 in the cold period of the year would be greater than the warm period of the year (Figure 5).

Fig. 5: Variation of evaporation from Chahnimeh reservoirs in Sistan plain under RCP 4.5 Scenario for the periods of 2030-2050 and 2050-2100

The Results of Modeling Maximum and Minimum Evaporation Under RCP 8.5 Scenario for Time Periods 2080-2100 and 2030-2050

The maximum values of evaporation under RCP 8.5 scenario would be increased compared to the base period only in July. In this scenario, the minimum amount of evaporation to the cold months of year would be greater than the warm months of the year compared to the base period. Similar to the previous scenarios, the minimum values of evaporation in RCP 8.5 would also increase and this increment in the warm months was greater than the cold months of the year. Reducing the amount of maximum evaporation and increasing the amount of minimum evaporation in two next periods compared to the base period will result in reduction of the range of evaporation changes (Figure 6).
Comparison of the Results of Maximum Evaporation Modeling Under RCP Scenarios for the Periods of 2030-2050 and 2080-2100

By studying the results of maximum evaporation modeling in two future time periods, it became clear that the values of maximum evaporation in the period of 2030-2050 would be higher than the period of 2080-2000. Indeed, the moisture saturation of the atmosphere and cloudiness increment in the period 2080-2100 would decrease the amount of maximum evaporation during this period (Figure 7). In addition, the values of minimum evaporation relative to base period would be increased under all scenarios and for both time periods due to an increase of mean atmospheric temperature and changes in climate variables. This increment in RCP 2.6 scenario would be more considerable than the other scenarios (Figure 8).

Fig. 6: Variation of evaporation from Chahnimeh reservoirs in Sistan plain under RCP 8.5 Scenario for the periods of 2030-2050 and 2050-2100

Fig. 7: Comparison of the results of maximum evaporation modeling under RCP Scenarios for the periods of 2030-2050 and 2080-2100
IV. Conclusion

This study was aimed at investigating the variations of evaporation in the Chahnimeh reservoirs in Sistan plain for two future periods and applying three RCP scenarios to examine the effects of climate change on evaporation. The findings of this study indicated that sea level pressure, wind speed, geopotential height and air temperature had the most effect on daily evaporation values. The results of evaporation modeling revealed that the variations of evaporation would be decreased for two time periods under all scenarios. It was concluded that increasing greenhouse gas concentrations with their positive and negative feedbacks, like increasing the moisture content of atmosphere, cloudiness incretion, etc., reduced the intensity of maximum evaporation and increased the value of daily minimum evaporation instead. The highest decrease in the maximum evaporation amounts and the highest increase in the minimum evaporation amounts would occur in the cold months of the year and in the warm months of the year, respectively. Evaporation modeling for selected time periods showed that the amount of maximum evaporation in the period of 2030-2050 was more than that of the period of 2080-2100. Indeed, the saturation of atmosphere and cloudiness incretion in the period 2080-2100 would decrease the amount of maximum evaporation during this period. In addition, the values of minimum evaporation relative to base period would be increased under all scenarios and for both time periods due to an increase of mean air temperature and changes in climatic variables. This incretion resulted from RCP 2.6 scenario would be more considerable than the other scenarios.
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