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Assessment of future climate change impacts on hydrological behavior of Richmond River Catchment

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Abstract

This study evaluated the impacts of future climate change on the hydrological response of the Richmond River Catchment in New South Wales (NSW), Australia, using the conceptual rainfall-runoff modeling approach (the Hydrologiska Byrans Vattenbalansavdelning (HBV) model). Daily observations of rainfall, temperature, and streamflow and long-term monthly mean potential evapotranspiration from the meteorological and hydrological stations within the catchment for the period of 1972−2014 were used to run, calibrate, and validate the HBV model prior to the streamflow prediction. Future climate signals of rainfall and temperature were extracted from a multi-model ensemble of seven global climate models (GCMs) of the Coupled Model Intercomparison Project Phase 3 (CMIP3) with three regional climate scenarios, A2, A1B, and B1. The calibrated HBV model was then forced with the ensemble mean of the downscaled daily rainfall and temperature to simulate daily future runoff at the catchment outlet for the early part (2016−2043), middle part (2044−2071), and late part (2072−2099) of the 21st century. All scenarios during the future periods present decreasing tendencies in the annual mean streamflow ranging between 1% and 24.3% as compared with the observed period. For the maximum and minimum flows, all scenarios during the early, middle, and late parts of the century revealed significant declining tendencies in the annual mean maximum and minimum streamflows, ranging between 30% and 44.4% relative to the observed period. These findings can assist the water managers and the community of the Richmond River Catchment in managing the usage of future water resources in a more sustainable way.

Keywords: Climate change impact; Hydrological modeling; HBV model; GCMs; Richmond River Catchment; Australia

1. Introduction

Future climate changes resulting from anthropogenic global warming constitute a growing problem for most of the world. Climate change can directly affect the availability of future water resources, mainly through changes in precipitation and temperature, and secondarily through changes in vegetation water use (Cheng et al., 2014). Several parts of the world are suffering from water shortage as a result of climate change. Barron et al. (2011) reported that, since the mid-1970s, a noticeable climate shift in many parts of Australia has increased temperatures and reduced rainfall, resulting in a decline in the availability of local water resources. Numerous studies have confirmed this shift in the hydrological behavior across many local Australian catchments (Chiew et al., 1995, 2009; Hennessy et al., 2007; CSIRO, 2009; Bari et al., 2010; Silberstein et al., 2012; McFarlane et al., 2012; Islam et al., 2014; Al-Safi and Sarukkalige, 2017). Since 1997, south-eastern Australia has experienced a substantial rainfall reduction with below-average long-term trends (1958−1998), which has badly impacted the current water resources in the

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region (Timbal and Jones, 2008). According to the recent climate predictions, rainfall reduction trends are expected to continue in most parts of southeastern Australia as a result of global warming (Pittock, 2003; CSIRO and BOM, 2007). Consequently, the problems of below-average rainfall trends and the resulting streamflow decline require particular attention from the hydrological research community to establish a sustainable water resources management in the region and overcome the problem of water shortage.

The impacts of climate change on catchment hydrology can be estimated using hydrological modeling procedures. Climate change impact studies normally use the hydrological modeling approach to simulate the daily, monthly, and seasonal streamflow characteristics and predict the combined impact of climate change and other components on the hydrological status of local catchments (Chiew et al., 2009). Hydrological simulation at catchment scale usually requires the predictions of future climate conditions to simulate future streamflow at the catchment outlet. Future climate series of rainfall and temperature can be extracted from the analysis of global climate models (GCMs) at regional and global scales. According to Zorita and Storch (1999) and Solomon et al. (2007), GCMs represent a fair source for extracting the local and continental future climate signals. However, the resolution of climate series outputs resulting from GCMs is too coarse for direct use in catchment-scale hydrological modeling and needs to be downscaled before the simulation process (Fowler et al., 2007). Many hydrological studies have been conducted around the world to address the problem of climate change and its influence on future water demands (Kundzewicz et al., 2007; Bates et al., 2008; Praskievicz and Chang, 2009; Whitehead et al., 2009; Driessen et al., 2010). Charles et al. (2010) pointed out that a plethora of hydrological impact studies with a diversity of GCMs and warming scenarios have provided warnings of an inevitable decline in future rainfall and runoff trends in many parts of Australia, and the currently available water resources will probably not meet the future demands for the continent. In short, the concern of diminished water accessibility in many Australian regions needs to be carefully addressed in order to achieve consistent water management and to meet the future water demands in these areas.

The main objective of the present work was to assess future climate change impacts on the hydrological behavior of the Richmond River Catchment in New South Wales (NSW), Australia. The study involved the application of a conceptual lumped-parameters Hydrologiska Byrans Vattenbalansavdelning (HBV) model to perform the hydrological modeling. Global-scale future climate series (monthly mean outputs) were obtained from a multi-model ensemble of seven GCMs of the Coupled Model Intercomparison Project Phase 3 (CMIP3) for three climate scenarios: A2, B1, and A1B. The data came from the *Intragovernmental Panel on Climate Change Fourth Assessment Report* (IPCC-AR4) of the World Climate Research Programme (WCRP). According to the *Special Report on Emission Scenarios* (IPCC, 2000), the A2 scenario represents a very heterogeneous world with continuous population growth, slow economic and technological development, and the average CO_2 emission reaching 850 ppm by the end of this century. The B1 scenario is a convergent world with a global population that peaks by the middle of the 21st century and decreases afterwards with rapid economic and technological development. For the B1 scenario, the average concentration of CO_2 emission first increases at the same rate as it does in the A2 scenario, and then decreases near the mid-century, reaching 550 ppm (IPCC, 2000). Meanwhile, the A1B scenario represents a balanced status across all energy sources. The Long Ashton Research Station Weather Generator Version 5.5 (LARS-WG 5.5) was utilized in this study to extract the local-scale daily future rainfall and temperature from each of the seven GCMs' outputs. The ensemble mean of the downscaled seven GCMs was then derived and used as input data to force the HBV rainfall-runoff model to simulate the future daily streamflow at the Casino Gauging Station on the Richmond River. The outcomes of this research can deliver effective water management policies in the study area and help to overcome the problem of low water accessibility in the future.

2. Catchment description

The Richmond River Catchment, with an approximate area of 7000 km^2, is located in the distant northern part of NSW, Australia. It extends from the Border Ranges in the north to the Richmond Ranges in the west and south, with variable elevation, ranging from a few meters above sea level near the coastal floodplain to more than 1000 m above sea level near the Border Ranges. The area includes World Heritage sites and diverse geography, including rainforest, agricultural lands, and coastal estuaries. The catchment also comprises popular tourist places such as Ballina and supports a continuously growing population attracted by the region's coastal lifestyle. Furthermore, it holds extensive agricultural lands and wetlands, which consume high quantities of water. Therefore, the impact of future climate change on the local water resources in the catchment is highly significant to designing efficient and sustainable water management strategies in the area. In the present work, the area upstream the Casino Gauging Station was taken into consideration (Fig. 1), as it holds a continuous record of hydrometeorological data for a period of 43 years (1972−2014). It stretches between the latitudes of 28.00°S to 29.30°S and longitudes of 152.15°E to 153.15°E and encompasses an approximate drainage area of 1790 km^2. The catchment has Mediterranean climatic conditions with a relatively warm dry summer, approximately ranging between 27 °C and 30 °C, and a moderate winter ranging between 19 °C and 20 °C (CSIRO and BOM, 2007). The period between November and April includes the peak rainfall, which varies between 1350 and 1650 mm/year in the catchment's coastal areas, whereas the interior areas receive the lowest amount of precipitation, under 800 mm/year at Armidale (CSIRO and BOM, 2007).

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