Simulating Precipitation of Bahawalpur and its Adjoining Cholistan Desert of Pakistandue to Climate Change

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Abstract: The studies related to impact of climate change are hot topics of the day because their output is applied by the researchers and planners for future management of water resources. This study focusses on the precipitation changes in Bahawalpur and its adjoining Cholistan desert. Results of two GCMs i.e. CGCM and NPCM with experiment 1 run in each have been applied for SRES A2 IPCC scenario. K-NN statistical downscaling method has been applied to scale down GCM results up to the station of interest. The simulated results for the period 2001-2030, 2031-2060, 2061-2090 and 2091-2100 when compared with the base period (1971-2000) indicated increase in precipitation. Although, total average annual change is 244.78% and 276.12% for CGCM1 and NPCM1 models, respectively, yet more importantly are ranges of increases as 63.64-172.73% during winter (DJF), 31.03-224.14%, 194.49-345.67% during summer (monsoon, JJA) and 517.39-600% during autumn (SON). Such predictions indicate promising improvements in the rainfall for the deserts and will help to improve the water resources.

Key words: Climate change · Arid areas · GCM · Downscaling · Precipitation

INTRODUCTION

The world is facing changes in the climate at a rapid rate after the industrial revolution. As a result of this, the water resources are facing or expected to face extreme changes in terms of heavy floods and droughts. Emission of greenhouse gases (GHGs) is causing global warming that results in temperature increases, boosting evaporation and evapotranspiration and eventually disturb the precipitation occurrence [1, 2, 3, 4]. Impact of global warming is evaluated against a scenario which consider various factors responsible for disturbing the climate e.g. human activities like excessive emissions of greenhouse gases (GHGs), changes in land uses [5] etc. Precipitation, which is the main source of surface water, is affected by the climate change and this change ultimately affects the water resources [6, 7, 8, 9]. It is very important to understand [10] and predict pattern of precipitation.

Pakistan is an agriculture country and availability of water is considered as the most vibrant factor that controls economic growth of a country [11] Socio and economic development of arid areas is heavily dependent on water resources [12]. It is essential to investigate changes in precipitation in arid and semi-arid regions where life is dependent on it. Global Climate Models (GCMs) are considered the most powerful tools for estimation of such trends. Global Climate Model (GCM) are used to simulate environmental changes. These are the prevailing tools used to guesstimate variations and produce correct results globally. GCMs associate the impacts of atmosphere, land, ocean and ice [13]. GCMs work out behaviour of atmosphere against a scenario [14]. There are many studies on climate change which were based on different combinations of the GCMs and the method of downscaling. The present study focuses the following

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two GCMs to simulate changes in precipitation and temperature for the study area on the basis of SRES A2 scenario [7, 14].

GCMs produce result in grid form, so point of interest i.e. station is located away from the simulated GCM data point [1, 15, 16, 17, 18, 19]. There is always need to use statistical and dynamical downscaling technique to get the result exactly at the station [9, 20, 21, 22, 23, 24]. Hassan and Ghumman [9] also introduced another graphical method for visual downscaling GCM results at the stations. In this study, results of two GCMs have been downscaled using k-NN statistical downscaling technique. K-NN [25] is a well-known algorithm in pattern classification. It is simple as well as effective [5]. In this method, a set of weights is developed by using following (1 to 3) equations [4]:

$$W(x,y)i = \frac{\exp[-D(x,y)i]}{\sum_{i=1}^{N}\exp[-D(x,y)i]} \tag{1}$$

$$\sum_{i=1}^{N}W(x,y)i = 1 \tag{2}$$

$$P = \sum_{i=1}^{N}W(x,y)iPi \tag{3}$$

In this equation, x = Longitude, y = Latitude, P = Precipitation at unknown point, Pi = Precipitation of respective points that are nearest to query point whose precipitation is known. (Note: Use T in place of P in above equations if temperature is the intended parameter).

MATERIALS AND METHODS

Study Area: The Cholistan Desert which is locally known as Rohi, is located 30 km (19 mi) south and south-west of Bahawalpur, Punjab as shown in figure 1. It covers an area of 26, 300 km². There exist the Thar Desert that extends into Sindh and India. It is 89 meters above mean sea level and its coordinates are 28°15'0" N and 70°45'0" E in DMS (Degrees Minutes Seconds) or 28.25 and 70.75 (in decimal degrees). The desert is large with little or no vegetation due to extreme environmental conditions.

Figure 2 below shows the monthly mean temperature and rainfall in Cholistan desert during 2005-2009 that was processed from the raw data provided by Regional Office of Pakistan Council of Research in Water Resources, Bahawalpur, Pakistan. In this figure, it can be observed that minimum mean temperature is 15°C in January, maximum mean temperature is 38°C in June, approximately.

Observed minimum mean rainfall is 2mm in November and maximum mean rainfall 55mm in July, approximately. Average mean monthly rainfall is around 14mm and annual rainfall is 168mm which is slightly less than the nearest met station of Bahawalpur. It is due to such less rainfall and high temperatures that this area has desert conditions with less or almost no vegetation.

Cholistan desert is famous for pottery as it belongs to that old Indus Civilization Cholistan soil is very fine, which is suitable for making pottery. The soil is so fine that houses in this area are constructed from this soil and when plastered with mud, these look as if they were cemented.

Data and its Analysis: There is no meteorological station in Cholistan but due to its closest location near Bahawalpur (at a distance of 30km), data of Bahawalpur has been used. Application of Bahawalpur data at Cholistan has been validated by doing a comparison of figures 3 and 4. Figure 3 represents mean monthly precipitation at Bahawalpur on the basis of 30 years (1971-2000) data obtained from Pakistan meteorological Department (PMD), Islamabad. Figure 4 has been worked out from the SamSam model by pointing in the Cholistan desert. Figurative and numerical comparison of these two figures indicates that Cholistan receives almost 10% less rainfall annually. So, any simulation done for Bahawalpur may be reduced by this percentage to get approximate impact of climate change in Cholistan.

Methodology: Following two GCMs have been applied in this study:

CGCM1: Canadian Centre for Climate Modelling and Analysis, Canada developed this General circulation model. It has 96x48 grid points oriented from West to East and from North to South. It is globally coupled ocean-atmosphere-sea-ice model with CGCM1 having resolution of 3.5°x3.71°. Total surface solar radiation (W/m²) on ground, mean sea level pressure (Pa), Total Precipitation (mm/day), Temperature (°K) 2m above ground, Maximum temperature (°K) 2m above ground, Minimum temperature (°K) 2m above ground, Screen Specific humidity (kg/kg) and wind speed (m/s) at 10m above ground are considered in all experiments.

NPCM1: It is developed by NCAR (National Centre for Atmospheric Research which is located in Colorado USA). Its grid resolution is 2.183°x2.791°. Surface air temperature (°K), Mean Sea Level pressure (Pa),
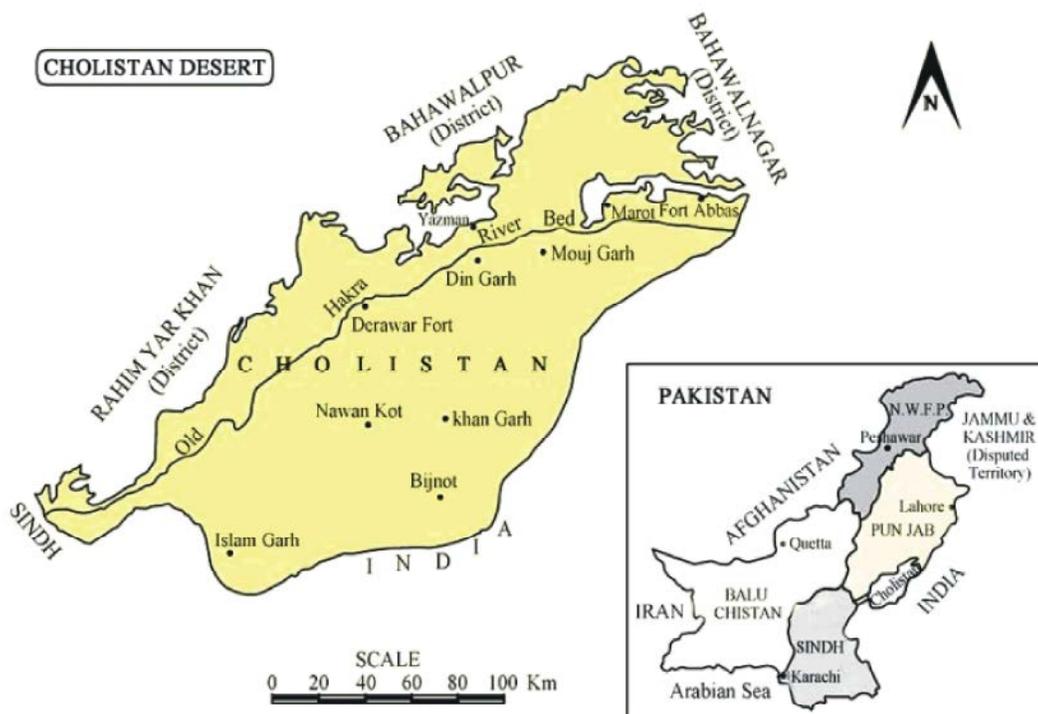
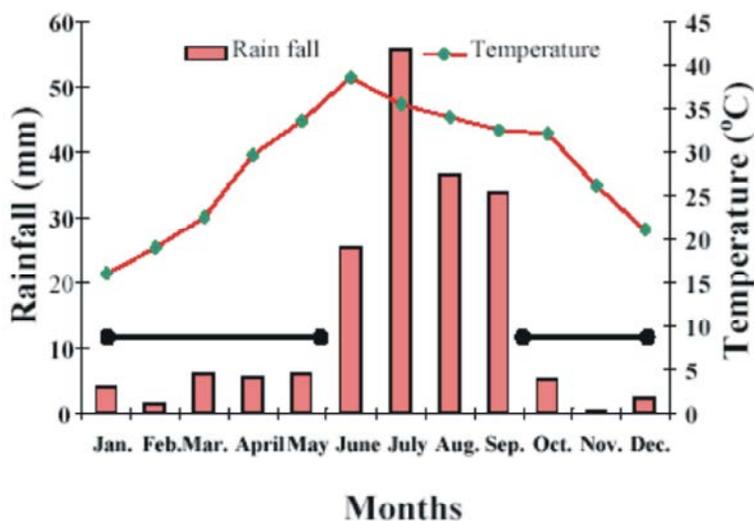Fig. 1: Location of Cholistan Desert [2]

Fig. 2: Monthly mean temperature and rainfall in Cholistan desert during 2005-2009 (Processed from the raw data provided by Regional Office of Pakistan Council of Research in Water Resources, Bahawalpur, Pakistan) [26]

Total Precipitation (mm/day), Here all experiments consider surface temperature (°K), mixing ratio (kg/kg), total incident solar radiation (W/m^2), zonal wind (m/s) and meridional/v-wind (m/s).

Following three experiments are performed in each of these two GCMs [27]:

- Control Integration: In this experiment, simulations are carried out for several hundred years keeping the atmospheric forces constant. Its data is also listed by IPCC data centre.
- Integration of Greenhouse gases (GHGs): The increase in concentration of GHGs is according to IS92a emission scenario of IPCC from 1991 to 2100.
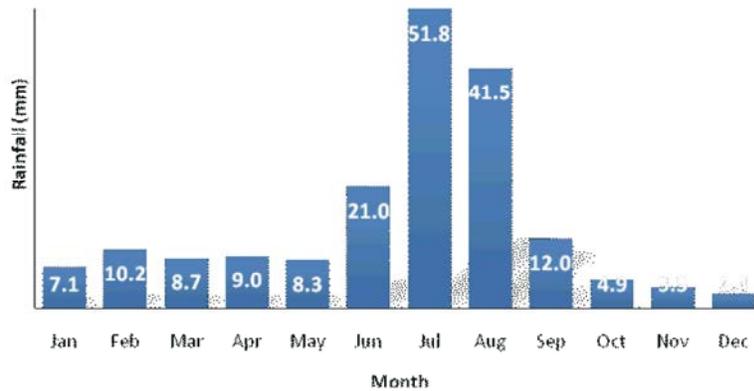
Fig. 3: Mean monthly precipitation at Bahawalpur (1971-2000 average)

Fig. 4: Mean monthly precipitation at Cholistan (SamSam model output)

- Integration of GHGs and sulphate aerosol: It involves integration of sulphate aerosols in addition to three GHGs forcing.

Downscaling: It is an important step in the study of impacts of climate change. Downscaling is required because GCMs produce results in grid form and the station of interest is away from the grid points. Hence, value of closest grid point can't be directly considered as station-of-interest value. Impact of all surrounding four grid point values must be weighed by using suitable statistical, dynamical etc. downscaling technique. These methods are simple as well as complex [9, 20, 21, 22, 24, 28]. In this study, k-NN statistical technique has been applied by using equations explained in introduction.

RESULTS AND DISCUSSION

Average of observed precipitation for period of 1980-2000 has been used as base period.

Two models CGCM (run 1) and NPCM (run 1) are studied for precipitationchanges during and up to the end of this century. Results have been averaged for 30 years and last ten years i.e. 2001-2030, 2031-2060, 2061-2090 and 2091-2100 and then compared with the average of base period i.e. 1980-2000.

Table 1 and Figure 5 indicate amounts of precipitation (mm/day) during the base period and simulated periods, as defined above, by extracting data from CGCM1 model output. For each season, base period (1971-2000) average could also be observed in this figure. In this figure, it is observed that: (a) during winter, daily precipitation is expected to increase and reach maximum value during 2031-2060 after which it will decrease and become even less than base period, (b) during spring, there is almost negligible change in daily precipitation during the present century, (c) during summer/monsoon, daily precipitation are expected to increase much and will keep on increasing slightly in each 30 years span, (d) during autumn, daily precipitation is also expected to increase much than the base period and that increase will remain at the same level. As a result, annual average of daily precipitation shows increase in precipitation.
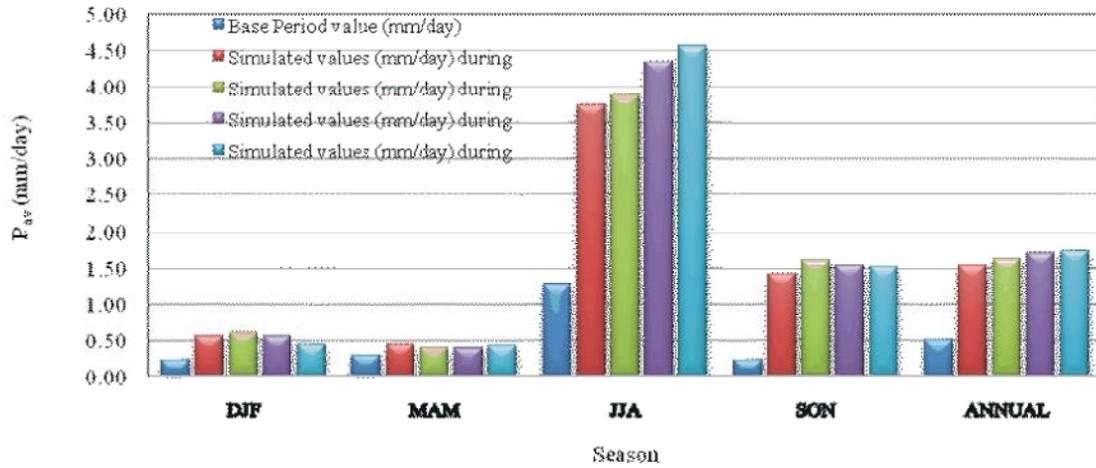
Fig. 5: Average precipitation (mm/day) extracted from CGCM1 model output
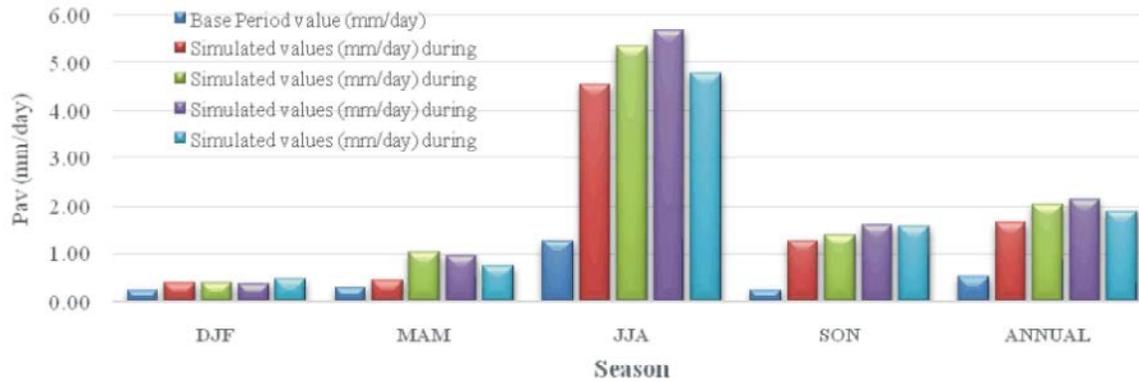

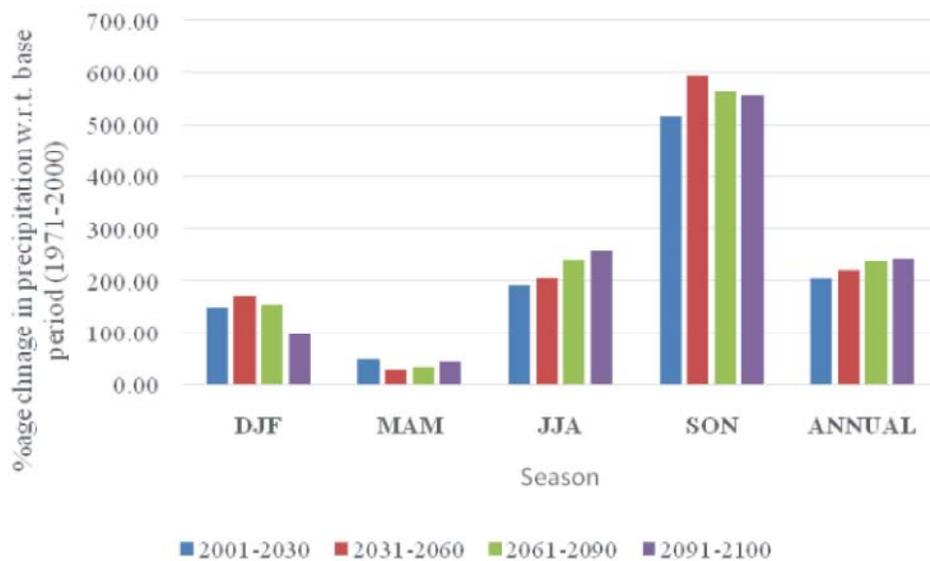Fig. 6: Average precipitation (mm/day) extracted from NPCM1 model output

Fig. 7: %age change in average precipitation extracted from CGCM1 model output
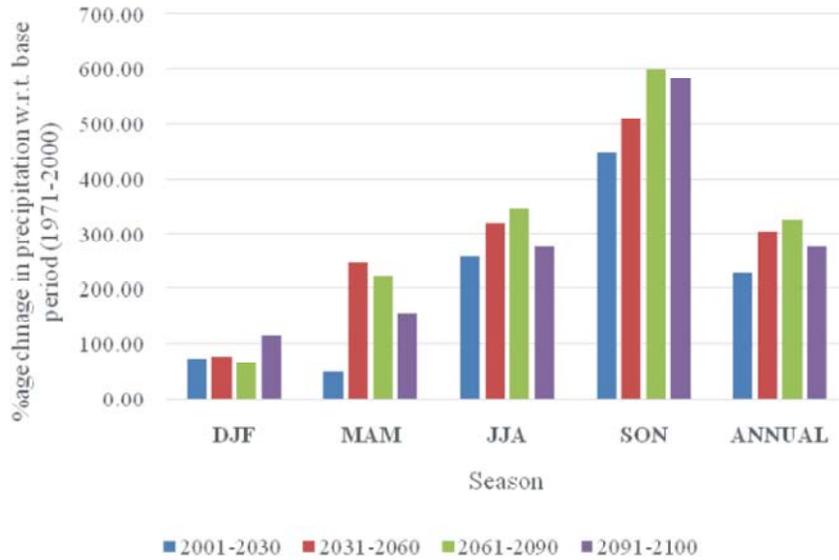
Fig. 8: %age change in average precipitation extracted from NPCM1 model output

Table 1: Seasonal and annual precipitation in mm/day – output ofCGCM1 model

| Season | Base Period value (mm/day) | Simulated values (mm/day) during | | | |
		2001-2030	2031-2060	2061-2090	2091-2100
DJF	0.22	0.55	0.60	0.56	0.44
MAM	0.29	0.44	0.38	0.39	0.42
JJA	1.27	3.74	3.88	4.34	4.56
SON	0.23	1.42	1.60	1.53	1.51
ANNUAL	0.50	1.54	1.62	1.71	1.73

Table 2: Seasonal and annual precipitation in mm/day – output ofNPCM1 model

| Season | Base Period value | Simulated values (mm/day) during | | | |
		2001-2030	2031-2060	2061-2090	2091-2100
DJF	0.22	0.38	0.39	0.36	0.47
MAM	0.29	0.43	1.01	0.94	0.74
JJA	1.27	4.54	5.32	5.66	4.78
SON	0.23	1.26	1.40	1.61	1.57
ANNUAL	0.50	1.65	2.03	2.14	1.89

Table 3: %age change in seasonal and annual precipitation w.r.t. base period – output ofCGCM1 model

| Season | %age change during Simulation Period | | | |
	2001-2030	2031-2060	2061-2090	2091-2100
DJF	150.00	172.73	154.55	100.00
MAM	51.72	31.03	34.48	44.83
JJA	194.49	205.51	241.73	259.06
SON	517.39	595.65	565.22	556.52
ANNUAL	205.97	221.39	239.30	244.78

Table 4: %age change in seasonal and annual precipitation w.r.t. base period - output ofNPCM1 model

| Season | %age change during Simulation Period | | | |
	2001-2030	2031-2060	2061-2090	2091-2100
DJF	72.73	77.27	63.64	113.64
MAM	48.28	248.28	224.14	155.17
JJA	257.48	318.90	345.67	276.38
SON	447.83	508.70	600.00	582.61
ANNUAL	228.86	303.98	326.37	276.12

Table 2 and Figure 6 indicate amounts of precipitation (mm/day) during the base period and simulated periods, as defined above, by extracting data from NPCM1 model output. For each season, base period (1971-2000) average could also be observed in this figure. In this figure, it is observed that: (a) during winter, daily precipitation is expected to increase and this increase will become almost uniform, (b) during spring, daily precipitation is expected to increase and reach maximum value during 2031-2060 and 2061-2090, (c) during summer/monsoon, daily precipitation are expected to increase much and will have maximum values during 2031-2060 and 2061-2090, (d) during autumn, daily precipitation is also expected to increase much than the base period and that increase will remain almost at the same level. As a result, annual average of daily precipitation shows increase in precipitation.

According to CGCM1 model (Table 3 and Figure 7), Bahawalpur and Cholistan are expected to experience average change in precipitation in the range of 100% to 172.73% in Winter (DJF), 34.48% to 51.72% in Spring (MAM), 194.49% to 259.06% in Summer (JJA), 517.39% to 595.65% in Autumn (SON) and there will be annual average increase of 205.97% to 244.78%.

According to NPCM1 model (Table 4 and Figure 8), Bahawalpur and Cholistan are expected to experience average change in precipitation in the range of 63.64% to 113.64% in Winter (DJF), 48.28% to 24.28% in Spring (MAM), 257.48% to 345.67% in Summer (JJA), 447.83% to 600% in Autumn (SON) and there will be annual average increase of 228.86% to 276.12%.

In the above results for desert and arid region, percentage increase is indicatedhighest in SON (autumn). This trend does not mean that autumn will become the heaviest rainfall seasonbut it is due to mathematical fact that for lessernumeric value, a small increase results in ahigher percentile value.

CONCLUSIONS

In above results, it is observed that there existsa physical relationship between energy and hydrological cycle. Seasonal variation in precipitation occurrence will have the same trend as being observed at present, that is, monsoon being the maximum rainfall and autumn the least rainfall seasons.

Although, the results of CGCM1 and NPCM1 vary from each other due to their different assumptions, yet models almost agree with each other predicting annual average daily (mm) increases of 244.78% and 276.12% increase in precipitation, respectively. This difference is due to the assumptions and approximations of physical processes considered in each GCM.

REFERENCES

1. Asadieh, B. and N.Y. Krakauer, 2015. Global trends in extreme precipitation: climate models versus observations. Hydrol. Earth Syst. Sci., 19: 877-891,

2. Hong, Z., L.Z. Ling, L. Jia, D.A. Rui and D. Yun, 2018, Climate and Hydrological Change Characteristics and Applicability of GLDAS Data in the YarlungZangbo River Basin, China, Water 10, 254; doi:10.3390/w10030254.

3. Mahmood, R., S. Jia and M.S. Babel, 2016. Potential Impacts of Climate Change on Water Resources in the Kunhar River Basin, Pakistan, Water, 8(23): 1-24.

4. Masaaki, S., 1987. Method of numerical integration of oscillatory functions by DE-formula with the Richardson extrapolation, Journal of Computational and Applied Mathematics, 17(1-2): 47-68.

5. Jones, P.D., C. Harpham, A. Burton and C.M. Goodess, 2016. Downscaling regional climate model outputs for the Caribbean using weather generator, Int. J. Climatol., (wileyonlinelibrary.com) DOI: 10.1002/joc.4624.

6. Benestad, R.E., K.M. Parding, K. Isaksen and A. Mezghani, 2016. Climate change and projections for the Barents region: what is expected to change and what will stay the same?, Environmental Research Letters, Vol 11, 054017, pp: 1-7.

7. Peters, G.P., R.M. Andrew, T. Boden, J.G. Canadell, P. Ciais, C. Le Quéré, G. Marland, M.R. Raupach and C. Wilson, 2013, The challenge to keep global warming below 2 C. Nat, Climate Change, 3(1): 4-6. http://dx.doi.org/10.1038/nclimate1783.

8. Shakir, H., S. Xianfang, R. Guoyu, H. Iqtidar, H. Dongmei and M.H. Zaman, 2017. Evaluation of gridded precipitation data in the Hindu Kush-Karakoram - Himalaya mountainous area Hydrological Sciences Journal, https://doi.org/ 10.1080/02626667. 138454.

9. Wang, H., W. Xiao, J. Wang, Y. Wang, Y. Huang, B. Hou and C. Lu, 2016. The Impact of Climate Change on the Duration and Division of Flood Season in the Fenhe River Basin, China, Water, 8(105): 1-11.

10. Roudier, P., A. Ducharne and L. Feyen, 2014 Climate. change impacts onrunoff in West Africa: a review. Hydrol. Earth Syst. Sci., 18: 2789-2801, doi:10.5194/hess-18-2789-2014.

11. Eyad, A. and M. Broder, 2013. Modelling Rainfall Runoff Relations Using HEC-HMS and IHACRES for a Single Rain Event in an Arid Region of Jordan, Water Resour Management, 27: 2391-2409. DOI 10.1007/s11269-013-0293-4

12. Congjian, S., S. Yanjun, C. Yaning, C. Wei, L. Weibo and Z. Yongqing, 2017. Quantitative evaluation of the rainfall influence on streamflow inan inland mountainous river basin within Central Asia, Hydrological Sciences Journal, DOI:10.1080/02626667.2017.1390314.

13. Ishtiaq, H., R.G. Abdul and N.H. Hashim, 2016. Global warming and temperature changes for Saudi Arabia, Journal of Biodiversity and Environmental Sciences (JBES), ISSN: 2220-6663 (Print) 2222-3045 (Online), 8(1): 179-191.

14. IPCC, 2014, Climate Change 2014: Impacts, Adaptation and Vulnerability. IPCC WGII AR5 Summary for Policymakers.

15. Burke, M., J. Dykema, D.B. Lobell, E. Miguel and S. Satyanath, 2015. Incorporating Climate Uncertainty into Estimates of Climate Change Impacts, REST Journal Review of Economics and Statistics, REST, 97(2): 461-471, DOI: 10.1162/REST_a_00478.

16. Crochemore, L., Ramos, M.H. and Pappenberger, F., 2016, Bias correcting precipitation forecasts to improve the skill of seasonal stream flow forecasts.Hydrol. Earth Syst. Sci. Discuss., DOI: 10.5194/hess-2016-78.

17. Hassan, I., A.R. Ghumman, Y. Ghazaw, R.H. Abdel-Maguid and B. Samreen, 2017. Climate Change Impact on Precipitation in Arid Areas of Pakistan, International Journal of Water Resources and Arid Environments, 6(1): 80-88, ISSN 2079-7079.

18. Hassan, I., A.R. Ghumman, Y. Ghazaw, R.H. Abdel-Maguid and B. Samreen, 2016. Climate Change Impact on Precipitation in Arid Areas of Pakistan, 7th International Conference on Water Resources and Arid Environments (ICWRAE 7): 195-203, Riyadh, Saudi Arabia.

19. Nguyen, H., R. Mehrotra and A. Sharma, 2016. Correcting for systematic biases in GCM simulations in the frequency domain, Journal of Hydrology, 538: 117-126.

20. Heinzeller, D., M.G. Duda and H. Kunstmann, 2016. Towards convection-resolving, global atmospheric simulations with the Model for Prediction Across Scales (MPAS) v3.1: an extreme scaling experiment, Geosci. Model Dev., 9: 77-110.

21. Langebroek, P.M. and K.H. Nisancioglu, 2016. Moderate Greenland ice sheet melt during the last interglacial constrained by present-day observations and paleo ice core reconstructions, The Cryosphere Discuss., DOI: 10.5194/tc-2016-15.

22. Onyutha, C., H. Tabari, A. Rutkowska, P.N. Ogiramoi, and P. Willems, 2016. Comparison of different statistical downscaling methods for climate change rainfall projections over the Lake Victoria basin considering CMIP3 and CMIP5, Journal of Hydro-environment Research, 12: 31-45.

23. Peng, L., Q. Xiaobin, Y. Yi, M. Yuanyuan and J. Shuanglong, 2018. Assessment of the Performance of Three Dynamical Climate Downscaling Methods Using Different Land Surface Information over China, Atmosphere, 9: 101; doi:10.3390/ atmos9030101.

24. Yousefian, S., F. Gauthier, A. Morán-Guerrero, R.R. Richardson, H.J. Curran, N.J. Quinlan and R.F.D. Monaghan, 2015. Simplified Approach to the Prediction and Analysis of Temperature Inhomogeneity in Rapid Compression Machines, Energy Fuels, 29(12): 8216-8225.

25. StatSoft, Inc., 1984-2008. k-Nearest Neighbors". STATISTICA is a trademark of StatSoft, Inc.

26. https://www.researchgate.net/figure/Monthly-mean-temperature-and-rainfall-in-Cholistan-desert-during-2005-2009-Processed_fig2_43047420).

27. Abdul, R.G., H. Ishtiaq, U.Z.K. Qaiser and A.K. Mumtaz, 2013. Investigation of impact of environmental changes on precipitation pattern of Pakistan, Environ Monitoring Assessment, 185: 4897-4905.

28. Hassan I. and A.R. Ghumman, 2015. Application of Civil Engineering Softwares for Downscaling GCM Results, International Invention Journal of Engineering Science and Technology, 2(1): xxx-xxx.