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Prediction of Precipitation for Considering Climate Change and GCM Outputs: Satluj River

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ABSTRACT Precipitation data is of utmost importance to carry out many hydro-meteorological studies. Observed warming over several decades has been linked to changes in the large-scale hydrological cycle such as: increasing atmospheric water vapour content, changing precipitation patterns, intensity and extremes, reduced snow cover and widespread melting of ice, and changes in soil moisture and runoff. Precipitation changes show substantial spatial and inter-decadal variability. General Circulation Models (GCMs), representing physical processes in the atmosphere, ocean, cryosphere and land surface, are the most advanced tools currently available for simulating the response of the global climate system. Recent interest in global warming has also increased concerns about the possible changes in rainfall amount including floods and drought patterns. This study is based on statistical downscaling, which provide good example of focusing on predicting the rainfall using the input of coarse GCM outputs. In this study, we have used GCM outputs for predicting the rainfall. It is obtained from the study that predicted rain values are higher for the first 30 years in compared to remaining prediction periods. The result has shown that winter rainfall may highly decrease in compared to monsoon, post monsoon and pre-monsoon seasons.

Key Words: *Downscaling, General circulation model, Global warning, Rainfall Prediction*

1 INTRODUCTION

Precipitation is one of the crucial parameters of hydrological cycle. It is one of the major driving forces in hydro-meteorological analysis. Infiltration, evaporation, transpiration, ground water, runoff and so on are governed by precipitation. Precipitation may be the first parameter that has been measured by man. Most of the hydro-meteorological phenomena depend on the availability of precipitation (that is, rainfall in liquid form). In recent days, precipitation measurements have been conducted by ground gauging stations, satellite based estimation, radar rain gauges. However, due to financial constraint, difficult to access and so on many parts of the world (mainly in Himalayan region) do not have sufficient precipitation gauging stations.

The General Circulation Model (GCM) represents physical processes in the atmosphere, ocean, cryosphere and land surface. It is one the most advanced tools currently available for simulating the response of the global climate system. The atmospheric or oceanic GCMs

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(Atmospheric General Circulation Model-AGCM or Ocean General Circulation Model-OGCM) are key components of GCMs which include land-surface, sea-ice and ocean components. Data generation by downscaling GCM output will be one of the options to know the future rainfall condition in the particular region. Downscaling is a process of the development of climate data for a point or small area from regional climate information. The regional climate data may originate either from a climate model or from observations. Usually the two downscaling techniques such as dynamical and statistical are in practice.

This study has been initiated by considering the importance of the matter that very few scientific works relating to climate change by general circulation model have been carried out in South Asian region. We are trying to get future rainfall at Satluj basin using GCM and statistical downscaling technique. We have assumed that the predicted rainfalls will be highly useful to improve our understanding about climate change and its impact. It is also assumed that the results obtained from this study may become a noteworthy scientific document for further planning and development of water resources projects at or near by the Satluj River. Therefore, the following objectives have been carried out in this study:

- To perform GCM output at a basin level.
- To predict future rainfall.
- To identify relationships between observed and predicted rainfalls.

2 MATERIALS AND METHODS

2.1 Study area

This study has been carried out for Satluj River near by the Bhakra dam. The Satluj River rises from the lakes of Mansarovar and Rakastal in the Tibetan Plateau at an elevation of about 4572 m. It is one of the main tributaries of the Indus River. It is found that about 65 % area of the Satluj River basin has been covered by snow in winter and this river has been categorized in the Himalayan river system (Figure 1).

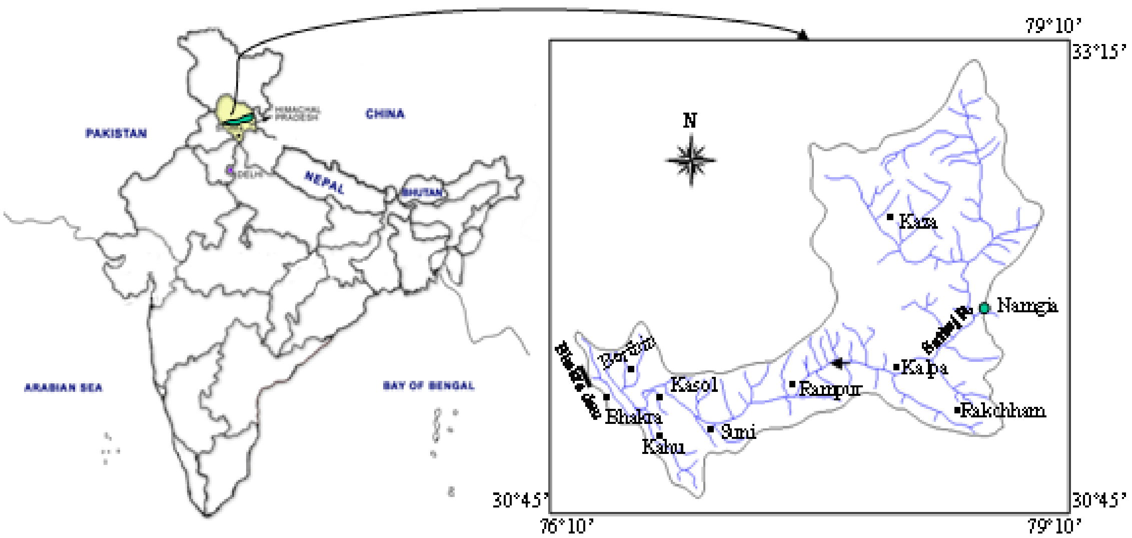

Figure 1 Location map of the Satluj basin up to Bhakra dam with hydro meteorological stations (Gautam *et al.*, 2012)

Satluj River is the longest of the five rivers that flow through the region of Punjab in Northern India and it finally mix with Indus in Pakistan. The total catchment area of the river up to the Bhakra dam is about 56, 500 km^2, of which about 22, 305 km^2 lies in India (Jain, 2008). The elevation of the catchment varies from 500 to 7000 m, and only a very small area exists above 6000 m. The Satluj River receives cool and snowmelt water from the upstream of the basin during the spring and summer months.

2.2 Method

Data set of wind speed (uwind, vwind), relative humidity, mean sea level pressure, geopotential height and air temperature from 1948 to 2004 have been considered to carry out the study. Those reanalysis data were produced by the National Center for Environmental Prediction/ National Center for Atmospheric Research (NCEP/NCAR). The data have been obtained through the website of National Oceanic and Atmospheric Administration (NOAA) as, http://www.esrl.noaa.gov (NOAA, 2009). In the absence of adequate observed climatological data, the NCEP/ NCAR data have been used as a proxy to the observed data.

GCM outputs of Center for Climate System Research/National Institute for Environmental Studies (CCSR/NIES) Japan have been considered from 2001 to 2100 for projecting future rainfalls. The gridded data sets of mean sea level pressure, specific humidity, wind speed, air temperature have been used as GCM outputs. The GCM data are available in the website of Intergovernmental panel on climate change (IPCC) as, http://www.mad.zmaw.de/IPCC_DDC/html/ddc_gcmdata.html (IPCC, 2009). Mean monthly rainfall of Kasol from 1977 to 2004 have been used as observed rainfall.

We have applied statistical downscaling technique to find out quantitative relationship between large-scale atmospheric variables (predictors) and local surface variables (predictands) (Figure 2). Statistical downscaling produces future values based on statistical relationship between large-scale climate features and hydrologic variables like precipitation (Wilby *et al.,* 2004).

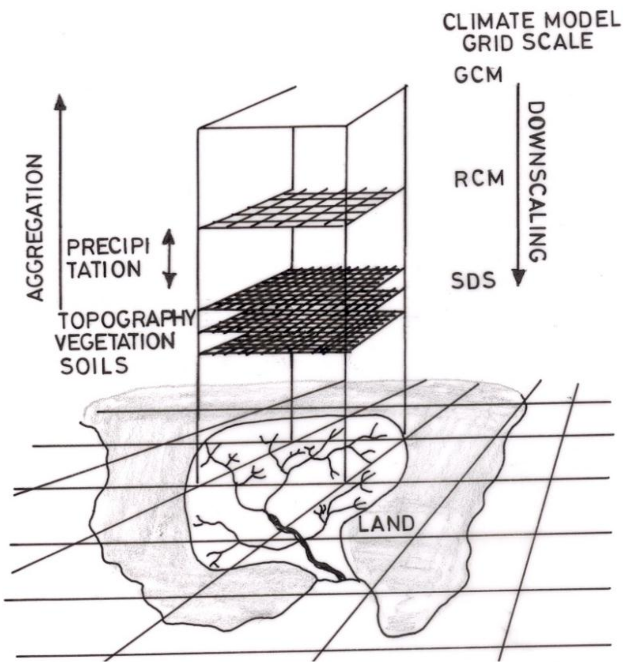

Figure 2 Illustrating the general approach to downscaling **(**Wilby and Dawson, 2007)

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In present study, statistical downscaling has been performed in the following manner. Initially, standardization has been performed for both NCEP and GCM output data set. Then Principal Component Analysis (PCA) has been carried out for both NCEP and GCM data set using matrix laboratory (MATLAB). PCA is performed to reduce the dimensionality of the predictor variables. Regression coefficients have been found out with the relationship between NCEP data set and observed rainfall. Future rainfalls have been predicted using the regression coefficients to the PCA of GCM output.

Rainfall variability has been conducted to find out the inconsistency in between observed and predicted rainfall values. In this study, monthly variations of rainfall have been obtained by taking averages of each months of observed and predicted rainfalls based on the average of observed rainfall.

We performed trend analysis to identify increasing or decreasing tendency in the data set and it is one of the important tools to be performed in a hydrologic series. In this study, Mann Kendall (MK) test is applied to find out trend in the observed and predicted data set.

The MK (MK) test is based on the test statistic 'S', which is defined as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(x_j - x_i) \quad (1)$$

where the x_j are the sequential data values, n is the length of the data set, and :

$$\mathrm{Sgn}(\theta) = \begin{cases} +1 & \text{if } \theta > 0 \\ 0 & \text{if } \theta = 0 \\ -1 & \text{if } \theta < 0 \end{cases} \quad (2)$$

Mann (1945) and Kendall (1975) have documented that when n≥8, the statistic S is approximately normally distributed with the mean and the variance as follows:

$$E(S) = 0 \quad (3)$$

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n} t_i i(i-1)(2i+5)}{18} \quad (4)$$

where t_i is the number of ties of extent i. The standardized test statistic Z is computed by:

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{var(s)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{var(S)}} & S < 0 \end{cases} \quad (5)$$

The standardized MK statistic Z follows the standard normal distribution with mean of zero and variance of one (Yue *et al.*, 2002).

3 RESULTS AND DISCUSSIONS

3.1 Prediction of rainfall

It is already mentioned that principal component analyses have been carried out from the NCEP data set within the period of 1977 to 2004. In present study, with the application of PCA, 98 % variability was explained by nine components. Then regression coefficients are obtained with the relationship between PCA of NCEP data and observed rainfalls, which are given in Table 1.

Hence, using these nine principal components (pci_1, $pci_2 \ldots pci_9$) and nine regression coefficients (d_0, d_1, $d_2 \ldots d_9$); rainfalls at time t have been obtained through the equation 6:

$$Rain_t = d_0 + \sum_{i=1}^{9} di * pcit \quad (6)$$

In this way, rainfalls were predicted with the relationship between regression coefficients obtained from NCEP data set and PCA obtained from GCM output. Diagrammatic representation of the predicted rainfall values are given below.

Figure 3 has been drawn for the predicted rainfalls from 2001 to 2100 and it has shown that maximum monthly rainfalls are above 325 mm in many years from 2001 to 2030 compared to remaining period of the prediction. Figures 4, 5 and 6 have been drawn on the predicated monthly rainfalls for the years 2030, 2050 and 2080 respectively. All the figures (i.e. 4, 5 and 6) have shown that there will be no rainfall in the months of December and January. The amount of rainfall will be very high in June, July and August in compared to the remaining months. These two facts are similar to existing condition as there is high amount of rainfall in monsoon (June-September) and less or almost no rainfall in winter (December-January). Sinha Ray and Srivastava (1999) have also found decreasing trend of rainfall in winter.

Table 1 Regression Coefficients

Regression Coefficients	d_0	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9
Values	109.911	17.4775	-12.0145	33.5482	7.360	4.8876	-16.618	-15.2995	-13.1086	-31.181

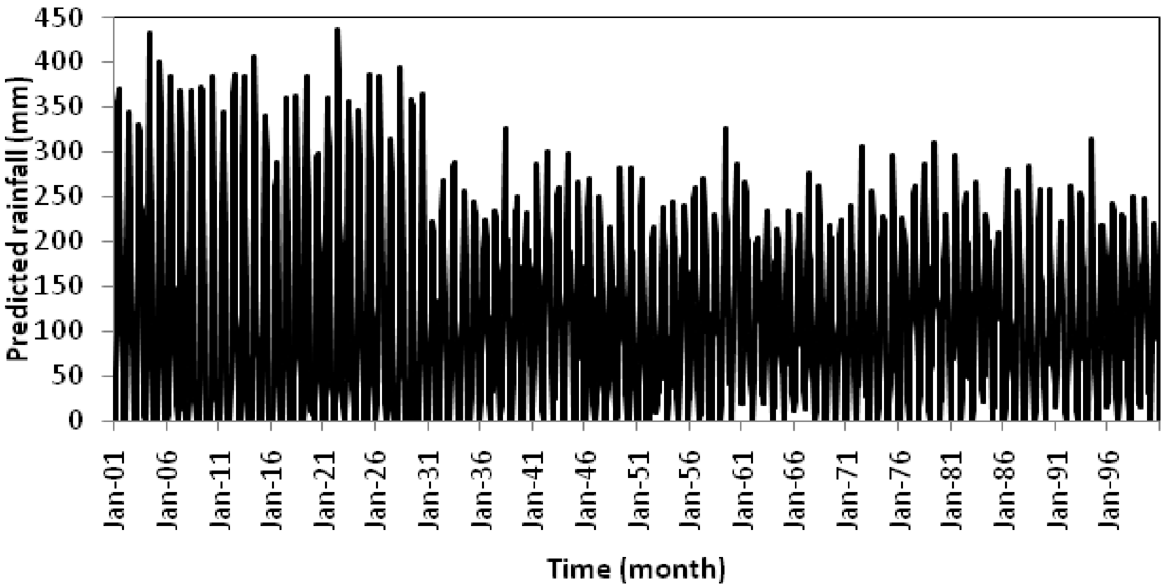

Figure 3 Predicted rainfalls for 2001 to 2100 for the study area

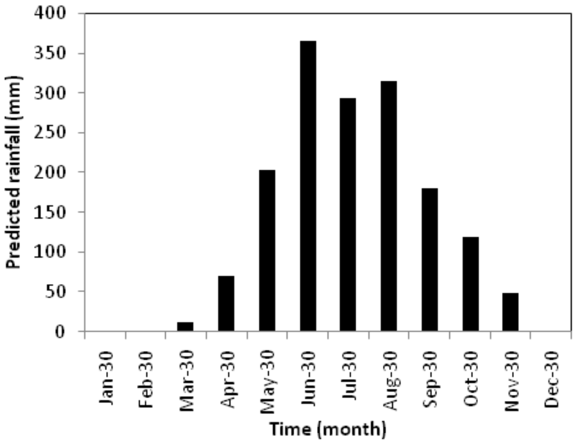

Figure 4 Predicted monthly rainfall for 2030

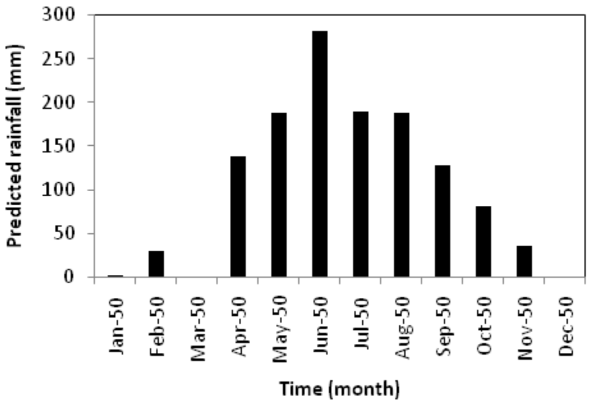

Figure 5 Predicted monthly rainfall for 2050

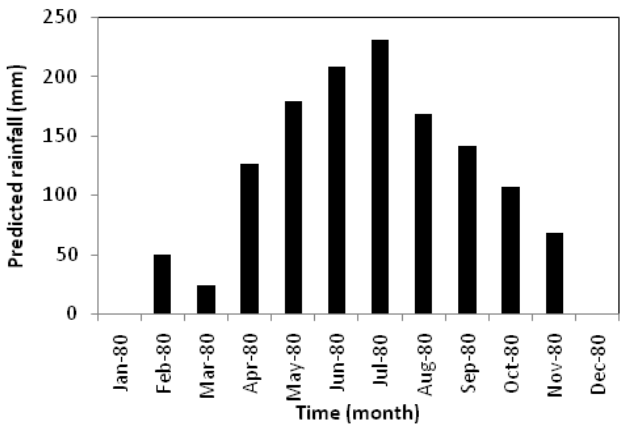

Figure 6 Predicted monthly rainfall for 2080

3.2 Rainfall variability

Rainfall variability has been calculated by taking monthly rainfalls from 1977 to 2004 as well as from 2001 to 2100 within the same month of observed and predicted rainfall data set. The diagrammatic representation of the rainfall variability has been given in the Figure 7. It is obtained from figure 7 that there is a condition of positive rainfall variability, which shows predicted values are higher in the months of April, May, June, October and November. Likewise, the predicted values are lower than observed, that is, negative rainfall variability were appeared for the months of January, February, March, July, August and December. The predicted and observed values are quite closer in the month of September.

A scatter plot has been drawn between average observed rainfall and predicted rainfall values in Figure 8. The figure shows that lower and medium rainfall values are highly correlated in comparison to the higher values.

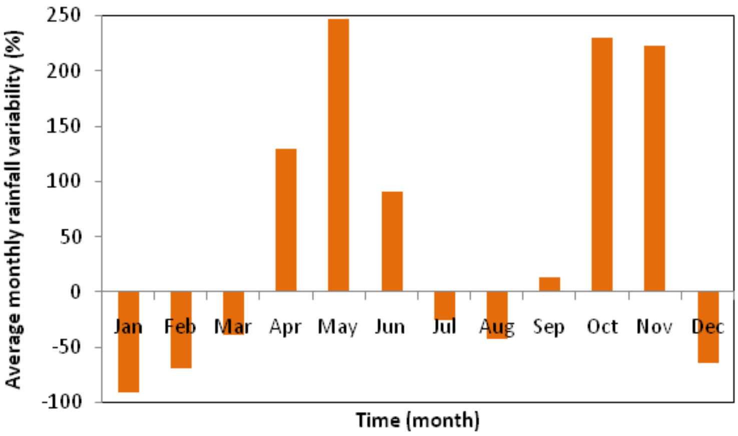

Figure 7 Monthly rainfall variability based on observed rain data set

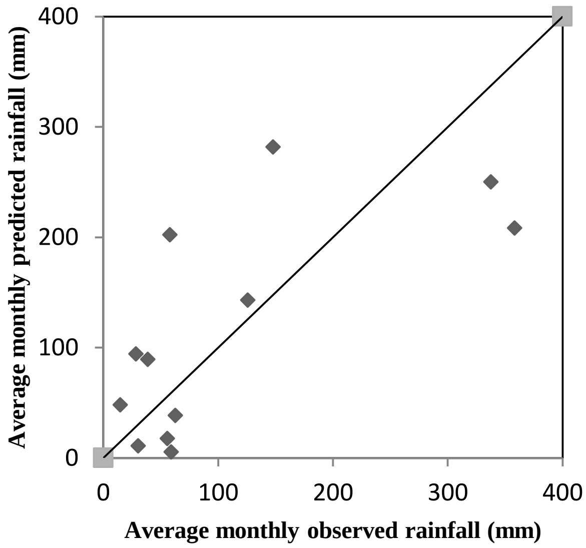

Figure 8 Scatter plot between monthly averages of observed and predicted rainfalls

3.3 Trend analysis of rainfall

MK test has been applied to identify the trend in the observed and predicted rainfalls. The test statistics for observed and predicted rainfalls are -0.18 and 0.17. This test has shown that there is no trend in the observed and predicted rainfalls at 5% significant level. This result is quite similar to the conclusion made by Sarker and Thapliyal (1988) and Thapliyal and Kulshrestha (1991).

4 CONCLUSION

This study has shown that future rainfalls are above 325 mm in many years for the first 30 years and the same trend is not observed during the remaining period of the prediction. The simulated rainfall of 2030, 2050 and 2080have shown that the future rainfall will highly decrease for winter season in compared to monsoon, post monsoon and pre-monsoon seasons. Hence, it can be finalized that future rainfalls will highly decrease for winter season in comparison to other seasons.

Rainfall variability has been conducted based on the observed data set and the result indicated that rainfall values of December, January and February are on highly decreasing order and the rainfalls of May, October and November are on highly increasing order. The Mann Kendall test has shown that there is no trend in the observed and predicted rainfalls at 5% significant level.

Last but not the least, it can be concluded that the results obtained from this study may be crucial in water resources planning and management of Satluj River basin.

5 ACKNOWLEDGEMENT

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6 REFERENCES

Gautam, N.P., Arora, M., Goel, N.K. and Kumar, A.R.S. Investigating the impact of climate change on future runoff of river Satluj. J. Hydrol. Meteorol., 2012; 8(1): 10-21

IPCC. http://www.mad.zmaw.de/IPCC_ DDC/ html/ddc_gcmdata.html, accessed 15 November 2009.

Jain, S.K. Development of integrated discharge and sediment rating relation using a Compound Neural Network, J. Hydrol. Engr., 2008; 13(3): 124-131.

NOAA. http://www.esrl.noaa.gov, accessed 15 November 2009.

Sarker, R.P. and Thapliyal, V. Climate change and variability. Mausam, 1988; 39: 127-138.

Sinha Ray, K.C. and Srivastava, A.K. Is there any change in extreme events like droughts and heavy rainfall? INTROPMET-97, IIT New Delhi, 2-5 Dec., 1997.

Thapliyal, V. and Kulshreshtha, S.M. Climate changes and trends over India. Mausam, 1991; 42: 333-338.

Wilby, R.L. and Dawson, C.W. SDSM 4.2- A decision support tool for the assessment of regional climate change impacts, United Kingdom. 2007.

Wilby, R.L., Charles, S.P., Zorita E., Timbal B., Whetton, P. and Mearns L.O. Guidelines for use of Climate Scenarios Developed from Statistical Downscaling Methods. Supporting material of the Intergovernmental Panel on Climate Change (IPCC), prepared on behalf of Task Group on Data and Scenario Support for Impacts and Climate Analysis (TGICA), 2004; 27 P.

[DOR: 20.1001.1.23222700.2014.2.4.1.4]

Yue, S., Pilon, P. and Cavadias, G. Power of the Mann-Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. J. Hydrol., 2002; 259: 254-271.

برآورد بارش با توجه به خروجی‌های تغییر اقلیم و مدل‌های GCM: رودخانه Satluj

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چکیده داده‌های بارش در بسیاری از مطالعات آب و هواشناسی دارای بیش‌ترین اهمیت است. گرم شدگی رخ داده طی چندین دهه به تغییرات چرخه آب‌شناسی در مقیاس بزرگ از قبیل افزایش محتوای بخار آب اتمسفر، تغییر الگوها، شدت و وقایع حدی بارش، کاهش پوشش برف، ذوب گسترده یخ‌های قطبی و تغییر در رطوبت خاک و رواناب ارتباط داده شده است. تغییرات بارش تغییرپذیری مکانی و بین دهه‌ای قابل توجهی نشان می‌دهد. مدل‌های گردش عمومی (GCM) از طریق بررسی فرآیندهای فیزیکی در اتمسفر، اقیانوس، یخ‌ها و سطح زمین، پیشرفته‌ترین ابزارهای در دسترس برای شبیه سازی پاسخ سامانه جهانی اقلیم هستند. علایق پژوهشی جدید در رابطه با گرم شدن جهانی نیز نگرانی در خصوص تغییرات ممکن در مقدار بارندگی شامل الگوهای سیل و خشکسالی را افزایش داد. مطالعه حاضر نمونه مناسبی از تلاش برای برآورد بارندگی با استفاده از خروجی‌های بزرگ مقیاس GCM به عنوان ورودی ارائه می‌دهد و بر مبنای ریز مقیاس‌سازی آماری استوار است. در مطالعه حاضر از خروجی مدل‌های GCM برای برآورد بارندگی استفاده شده است. ایده مذکور از مطالعه‌ای گرفته شده که مقادیر برآوردی بارندگی برای ۳۰ سال اول را بیش‌تر از دیگر دوره‌های باقی مانده ذکر کرده است. نتایج نشان داد که در مقایسه با فصول موسمی و نیز فصول قبل و بعد موسمی، بارندگی زمستان ممکن است به شدت کاهش یابد.

کلمات کلیدی: برآورد بارندگی، ریزمقیاس‌سازی، گرم شدن جهانی، مدل گردش عمومی