Abstract

The dynamics of hydrological systems are changing with the changing climate, which will affect energy and food security. Apart from added uncertainty in the hydrological systems, the changing climate is responsible for increased frequency and intensity of hydrological extremes with regional variations, as suggested by numerous studies. The assessment of these regional variations will help identify the vulnerable region(s) and monitor/mitigate hydrological extremes. However, studies for identifying vulnerable regions on fine-spatial resolution mostly lack in the Indian context. The primary objective of this thesis is to model the interaction between the meteorological and hydrological systems under the changing climate and utilize the developed modeling approach to analyze different types of hydrological extreme across India to identify the vulnerable areas.

In the first part of the thesis, the inter-relationships between the meteorological and hydrological variables (hydro-meteorological association) are modeled by formulating a hybrid Wavelet – Auto-Regressive model with eXogenous inputs (Wavelet-ARX) model. The model is utilized to predict the total monthly precipitation for different basins across India. The model revealed that the hydro-meteorological association is prominent at the wavelet component level. Additionally, using relative importance analysis of the inputs, major meteorological forcings for monthly precipitation are identified for different basins across India and the Indian mainland as a whole.

After identifying the meteorological forcings for precipitation, changes in observed daily precipitation (both mean and extreme characteristics) over India between 1930-1970 and 1971-2017 are analyzed. The locations exhibiting an increase in extreme precipitation magnitude are mostly lying in south India, however, most of the north, central and north-east India show a decrease in extreme precipitation magnitude. Analysis of Coordinated Regional Downscaling Experiment (CORDEX) data suggests that despite the pan-India increase in extreme precipitation magnitude, the change in south India will be significantly higher than in north India. Analysis of meteorological forcings affecting precipitation suggests that the primary reason for this contrast is the eastward shift in moisture flux over the Indian Ocean region, which is also validated by using reanalysis data.

These changes in precipitation extremes will affect other hydrological systems/extremes. However, CORDEX precipitation is expected to have bias, which is required to be corrected before any hydrological modeling. Most of the bias-correction schemes are not designed for zero-inflated variables like precipitation, and some of them ignore zero values. Hence, a stochastic copula-based bias-correction approach for zero-inflated variable like daily precipitation is formulated. The proposed approach outperformed the conventional bias-correction approach (Quatile Mapping) all over Indian mainland, despite varying climatology. The bias-corrected CORDEX precipitation is used in further analysis of other hydrological extremes.

In the next part of the thesis, different types of drought, another hydrological extreme, are analyzed for their temporal consequences. The hypothesis behind the temporal consequence of drought is based on continuous water transport in the hydrological cycle. A deficit in one part/component of the hydrological cycle should propagate to another part/component. For instance, prolonged meteorological drought with high evapotranspiration loss may evolve into soil moisture deficit causing agricultural drought, further evolving into hydrological drought. However, this propagation is not straight-forward and is affected by multiple geo-climatic and man-made factors. In this part of thesis, the temporal translation of drought is modeled at multi-resolution wavelet component level. The formulated models predicted the state of agricultural and hydrological drought, given the status of the predecessor drought in the Upper Mahanadi Basin, with satisfactory performance. The models performed marginally better for predicting agricultural drought as compared to hydrological drought. The status of future agricultural drought in basins across India is analyzed using bias-corrected precipitation in the developed model. In the future, central, north, and north-east India are more prone to agricultural drought compared to south India.

In the last part of the thesis, change in streamflow variability of three developed basins across India is assessed under the changing climate. Only some of the streamflow modeling approaches like HydroClimatic Conceptual Streamflow (HCCS) consider the climate change impact. However, the HCCS cannot model the effect of man-made structures built in the course of the river. Hence, the HCCS model is upgraded for developed basins by including an optional routing module for intervened sub-basin. The upgraded HCCS model runs differently for virgin and intervened sub-basin and can predict streamflow at any river section. Analysis of streamflow variability for the three basins suggests that the streamflow might not be adequate to fulfill community demand in the future.

Overall, studies in this thesis provide an insight into how hydrological variables and their extremes are going to be altered across India under changing climate. Results/developed datasets are expected to be useful to the community.

Keywords: Hydrological Extremes, Climate Change, Extreme Rainfall, Bias-Correction, Droughts, Streamflow, Multi-Resolution Wavelet Transform, Copula