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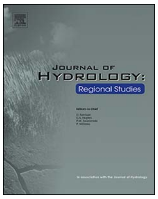

Impact of climate change on water resources of upper Kharun catchment in Chhattisgarh, India

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ABSTRACT

Study region: The Upper Kharun Catchment (UKC) is one of the most important, economically sound and highly populated watersheds of Chhattisgarh state in India. The inhabitants strongly depend on monsoon and are severely prone to water stress.

Study focus: This research aims to assess the impact of climate change on water balance components.

New hydrological insights for the region: The station-level bias-corrected PRECIS (Providing REgional Climates for Impact Studies) projections generally show increasing trends for annual rainfall and temperature. Hydrological simulations, performed by SWAT (Soil and Water Assessment Tool), indicate over-proportional runoff-rainfall and under-proportional percolation-rainfall relationships. Simulated annual discharge for 2020s will decrease by 2.9% on average (with a decrease of 25.9% for q1 to an increase by 23.6% for q14); for 2050s an average increase by 12.4% (17.6% decrease for q1 to 39.4% increase for q0); for 2080s an average increase of 39.5% (16.3% increase for q1 to an increase of 63.7% for q0). Respective ranges on percolation: for 2020s an average decrease by 0.8% (12.8% decrease for q1 to an increase of 8.7% for q14); for 2050s an average increase by 2.5% (10.3% decrease for q1 to 15.4% increase for q0); for 2080s an average increase by 7.5% (0.3% decrease for q1 to 13.7% increase for q0). These over- and under-proportional relationships indicate future enhancement of floods and question sufficiency of groundwater recharge.

Abbreviations: ARS, Agricultural Research Service; ZEF, Center for Development Research; CGCOST, Chhattisgarh Council of Science and Technology; GCM, General Circulation Model; DAAD, German Academic Exchange Service; IITM, Indian Institute of Tropical Meteorology; IMK-IFU, Institute of Meteorology and Climate Research; IPCC, Intergovernmental Panel on Climate Change; KIT, Karlsruhe Institute of Technology; NDVI, Normalized Difference Vegetation Index; PRECIS, Providing Regional Climates for Impact Studies; RCM, Regional Climate Model; SWAT, Soil and Water Assessment Tool; USDA, United States Department of Agriculture; UKC, Upper Kharun Catchment

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1. Introduction

According to the Intergovernmental Panel on Climate Change (IPCC AR5, 2014), the global mean temperature may increase up to 4 °C by 2100, and will severely affect the availability of water resources and the water demand across the world. The combined effect on the water supply and the demand side is expected to increase supply-demand gaps in tendency, which in turn is exacerbating the current challenges of water management.

Climate change will likely affect the surface and groundwater resources due to the expected changes in precipitation and evapotranspiration and the spatio-temporal distribution of these essential water balance components (Garner et al., 2017; Kirby et al., 2016; Bear et al., 1999). Increased intensities of precipitation will lead to higher rates of surface runoff, an increased risk of flood and decreased rates of groundwater recharge (Trenberth, 2011). A rise in temperature causes higher evapotranspiration, and, in turn, further enhances the demand for irrigation water, by far already the biggest water consumer under present conditions (Wang et al., 2012). In order to enable water management to cope with future challenges, the impact of climate change on the water balance needs to be quantified from regional to local (basin) scales. Research activities during the last decades increasingly address this issue.

General Circulation Models (GCMs) are often used for understanding the climate dynamics and projecting future climate change. They can provide input data for climate change impact studies on coarse horizontal scales (typically in the order of 100–300 km). This resolution, however, is still too coarse for any regional or local scale climate change impact studies. For obtaining the climate variables on regional scale, the projections of climate variables need be downscaled from the GCM resolution, utilizing either dynamical or statistical methods (IPCC, 2001). Downscaling by a dynamical approach using a regional climate model (RCM) delivers physically consistent climate variable (usually horizontal resolutions of 5–50 km). However, even high-resolution RCM output is still prone to systematic errors (biases) compared to point observations. Therefore, bias corrections are often applied to RCM simulations to study the impact of climate change on the hydrology of a basin by hydrological models.

In literature, several bias correction methodologies of different complexity have been developed (e.g., Sippel et al., 2016; Berg et al., 2012; Bordoy and Burlando, 2013; Haerter et al., 2011; Piani et al., 2010; Terink et al., 2010). All of them derive a transfer function between the large scale climate information from GCM (or RCM) scales and local scales. These transfer functions are then applied for the future climate projections under the assumption of stationary conditions. Current bias correction methods range from simple linear methods e.g. (Hay et al., 2000; Lenderink et al., 2007) via statistical distribution-based algorithms e.g. (Themeßl et al., 2011; Piani et al., 2010) towards Copulas, which are able to consider complex dependence structures and allow a dynamic correction (e.g., Laux et al., 2011; Mao et al., 2015).

Climate change is evident in Indian sub-continent. Numerous studies have predicted an increasing trend in annual surface temperature (Rupa Kumar et al., 1994; Pant et al., 1999; Singh and Sontakke, 2002; Subash and Sikka, 2014) and a significant decreasing/increasing trend in rainfall at different regional and local scale in India (Chaudhary and Abhyankar, 1979; Srivastava et al., 1998; Kumar et al., 2005; Kumar et al., 2010; Adarsh and Janga Reddy, 2015). Throughout the 21st century, it is projected that India and Southeast Asian countries will face more warming than the global mean and there will be greater variations in temperature, with higher warming rates in winter than in summer in India (Christensen et al., 2007). Bhadwal (2003) reports about an increased variability in summer monsoon precipitation, which may severely affect water resources and may cause drastic losses in the agricultural sector. Dash et al. (2007) reported of a decreasing trend in monsoon rainfall and an increasing trend in pre- and post-monsoon periods based on rainfall time series data from 1871 to 2002. Guhathakurta and Rajeevan (2008) performed monthly rainfall observations for linear trends across 36 climatological regions (representing different parts of India) during the period 1901–2003. They found significant decreases in monsoon rainfall for Jharkhand, Chhattisgarh and Kerala, whereas 8 regions showed significant increases.

A number of studies have assessed the impact of climate change projections on the hydrology of various regions throughout the world (e.g., Dragoni, 1998; Buffoni et al., 2002; Labat et al., 2004; Huntington, 2006; IPCC, 2007). However, process-based studies for catchments in India are scarce; some of them applied the Soil and Water Assessment Tool (SWAT) model (e.g., Kulkarni et al., 2014; Dhar and Mazumdar, 2009; Gosain et al., 2006).

India's freshwater resources are mainly generated by the southwest monsoon. As a consequence, fulfilling water requirements for agriculture, industries, domestic purposes, energy sectors and ecosystems depends on the monsoonal system. More than 80% of the annual rainfall occurs during the monsoon period i.e., between June-September (Kumar et al., 2010). Therefore, any change in the climate, in particular during the Indian southwest monsoon would have a significant impact on the agricultural production, which is already now under stress due to high population growth rates and problems related to water resources management (Mall et al., 2006). In spite of the uncertainties about the precise magnitude of climate change and its possible impacts (particularly on regional scales) measures must be taken to anticipate, prevent or minimize its adverse effects on water availability. Understanding the impacts of climate change (based on scenarios) on water balance components requires hydrological modeling and one such hydrological model used in this study is Soil and Water Assessment Tool (SWAT). A detailed description of SWAT model and the reasons for its selection in this study are discussed in methodology section (3.3).

The Upper Kharun Catchment (UKC) features considerable population growth and dynamic changes in irrigation practices (extension, intensification) for meeting the increasing food demand. It is expected that the impacts of future climate change will be severe in the UKC, because its economy largely depends on agriculture. In spite of the uncertainties about the precise magnitude of climate change and its possible impacts, particularly on regional and local scales, measures must be taken to prevent or minimize the impacts of climate change and mitigate and/or adapt to its adverse effects on surface and groundwater availability.

Current analyses do not sufficiently address the impact of climate change and their interactions with water resources in UKC. Hence, considering the above facts, the overall aim of this research is to investigate the potential impacts of climate change on the