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Assessing Long-Term Climate Trends of Bharathapuzha Basin, Kerala, India

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ABSTRACT

Hydrologic models are widely used as important tools in climate change impact studies. For operationalising the hydrologic models need proper bias correction in the climate data. This study aims at finding out the best suitable climate model by comparing downscaled re-analysis data on precipitation and temperature from five regional climate models (RCM's) derived from different Global Climate Models (GCM's) with observed data of Bharathapuzha river basin, Kerala, on the basis of the four statistical parameters (standard deviation, correlation coefficient, coefficient of variation and centered root mean square difference). The GFDL-CM3 RCM compared better with the observed data and hence, was used for further data analysis. Bias in precipitation was corrected using power transformation which corrects the mean and coefficient of variation (CV) of the observations. Since temperature is approximately normally distributed, it was corrected by fitting it to the mean and standard deviation of the observations. Comparison of the post-processed climate data to observed climate data was carried out. It is predicted that there may be a decrease of 4% to 7% in average annual rainfall during 2041-70 compared to the present day average values, whereas the decrease may be up to 10% to 15% during 2071-99. Based on the results obtained, the annual maximum and minimum temperatures are expected to increase in the future. The results obtained can be utilised in formulating future water resources management plans and for assessing the impact of climate change in the area using hydrologic models.

Key Words: CORDEX; Bias Correction; Regional Climate Model; RCP'

INTRODUCTION

The hydrology of an area is affected by the climate change effects, which will eventually influence the life of the people living there. The use of hydrologic models as important tools for climate change impact studies has become popular (Terrink et al. 2010, Raneesh and Thampi 2011 and Bocchiolla et al. 2011). To assess and simulate such potential hydrological climate change impacts, these hydrologic models require reliable meteorological variables for current and future climate conditions (Teutschbein et al. 2011). Climate change occurs at local scales, but the Global Climate Models (GCM's) predict changes occurring at a global scale. Changes in temperature and precipitation alter the climatic conditions and subsequently hydrological and watershed processes in the long run. The effects of changes due to climatic variability on hydrological responses have been extensively carried out at a watershed and river basin scales (Jha et al. 2004, Terrink et al. 2010, Hurkmans et al. 2010, Teng et al. 2015). Information at local scale is essential for assessing the impact of climate change on natural systems especially hydrologic systems and to formulate adaptation and mitigation strategies. Sensitivity of regional hydrology to variable climatic conditions was explained by Neiman and Elathir (2005). The ensemble of Regional Climate Model (RCM) simulations need to be used along with bias correction methods (Deque et al. 2007,Giorgi 2006, Teutschbein and Seibert 2010). The availability of such information at the regional or local scale is one of the major issues that climate scientists are facing.

A high resolution regional simulation model has been developed by the World Climate Research Programme (WCRP) and is made available to the scientific community, through the CORDEX (Co-ordinated Regional Downscaling Experiment) program (Giorgi et al. 2009). The simulations over South Asian region (CORDEX-SA) are available for different models and are available at the data portal of Centre for Climate Change Research of Indian Institute of Tropical Meteorology (IITM), Pune, India (Patwardhan et al. 2014). These models are of approximately 50 km × 50 km horizontal resolution and have been derived using the lateral boundary conditions from Coupled Model Intercomparison Project Phase 5 (CMIP5). CORDEX-SA provides the multi-model outputs for different scenario conditions and gives a range of uncertainty of model simulations. The present study was carried out using these multi-model simulations.

Population size, economic activity, lifestyle, energy use, land use patterns, technology and climate policy are the major anthropogenic factors which drive the greenhouse gas emissions. Four different Representative Concentration Pathways (RCPs) which describe 21st century emissions have been defined (IPCC 2014). The four scenarios are a low so-called peak-and-decay scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one with very high emissions scenario (RCP8.5). RCP 4.5 represents a stabilisation scenario, where the total radiative forcing is stabilised before 2100 and RCP 8.5 is characterised by increasing greenhouse gas emissions over time.

Uncertainties exist in the projected climate change data and these uncertainties must be taken into account when assessing the impacts, vulnerability and adaptation options. Many things pertaining to the working of the climate system are not clearly understood yet, and hence uncertainties arise because of the incorrect or incomplete description of key processes and feedbacks in the model. A problem with the use of regional climate model output directly for hydrological purposes is that there is significant variation between the computed precipitation and temperature from the observed precipitation and temperature (Frei et al. 2003). Bias is defined as the time independent component of the error and it arises because of several reasons. Also, the biases in the output subsequently influence other hydrologic processes and the errors in bias corrected precipitation are typically amplified in modelled runoff (Teng et al. 2015). Some form of pre-processing is needed to remove biases present in the computed climate output fields before they are used for impact assessment studies (Christensen et al. 2008, Dobor et al. 2015).

Though the state of Kerala is blessed with an annual average rainfall of 3000 mm, the flow in the rivers during summer has become meagre. The variations of different climatological parameters are highly location specific and hence studies need to be done in the regional level. Bharathapuzha basin in Kerala is representative of many river basins of India which face severe drought and dearth of water (CWRDM, 2004). Hence an attempt was done for studying the temperature and rainfall variability in future based on predicted scenarios for the Bharathapuzha river basin in Kerala.

MATERIALS AND METHODS

Study Area

Bharathapuzha is the second longest river in Kerala, lies between 10° 25' - 11° 25' N and 75° 50' - 76° 55' E, and is about 209 km long (Bijukumar et al. 2013). The geographical area of the river basin is around 6186 km^2 spread across two states of India, namely Kerala and Tamil Nadu with a share of 71% and 29% respectively. The river originates from the Annamalai hills in Western Ghats near Pollachi in Tamil Nadu and discharges into the Arabian sea at Ponnani. The climate of the basin is humid tropical climate (Guhathakurta and Rajeevan 2007).

Meteorological data including daily precipitation and maximum and minimum temperatures were collected from the observatories located in the area, for the period 1971-2005. This period was taken as the reference period. Two future scenarios were considered for the periods 2041-70 and 2071-99 in this study.

The outputs of Regional Climate Models (RCMs) were compared and an appropriate RCM was selected. Observed data of Bharathapuzha river basin on precipitation and temperature during the reference period and historical data from 5 regional climate models (RCA4, CCAM (CCSM4), CCAM (CNRM), CCAM (GFDL-CM3) and CCAM (MPI) derived from the GCM's EC-EARTH, CCSM4, CNRM-CM5, GFDL-CM3 and MPI-ESM-LR respectively, were compared. The similarity of the data sets with the observed data was evaluated on the basis of four statistical parameters (standard deviation, correlation coefficient, coefficient of variation and centred root mean square difference). Two emission scenarios pathways selected for the study, RCP 4.5 and RCP 8.5 roughly correspond to the Special Report on Emission Scenarios (SRES) B1 and A1F1 respectively by 2100.

Precipitation and temperature are the key drivers for the hydrological regimes and hence, both were bias corrected. In the simplest formulations of bias correction, only the changes in a specific statistical aspect (mean value or the variance) of the computed field are used. Leander and Buishand (2007) found that a relatively simple non-linear correction, adjusting both the biases in the mean and its variability, leads to better reproduction of observed extreme daily and multi-daily precipitation amounts than the commonly used linear scaling correction. This power law transformation method which corrects for the coefficient of variation (CV) and the mean of the precipitation values was used in this study to correct for bias in precipitation data. The most important statistics (coefficient of variation, mean and standard deviation of the model data) were matched with corresponding quantities computed from the observed values. The daily precipitation P is transformed to a corrected value P^* using

$$P^* = aP^b \qquad (1)$$

where a and b are constants.

Correction for temperature involves shifting and scaling to adjust the mean and the variance. The corrected daily temperature T* is given by:

$$T^* = \bar{T}_{obs} \quad \frac{\sigma(T_{obs})}{\sigma(T_{mod})}(T_{mod} - \bar{T}_{obs}) + (\bar{T}_{obs} - \bar{T}_{mod})$$

where T_{mod} is the uncorrected daily temperature from GFDL-CM3 model and T_{obs} is the observed daily temperature. The average over the considered period is denoted by an overbar in the equation and σ the standard deviation. The bias corrected data for both scenarios and the two future scenario periods were compared with the observed data.

RESULTS AND DISCUSSION

Comparison of Predicted Data with Observed Data

Observed data of Bharathapuzha river basin on precipitation and temperature during the reference period and historical data from the 5 regional climate models were compared. The results of comparison of the observed data to the historical data of five models on the basis of the four statistical parameters (Standard deviation, Correlation coefficient, coefficient of variation and centered root mean square difference) is given in Table 1.

Bias Correction of Predicted Data

Even though the RCM GFDL-CM3 showed a good ability to simulate the present climate over the basin, the presence of uncertainties on the future climate because of systematic bias needs to be corrected. The method reported by Leander and Buishand was used for bias correction. The bias correction coefficients a and b obtained for different months is plotted in Figure 1.

Table 1. Statistical comparison of different model estimates with observed data

	EC-Earth	CCSM4	CNRM	GFDL-CM3	MPI	Observed
Precipitation						
Standard deviation	49.69	56.50	58.52	73.43	56.87	181.46
Correlation coefficient	0.24	0.68	0.74	0.76	0.78	
Coeff. of variation	0.44	0.58	0.62	0.66	0.59	1.03
Centered RMSE	3.86	1.75	1.88	1.57	1.71	
Maximum Temperature						
Standard deviation	2.92	2.47	2.62	2.32	2. 50	2.39
Correlation coefficient	-0.14	0.72	0.69	0.76	0.73	
Coeff. of variation	0.10	0.09	0.10	0.09	0.09	0.07
Centered RMSE	3.86	1.75	1.88	1.57	1.71	
Minimum Temperature						
Standard deviation	1.52	1.72	1.82	1.71	1.82	1.09
Correlation coefficient	0.49	0.77	0.78	0.82	0.81	
Coeff. of variation	0.09	0.08	0.09	0.08	0.09	0.05
Centered RMSE	1.31	1.07	1.13	0.99	1.08	

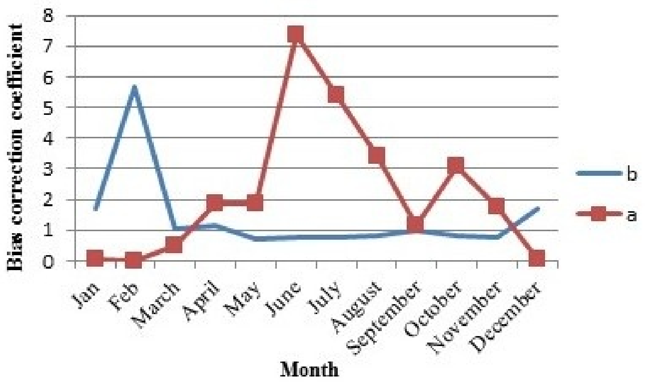

Figure 1. Comparison of transformation coefficients obtained during different months

The coefficient values determined by this method for each month were used to correct the precipitation and temperature data for the future periods. The model data for two emission scenarios RCP4.5 and RCP8.5 and two scenario periods 2041-70 and 2071-99 were corrected using this method. A marked improvement was achieved with nonlinear transformation, adjusting the mean as well as coefficient of variation of daily precipitation.

Impact on Precipitation

The monthly variation of the bias corrected data of precipitation for the two emission scenarios RCP4.5 and RCP8.5 for the periods 2041-70 and 2071-99 is shown in Figure 2. There is a consistent decrease in rainfall during all months except May, August, September, November and December for the two emission scenarios and for both future periods. After studying the rainfall trend during the southwest monsoon, it is observed that rainfall during the months of June and July showed a decrease whereas there was increase in rainfall during the months

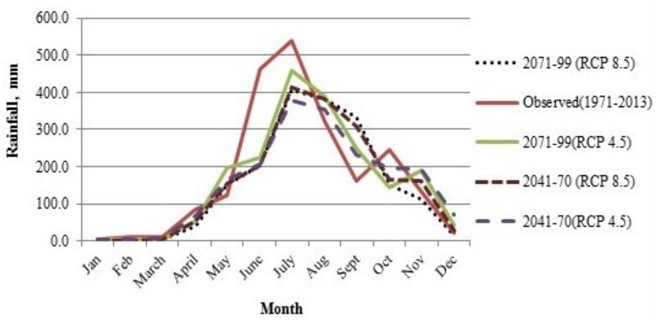

Figure 2. Comparison of present and bias corrected future scenario precipitation over Bharathapuzha basin

of August and September. A seasonal shift in the rainfall pattern is observed with a significant decrease in southwest monsoon (June to September) rainfall where as an increase in rainfall is observed during the northeast (October to November) monsoon period.

Based on the predictions done, there may be a decrease of 4% and 7% in average annual rainfall in the basin during 2041-70 under RCP4.5 and RCP8.5 respectively. It is also predicted that there may be a decrease of up to 10% and 15% in annual rainfall during 2071-99 during RCP4.5 and RCP8.5 respectively along with the seasonal shift.

Rainfall decline is more predominant in the months of June and July but not so in August and September. This decreasing trend in southwest monsoon rainfall in Kerala has been reported by other researchers (Guha-thakurta and Rajeevan 2007, Patwardhan et al. 2014, Raneesh and Thampi 2013).

Impact on Temperature

The monthly variation of the bias corrected data of maximum and minimum temperature for the two emission scenarios RCP4.5 and RCP8.5 for the periods 2041-70 and 2071-99 is shown in Figures 3 and 4 respectively. The annual maximum temperature in the basin may increase by 3-5 ºC (with an increase percentage of 8% to 9%) during 2041-70 under both scenarios. The increase in temperature under RCP4.5 during 2071-99 is almost to the same range, where as in the RCP8.5 scenario the increase was to the range of 4-8 ºC (8% to 15%) in the years 2071-99.

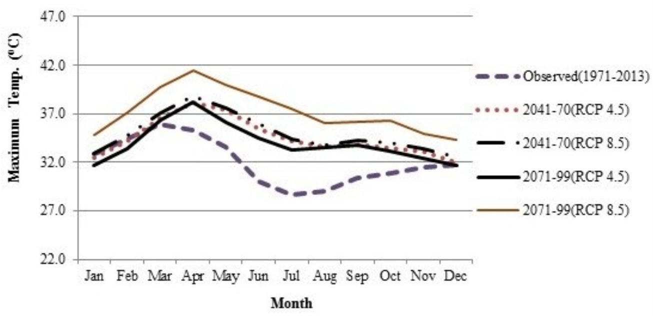

Figure 3. Comparison of present and bias corrected future scenario maximum temperature in Bharathapuzha basin

A similar increasing trend in temperature was also noted in the case of minimum temperature. The annual minimum temperature in the basin may also increase by

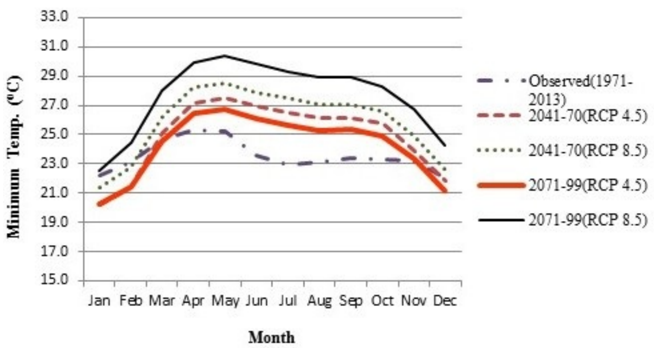

Figure 4. Comparison of present and bias corrected future scenario minimum temperature over Bharathapuzha basin

5% to 8% during 2041-70 under both RCPs, whereas the increase during 2071-99 under RCP8.5 may be up to 15%. The results obtained can be utilised in formulating future water resources management plans and for assessing the impact of climate change in the area using hydrologic models.

CONCLUSION

The probable changes of surface climate over Bharathapuzha river basin based on CORDEX simulations were analysed. Downscaled re-analysis data on precipitation and temperature from five regional climate models (RCM's) derived from different Global Climate Models (GCM's) were compared with observed data based on statistical parameters. GFDL-CM3 RCM compared better with the observed data and hence, future predicted data of the model was used for further data analysis after doing bias correction. The monthly variation of the bias corrected data of precipitation for the two emission scenarios (RCP4.5 and RCP8.5) for the periods 2041-70 and 2071-99 were compared with observed data, it is seen that there may be a consistent decrease in rainfall during all months except May, August, September, November and December. It is also predicted that there may be a decrease of 4% to 7% in average annual rainfall during 2041-70 whereas the decrease may be up to a tone of 10% to 15% during 2071-99. A seasonal shift in the rainfall pattern is observed with a significant decrease in southwest monsoon rainfall where as an increase in rainfall is observed during the northeast monsoon period. The annual maximum and minimum temperature in the basin is also predicted to increase in future under both scenarios. Results of simulation can be utilised in future for climate change impact assessment of hydrologic models in the area.

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REFERENCES

Bijukumar, A.S.; Philip, A.; Ali, S.; Sushama, and Raghavan, R. 2013. Fishes of River Bharathapuzha, Kerala, India: diversity, distribution, threats and conservation. Journal of Threatened Taxa 5(15): 4979–4993.

Bocchiola, D.; Diolaiuti, G.; Soncini A.; Mihalcea, C.; Mosconi, B.; Agata, C.D.; Mayer C.; Lambrecht, A.; Rosso, R. and Smiraglia, C. 2011. Prediction of future hydrological regimes in poorly gauged high altitude basins: the case study of the upper Indus, Pakistan. Hydrology and Earth System Sciences 15: 2059–2075. doi:10.5194/hess-15-2059-2011.

Christensen, J. H.; Boberg, F.; Christensen, O. B.; and LucasPicher, P. 2008. On the need for bias correction of regional climate change projections of temperature and precipitation. Geophysical Research Letters 35: L20709. doi:10.1029/2008gl035694.

CWRDM. 2004. Master Plan for Drought Mitigation in Palakkad District. CWRDM/WMD/04/2. CWRDM, Kozhokode. 123 pages.

Deque, M.; Rowell, D.P.; Lüthi, D.; Giorgi, F.; Christensen, J.H.; Rockel, B.; Jacob, D.; Kjellström, E.; De Castro, M. and Hurk, V. B. 2007. An inter comparison of regional climate simulations for Europe: assessing uncertainties in model projections. Climate Change 81: 53–70. http://dx.doi.org/10.1007/s10584-0069228-x.

Dobor, Z.; Barcza, T. H. A.; Havasi, F.; Horv, P.; Ittz and Bartholy, J. 2015. Bridging the gap between climate models and impact studies: the FORESEE Database. Geoscience data journal 2:1–11. doi: 10.1002/gdj3.22

Frei, C.; Christensen, J.H.; Deque, M.; Jacob, D.; Jones, R.G. 2003. Daily precipitation statistics in regional climate models: Evaluation and intercomparison for the European Alps. Journal of Geophysical Research 108 (D3), 4124. doi:10.1029/2002JD002287.

Giorgi, F. 2006. Regional climate modeling: status and perspectives. Journal de Physique IV 139:101–118. http://dx.doi.org/10.1051/jp4:2006139008.

Giorgi, F.; Jones, C. and Asrar, G.R. 2009. Addressing climate information needs at the regional level: the CORDEX framework. WMO Bulletin 58(3):175-182

Guhathakurta, P. and Rajeevan, M. 2007. Variabilities in the rainfall pattern over India. International Journal of Climatology 28: 1453-1469. 17.

Hurkmans, R.; Terink W, Uijlenhoet R, Torfs P, Jacob D. 2010. Changes in streamflow dynamics in the Rhine Basin under three high-resolution regional climate scenarios. Journal of Climate 23: 679-699.

IPCC (Intergovernmental Panel on Climate Change). 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, 151 pages.

Jha, M.; Z. Pan, E.S. Takle, and Gu, R. 2004. Impacts of climate change on stream flow in the Upper Mississippi River Basin: A regional climate model perspective, Journal of Geophysical Research 109, D09105, doi:10.1029/2003JD003686.

Leander, R. and Buishand, T. 2007. Resampling of regional climate model output for the simulation of extreme river flows. Journal of Hydrology 332: 487-496.

Niemann, J.D. and Eltahir, E.A.B. 2005. Sensitivity of regional hydrology to climate changes, with application to the Illinois River basin. Water Resources Research vol. 41, W07014, doi: 10.1029/2004WR003893

Patwardhan, S.; Kulkarni, A. and Kumar, K.K. 2014. Impact of Climate Change on the Characteristics of Indian Summer Monsoon Onset. International Journal of Atmospheric Sciences Vol. 201695, http://dx.doi.org/10.1155/2014/201695.

Raneesh, K.Y. and Thampi, S.G. 2011. A study on the impact of climate change on stream flow at the watershed scale in the humid tropics. Hydrological Sciences Journal 56: 946-965.

Raneesh, K.Y. and Thampi, S.G. 2013. Bias correction for RCM predictions of precipitation and temperature in the Chaliyar River Basin. Journal of Climatology and Weather Forecast 1(1):1-6.

Teng, J. N. J.; Potter, F. H. S.; Chiew, L.; Zhang, B.; Wang, J.; Vaze and Evans, J. P. 2015. How does bias correction of regional climate model precipitation affect modelled runoff? Hydrology and Earth System Sciences 19, 711–728. www.hydrol-earth-syst-sci.net/19/711/2015/ doi:10.5194/hess-19-711-2015.

Terink, W.; Hurkmans, R.T.W.L.; Torfs, P.J.J.F. and Uijlenhoet, R. 2010. Evaluation of a bias correction method applied to downscaled precipitation and temperature reanalysis data for the Rhine basin. Hydrology and Earth System Sciences 14: 687–703.

Teutschbein, C. and Seibert, J. 2010. Regional climate models for hydrological impact studies at the catchment scale: a review of recent modeling strategies. Geography Compass 4(7): 834–860. http://dx.doi.org/10.1111/j.17498198.2010.00357.x.

Teutschbein, C.; Wetterhall, F. and Seibert, J. 2011. Evaluation of Different Downscaling Techniques for Hydrological Climate-Change Impact Studies at the Catchment Scale. Climate Dynamics 37(9-10): 2087-2105. doi:10.1007/s00382-010-0979-8.

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