



Improved Hydrological Projections and Statistical Downscaling of Process-based Climate Models for the Upper Indus Basin

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Abstract

The availability of water resources plays an important role for the economy of a country. The nexus of Energy-Food-Water are interlinked and of particular importance in the uncertain environment of developing countries. In Pakistan, agriculture contributes 25 percent to the Gross Domestic Product. The Indus River contributes 44 percent of the available water to irrigation of crops and the ecosystem, and currently produces 5.112 Megawatt electricity, with the potential to produce 38.602 Megawatt electricity. This makes it important to investigate the status of water availability in the Upper Indus Basin under existing emission scenarios. In this study, the future availability of water is projected for the Indus River under the A2, B2, RCP4.5 and RCP8.5 emission scenarios.

The outputs of regional climate models (RCMs), providing regional climate for impact studies (PRECIS), Conformal-Cubic Atmospheric Model (CCAM) and Regional Climate Model (RegCM) are used as input data to the hydrological model to produce inflow projections upstream Tarbela Reservoir on the Indus River. Maximum temperature, minimum temperature and precipitation are investigated for possible climate change in the region. The hydrological model was calibrated for the 1995-2004 period and validated for the 1990-1994 period with almost 90% efficiencies. Increasing trends were noted in the river flow in the first half of the twenty first century under each emission scenarios, however, in the second half there is decline under some scenarios. Overall situation of water availability is better during future as compared to the baseline period (1960-1990 for A2 and B2 and 1976-2005 for RCPs) but there is water scarcity during some years. However, by proper management and optimum utilization of the available water, this scarcity can be resolved. A meta-analysis has been conducted to present a combined picture by combining the results from the individual outputs of the considered emission scenarios. Our meta-analysis shows higher confidence in RCPs projections as compared to the A2 and B2 scenarios.

Modelling and sensitivity analysis of river flow upstream Tarbela Reservoir has been accomplished by using linear and non-linear time series models and extreme value distributions. It was noted that seasonal Autoregressive Integrated Moving Average (SARIMA) models perform better. During extreme's modelling it was observed that more than one distribution can be used for analyzing river flow data depending on whether the interest is on lower order moments or higher order moments.

Different Global Climate/Circulation Models have different parameterization schemes, variation in boundary layers and different resolutions to model and forecast climate, therefore, relying on the projections from a single Global Climate Model may give deceptive results. This becomes more crucial when the study area has abrupt spatial variability in climate and consequently, selection of GCM(s) and uncertainty evaluations are important aspects in such an area. Posterior inclusion probability is used as model selection parameter under the Bayesian model averaging approach to select the best Global Climate/Circulation Model(s) among a set of competing models. Bayesian Model averaging is used to produce ensemble climate projections using the outputs from thirteen Global Circulation Models. In Bayesian model averaging, each model's assigned a weight equal to the posterior probability of being included in a regression model. Ensemble projection will increase the confidence as compared to single model's projections because it considers uncertainty inherent in the models.

The best models among thirteen Global climate models have not the same importance regarding maximum, minimum temperature and precipitation; however, some of these models are shared in the list of top five. In addition, different prior choices also have little influence on selection of GCMs. The ensemble projections and their 90% intervals almost covered the observed data. The ensemble projections have higher correlation with observed data than those of individual models output. Further, comparison of future projections using Bayesian model averaging shows that there are more changes under the RCP8.5; however, the projections under the RCP4.5 have more variability compared to that of RCP8.5. Prior to simulating the climatology, it is important to do a preliminary study and uncertainty analysis to choose a climate model for specific locations based on their climatic conditions.

Spatio-temporal dependence structure plays a pivotal role in understanding the meteorological characteristics of a watershed. This further affects the hydrological conditions and consequently will provide misleading results if it is not deemed properly. In Chapter 7 of this dissertation we modeled the dependence structure between climate variables including maximum, minimum temperature and precipitation in the Monsoon dominated zone of Pakistan. For modelling the dependence structure between temperature and precipitation at multiple sites, we utilized C-Vine, D-Vine and Student t-copula models. For temperature, multivariate mixture normal distributions and for precipitation gamma distributions have been used as marginals under the copula models. A comparison was made between C-Vine, D-Vine and Student t-copula with respect to observational and simulated spatial dependence structure to choose a better copula model for modelling the climate data.

The results show that all copula models performed well, there are only small differences in their performances. The copula models captured the patterns of spatial dependence structures between climate variables, however, t-copula has poor performance to reproducing the dependence structure with respect to magnitude. It is to note that important statistics of observed data have been closely approximated except maximum values for precipitation and minimum values for minimum temperature. Probability density functions of simulated data closely follow the pattern of observational data.