Abstract

Snowmelt dynamics and the frequency and intensity of rain-on-snow (RoS) events are expected to change in response to climate variations due to changes in precipitation, increase in air temperature and subsequent changes in the snow occurrence. Therefore, there is a need to understand the circumstances under which RoS events produce runoff and how the main drivers affect snowmelt.

This dissertation thesis compiles various types of research at different spatial and temporal scales, including the experimental site study and regional and international multi-catchment research. Mountainous catchments located in Central Europe were selected for the studies. Particular attention was paid to changes in elevation, with a specific focus on areas within the rain-snow transition zones where large changes in snow storage, snow dynamics and RoS occurrence typically occur due to warming climate. Various methodological approaches were used in the research (Papers I-IV). In our experimental study (Paper I), we assessed forest structure as an important parameter that significantly influences the amount of radiation fluxes that consequently affect snowpack energy balance and snowmelt rates. In Papers II-IV, a conceptual hydrological HBV model was used to simulate runoff components. We then identified RoS days/events, evaluated trends and spatial and temporal changes in the RoS occurrence, and assessed the hydrological response resulting from these hydrological events using the data series simulated by the model. We also attributed changes in selected climate variables, particularly air temperature and precipitation, to simulated possible variations in RoS events in the future climate (Paper IV).

This research highlighted the different roles of shortwave and longwave radiation in different forest structures, as well as the influence of other components of the snowpack energy balance. The results presented in Paper I revealed that energy from rain might be very important when assessing snowmelt at daily and shorter temporal resolutions. Notable effects of gradual forest decay on snowmelt processes were also demonstrated in this study, showing a 50% increase in modeled snowmelt rates in the disturbed forest. Our elevation-based methods accounted for the fact that only a part of the catchment contributes to runoff during the specific RoS events due to the strong dependence of snowmelt on air temperature at specific elevations (Paper II). Analyses of the runoff response showed that most of the RoS events (82% in Paper II, 72% in Paper III) did not cause a significant increase in runoff, highlighting the importance of the snowpack which can often prevent extreme runoff even when a large amount of rain occurs (Paper II). Nevertheless, notable climate change-driven RoS changes were identified and were highly variable across regions, elevations, and within the cold season (Papers III and IV). A significant decrease in RoS days (up to 75%) was projected for some lower-elevation sites. An increase in the number of RoS days was limited to higher elevations and the coldest winter months (Papers III and IV). Our projections also suggested that the RoS contribution to annual runoff will be considerably reduced; from the current 10% to 2-4% for the warmest projections in Czechia, and from 18% to 5-9% in Switzerland (Paper IV).

Although the overall impact of RoS on runoff is expected to be lower in the future, extreme hydrological response and flooding triggered by RoS events can still pose a significant flood risk. Therefore, understanding snowmelt processes and RoS behavior is essential for improving snowmelt models, effective water resource management, drought and flood forecasting and risk mitigation, especially in the face of climate change.

Keywords: snowmelt, rain-on-snow events, runoff, rain-snow transition zone, climate change