Abstract

Detecting, quantifying, and modelling the effects of human-induced climate change in regional hydrology is important for studying the impacts of such changes on the water resources systems as well as for reliable future projections and policy making for adaptation. This thesis attempts to detect, attribute and model changes in hydrologic variables due to impacts of climate change. The presence of human-induced climate change signals in regional hydrology and in regional precipitation extremes is investigated through formal fingerprint-based detection and attribution analyses, developing necessary modifications for suitability in regional hydrologic impact assessment studies. Statistical modelling of hydroclimatic extremes is further carried out for analyzing the associations between such extremes and their physical drivers. Applications on detection of change in return levels of hydrologic extremes of floods and droughts are finally carried out for use in hydrologic designs.

A regional fingerprint-based D&A analysis is first conducted to analyze changes in observed monsoon precipitation and streamflow in the rain-fed Mahanadi River Basin in India, considering the variability across different climate models. This is achieved through the use of observations, several climate models run with controlled forcing's, a principal component analysis and regression based statistical downscaling technique, and a Genetic Programming-based rainfall-runoff model. It is found that the decreases in observed hydrologic variables in the Mahanadi River basin across the second half of the twentieth century lie outside the range that is expected from natural internal variability of climate alone, at 95% statistical confidence level, for most of the climate models considered. However, unequivocal attribution to human-induced climate change cannot be claimed across all the climate models and uncertainties in the detection procedure, arising out of various sources including the use of models, cannot be ruled out.

The problem of detection and attribution is particularly important for hydrologic extremes since the impacts of global climate change on extremes, through interactions with existing human and natural systems, can have significant effects on the society. Using the fingerprint-based method, the presence of human-induced climate change signal is investigated for changes in annual maximum one-day (RX1D) and five-day accumulated (RX5D) precipitation over India. A century-long fine-resolution observed record is used along with multiple climate model simulations corresponding to anthropogenic (ANT) and anthropogenic plus natural (ALL) forcings as well as pre-industrial control runs that are used to estimate internal climate variability. To address scale and physical processes mismatch between observed precipitation extremes and model simulations, a standardized probability-based index is defined, based on the annual indices. It is inferred from this study that the observed trends are unlikely to have resulted from natural climate variability alone, implying possible irreversible changes in the hydrologic cycle. However, the ANT and ALL model runs underestimate the trends in precipitation extremes. The large presence of noise coupled with poor model

performance for precipitation extremes at smaller spatial scales makes regional attribution difficult. At very high (95%) confidence, no signals are detected for RX1D, while for the RX5D and multivariate cases, only the ANT signal is detected. In general, the ALL signal is detected less robustly than the ANT signal.

Subsequently, theoretical developments in the statistical Extreme Value Theory (EVT) are explored for modelling of extreme rainfall characteristics such as intensity, duration, and frequency, at regional scales. Based on recent advancements in the EVT that allow incorporating non-stationarity in the parameters of distributions, trends in extreme rainfall characteristics over India are analyzed using a high-resolution daily gridded dataset. The goal is detection and modelling of changes in peak-over-threshold (POT) rainfall series because of each of the physically-based covariates, namely, global average surface air temperature which is an indicator of human-induced global warming, the El-Nino Southern Oscillation-index (ENSO-index) which is an indicator of large-scale natural climate variability and local temperature changes which are indicators of localized effects. Intensity, duration, and frequency of extreme rainfall exhibit non-stationarity due to different drivers and no spatially uniform pattern is observed in the changes in them across the country. At most of the locations, duration of extreme rainfall spells is found to be stationary, while non-stationary associations between intensity or frequency and local changes in temperature are detected at a large number of locations. The models developed are further used for rainfall frequency analysis to show changes in the 100-year extreme rainfall event. The findings indicate varying nature of extreme rainfall characteristics and their drivers and emphasize the necessity of a comprehensive framework to assess the resulting risks of precipitation induced flooding.

The insights gained using EVT are further explored to analyze non-stationary changes in return levels of floods and droughts – a problem of interest to the hydrologic community from a design point of view. Using EVT, answers are sought for the question of how long the historical hydrologic design magnitudes or return levels of floods and droughts will hold good. Non-stationary formulations of two of the most important approaches in the EVT are used, namely, the block maxima approach for floods in the Columbia River and the peak-over-threshold approach for droughts in the Colorado River. When future return levels are compared with those from observed naturalized streamflows, the time of detection is computed as the time at which significant differences exist between them, accounting for the associated uncertainties. For either of floods or droughts, no uniform pattern of changes in return levels is observed across all the projections. No uniform pattern of changes in return levels is observed across all the projections, though earlier detection is achieved for more frequent extremes.

The findings highlight the need for modifications in hydrologic designs for adaptation against the varying risk of such extremes.