Climate change impact assessment on rainfall-runoff process: a case study of Pishin Reservoir Basin in Iran

R. MOHAMMADNEJAD, B. ZAHRAIE, M. NASSERI & A. TOOTCHI
School of Civil Engineering, University of Tehran, Tehran, Iran
bzahraie@ut.ac.ir

Abstract Impacts of climate change could have far-reaching and unpredictable consequences on water resources in many watersheds. In the past decade, many researchers have focused on assessing the impacts of climate change on the hydrologic cycle processes. In this study, impacts of the climate change on the Rainfall-Runoff Process (RRP) in Pishin Basin in Sistan-Baluchestan Province in southeast of Iran is investigated. AFFDEF which is a distributed rainfall-runoff model has been calibrated using Genetic Algorithm (GA) and tested using daily records of Pishin reservoir inflows and rain gauges in the basin. The calibrated model has been then utilized to simulate RRP under assessed conditions of climate change till the year 2050 using A2 and A1B scenarios from the SRES family of scenarios generated by the Intergovernmental Panel on Climate Change (IPCC). The results have shown that the calibrated model has been able to properly regenerate reservoir inflows and can be utilized as a useful tool for runoff prediction under different climate change scenarios.
Keywords climate change; SRES; rainfall-runoff modelling; AFFDEF

INTRODUCTION

Climate change is known as variations in statistical characteristics of weather indexes over periods of time ranging from decades to hundreds of years. It may be represented by the variations of the average weather parameters or the alterations in the distribution of meteorological events around their average. The most important evaluation test of climate change is based on dissimilarity in the statistical properties of the climate system when considered over different periods of decades or longer, regardless of its causes (Houghton 2001). It must be mentioned that fluctuations on periods shorter or around a few decades, such as El Niño, do not represent climate change by itself. IPCC, founded by UNEP, have provided some probable scenarios for global warming and CO_2 generation rates (IPCC 2007). New generations of the General Circulation Models (GCM) have been also developed by various countries based on these assumptions for the current century.

In this paper, effects of two probable SRES scenarios, namely A2 and A1B, on RRP in an arid area in southeast of Iran are investigated. For this purpose, AFFDEF distributed rainfall-runoff model is calibrated for the study area and is used to predict the runoff variations till the year 2050 due to climate change. The Group Method of Data Handling (GMDH) has been used as a statistical downscaling tool.

AFFDEF DISTRIBUTED RAINFALL-RUNOFF MODEL

AFFDEF has been developed by Moretti and Montanari (2007). It is a distributed conceptual continuous simulator of rainfall-runoff processes. It is recommended by the developers of the model to be used for short time steps up to daily simulations. The model input data includes Digital Elevation Model (DEM), observed records of rainfall and temperature, map of Curve Number variations over the watershed and classes of the Strickler roughness for the hill slope.

The model extracts the river network automatically from DEM by applying the D-8 method presented by Traboton (1997). This method allows estimating the flow paths and the contributing area to each cell. After delineation of the river network tree, the network determination is carried out by assigning to each DEM cell a maximum slope pointer and then processing each cell in order to organize the river network according to the Strahler's stream ordering system (*Strahler*, 1984). AFFDEF model uses different techniques including Inverse Distance Weighted (IDW) and Thiessen Polygon (TP) methods to convert point observations of rainfall to areal average values over basins.

The time step of the simulation can be either equal to the time interval of the observed rainfall or an integer sub-multiple according to the choice of the user. The simulation can be carried out for a single event as well as in continuous mode.

Fig. 1 shows the interaction between the soil, vegetation and atmosphere processes as modeled by AFFDEF. As it is shown, for each cell of coordinates (i, j), the model considers a local reservoir (interception reservoir), in which a first rate of the local rainfall $P_l[t,(i,j)]$ accumulates. In this Fig., the following variables are introduced (*Doorenbos et al.*, 1984):

C_{int}: a parameter, constant in space and time
$S(i,j)$: the local storativity which is computed using CN method
$P_n[t,(i,j)]$: intensity of surface runoff
$I[t,(i,j)]$: the intensity of the infiltrated water which is equal to $(P[t,(i,j)]-P_n[t,(i,j)])$
H :calibration parameter
$F[t,(i,j)]$: the water content at time t of the infiltration reservoir
$W[t,(i,j)]$: outflow from the infiltration reservoir
H, H_S: constant parameters with respect to both space and time
$E[t,(i,j)]$: effective evapotranspiration
$E_P[t,(i,j)]$: potential evapotranspiration

Surface and sub-surface flow is routed toward the basin outlet by applying the Muskingum-Cunge model with variable parameters (Cunge, 1969). The AFFDEF has the following parameters which have to be calibrated:

- A_0: Constant critical source area [km^2]
- W_v: Channel width/height ratio for the hill slope
- Ksv: Strickler roughness for hill slope [$m^{1/3}s^{-1}$]
- W_r: Channel width/height ratio
- Ksr_0, Ksr_1: max and min Strickler [$m^{1/3}s^{-1}$] for river network
- Ksat: saturated hydraulic conductivity [m/s]
- B_p: width of the rectangular cross section of the sub-surface flow [m]
- H_s: parameter for the infiltration reservoir [s]
- H: parameter for the infiltration reservoir
- C_{int}: parameter for the interception reservoir

The model uses Genetic Algorithm (GA) for calibration however for large watersheds, using GA may take a very long time and can be computationally expensive.

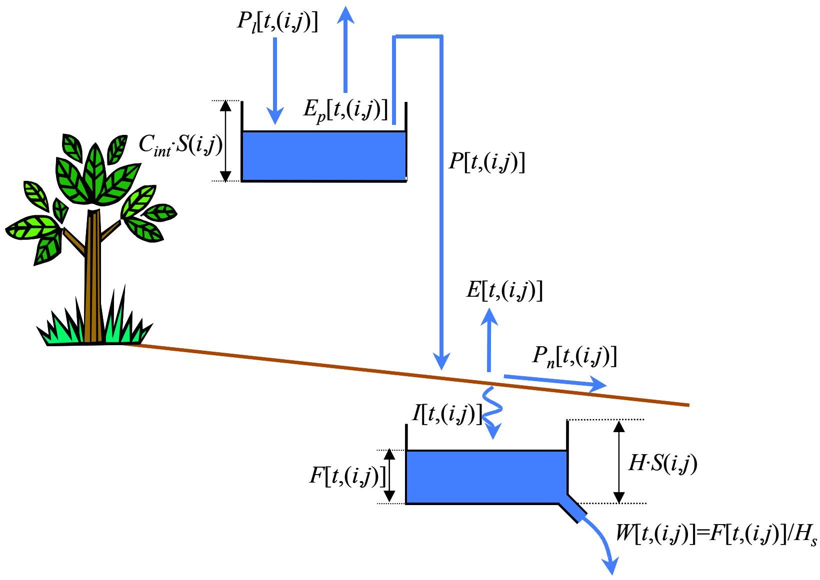

Fig.1. Interaction between soil, vegetation and atmosphere in AFFDEF model (Moretti and Montanari 2007).

CASE STUDY: PISHIN DAM BASIN

The case study is the upstream basin of Pishin Dam in Sistan & Balouchestan Province in Southeast Iran which is a very arid region affected by Monsoon systems. This basin with an area of 7214 km^2 is located in 60°54′-61°58′ eastern longitudes and 26°-27°2′ northern latitudes. The annual average rainfall over this basin is about 178 mm. The study area receives almost all of its annual rain in the months of December through March and in the Monsoon season during July and August. Almost no rain occurs in the rest of the months in the rain gauges across the province.

Pishin Dam with 63 m height and 1300 hectares lake area has been built on the Sarbaz River. This reservoir plays a significant role in supplying water demands and flood control in this basin. Ten years of historical daily records of two rain gauges namely, Pishin and Sarbaz has been used for AFFDEF model calibration and validation. In this study, the daily records of the years 2001-2006 have been used for model calibration and the data in the years 1997-2000 have been used for the model validation.

DOWNSCALING

GMDH is among data mining techniques which has various applications in regression and time series prediction (Nariman-Zadeh et al. 2005, Kim et al. 2009). In this paper, GMDH has been used as a statistical downscaling tool for prediction of precipitation variations due to climate change in the months of December and January through March. For this purpose, nine meteorological predictors including Geopotential Height (GH), Air Temperature (AT) at three levels of 200, 500 and 850 mbar, and also Sea Level Pressure (SLP), Surface Air Temperature (SAT), and Precipitable Water (PW) over 13° 94′ 37″ to 34° 22′ 54″ (latitude) and 56° 25′ to 78° 75′ (longitude) with grid resolution of 2.5°×3.75° (latitude × longitude) have been considered as the GMDH model input variables. The time series of daily aforementioned meterological variables has been obtained from IPCC-AR4 databank for IPSL-CM4 model. In table (1), model results and selected predictors for the stations of interest, Pishin and Sarbaz, are presented. The Mutual Information (MI) index has been used to select the best predictor. The reason for choosing IPSL-CM4 model is that it has shown a relatively better performance in the study area than the other IPCC recommended GCM models (see Cai et al. 2009 for more details).

Table1. Results of Precipitation Downscaling .

Station Name	Correlation Coefficient		Selected meteorological predictors (Latitude, Longitude)
	Calibration	Validation	
Pishin	63	53	**AT850(16.5,75), ATS(34.2,67.5), GH200(31.7,56.3), AT850(21.5,60), AT850(16.5,78.8), GH200(29.2,60), SLP(13.9,56.3)**
Sarbaz	71	70	**GH200(31.7,63.8), AT850(19,63.8), AT850(13.9,63.8), AT200(16.5,67.5), AT500(34.2,63.8), GH200(31.7,60), SLP(24.1,63.8), AT850(13.9,60)**

GHX00: Geopotential Height at X00 level,
TAX00: Air Temperature at X00 level

RAINFALL-RUNOFF MODLEING RESULTS

A tool called River Extractor has been developed in ArcGIS 9.3 in this study that operates as a wrapper. This tool takes SRTM 90 m DEM as an input and produces the necessary input files for running the first module (MOD1) of AFFDEF model. Fig. (2) River Extractor menu. Fig. (3) presents GIS format of the river network (output of MOD1) and CN spatial variations in the basin developed using Strahler's stream ordering system (*Strahler*, 1984).

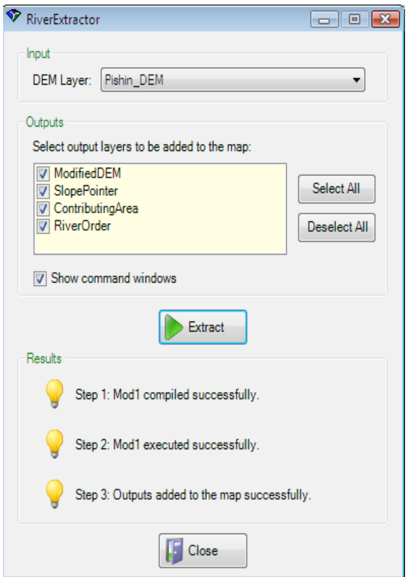

Fig. 2. River Extractor menu.

A semi-automatic procedure by combination of GA optimization method and manual tuning have been used for model calibration. The optimum values of the model parameters for Pishin basin are listed in Table 2. Fig. (4) and (5) show two sample rainfall-runoff events and the model computed values in the training and validating processes.

The daily downscaled precipitation in the two rain gauges in the months of December through March has been used to predict the Pishin reservoir inflow variations due to climate change. Fig. 6 shows the average reservoir inflow in this season, predicted for the year 2001 to 2050.

As can be seen in Table 3, however A2 scenario shows higher average discharges compared with A1B scenario, but both show a significant decrease compared to the historical observations. It also shows the maximum values of the predicted discharges are much lower than the observed values. Low standard deviations of the predicted discharges (when compared with historical records) show high uncertainty in these predictions for drought and flood management planning.

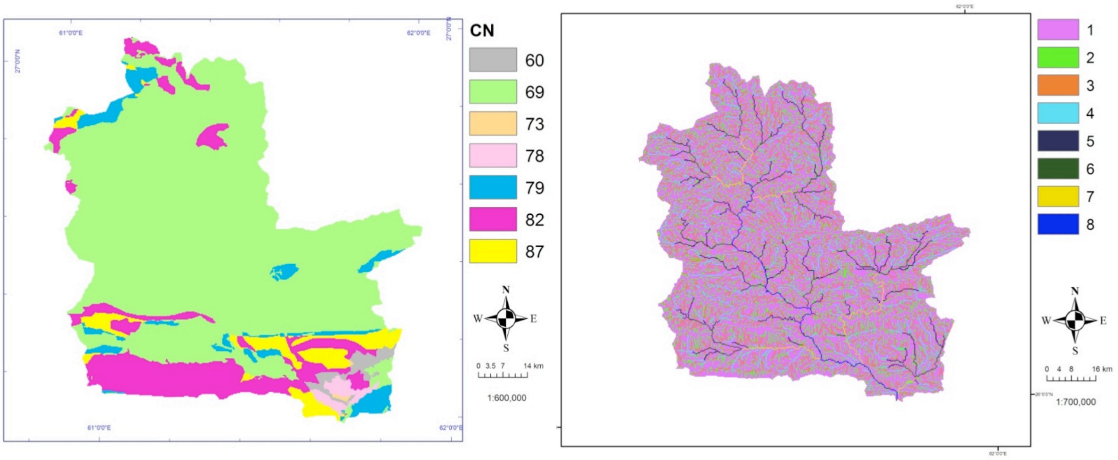

Fig. 3. River order and CN map in Pishin Basin computed by AFFDEF.

Table2. Calibrated AFFDEF parameters for Pishin Basin in Iran.

Parameter	Description	Value
A_0	Constant critical source area [km^2]	0.35
W_v	Channel width/height ratio for the hillslope	37950
K_{sv}	Strickler roughness for hillslope [$m^{1/3}s^{-1}$]	600
W_r	Channel width/height ratio	20
Ksr_0,Ksr_1	max and min Strickler [$m^{1/3}s^{-1}$] for river network	6,10
K_{sat}	saturated hydraulic conductivity [m/s]	0.00009
B_p	width of the rectangular cross section of the sub-surface flow [m]	0.5
H_s	parameter for the infiltration reservoir [s]	130000
H	parameter for the infiltration reservoir	0.75
C_{int}	parameter for the interception reservoir	0.0037

CONCLUSIONS

Results of this study have shown that AFFDEF model can be used for as a useful tool for investigating the effects of climate change on rainfall-runoff processes. The GA calibration tool is not as efficient as it can be and takes a very long time specially when the spatial resolution used in the model is high. IPSL-CM4 simulated meteorological variables does not show a high compatibility with the observations however it has been suggested as a suitable GCM model for the study area. GMDH has shown a relatively good performance as a statistical downscaling model and it can be considered for further developments in downscaling applications.

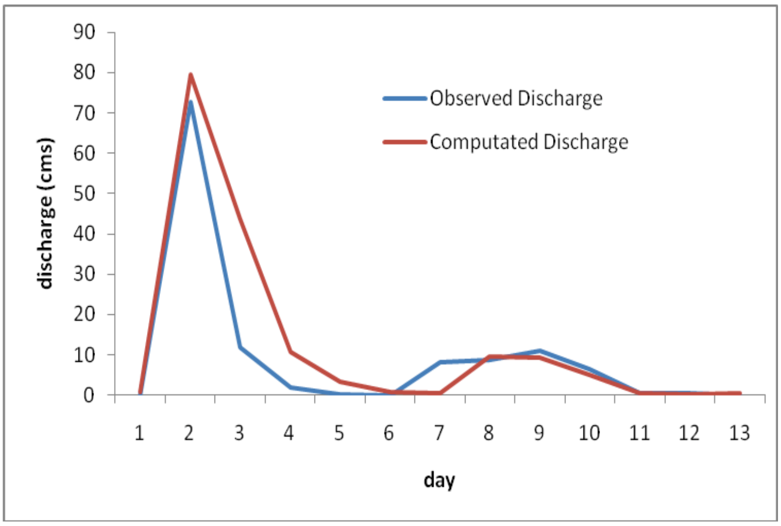

Fig. 4. Sample of simulated rainfall-runoff in calibration dataset (Feb. 6-18, 2005).

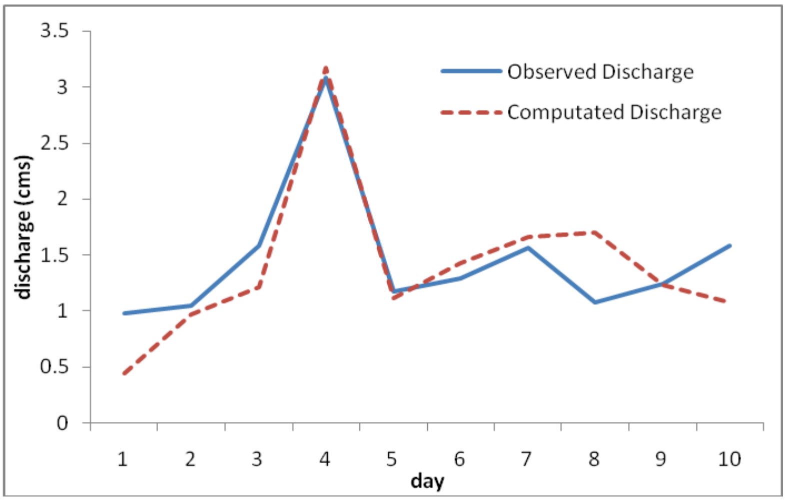

Fig. 5. Sample of simulated rainfall-runoff in the validation dataset (Feb., 20 to March 1, 1997).

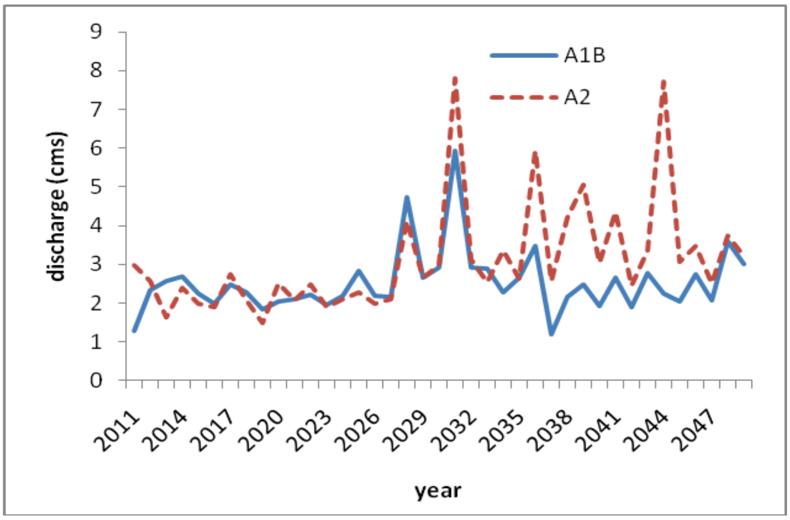

Fig. 6. Average Pishin Reservoir Inflows in the Months of Dec. through March Predicted based on the A1B and A2 Scenarios.

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Table 3. Statistical Properties of Pishin Reservoir Inflows.

Scenario	Period	Mean	Standard Deviation	Min	Max
A1B	2011-2020	1.85	3.95	0	34.36
	2021-2030	2.29	4.83	0	43.17
	2031-2040	2.45	7.19	0	137.94
	2041-2049	2.35	5.2	0	64.89
A2	2011-2020	1.86	3.91	0	44.68
	2021-2030	2.19	4.27	0	53.17
	2031-2040	3.8	10.05	0	237.94
	2041-2049	3.08	6.36	0	63.91
Observed	1970-1995	9.33	9.44	0	202.07
	1997-2006	4.77	41.31	0	843.4

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