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Flood projections within the Niger River Basin under future land use and climate change

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HIGHLIGHTS

- Modeling suggests increased floods of the Niger for future climate and land-use.
- Dry areas of the Sahelian and Sudanian region show a particularly high sensitivity.
- Projections for climate and land-use change result in diametrical impacts.
- Modeled land-use change effects were smaller than climatic effects.
- Ecohydrological modeling is a valuable tool to disentangle the impacts and drivers.

GRAPHICAL ABSTRACT

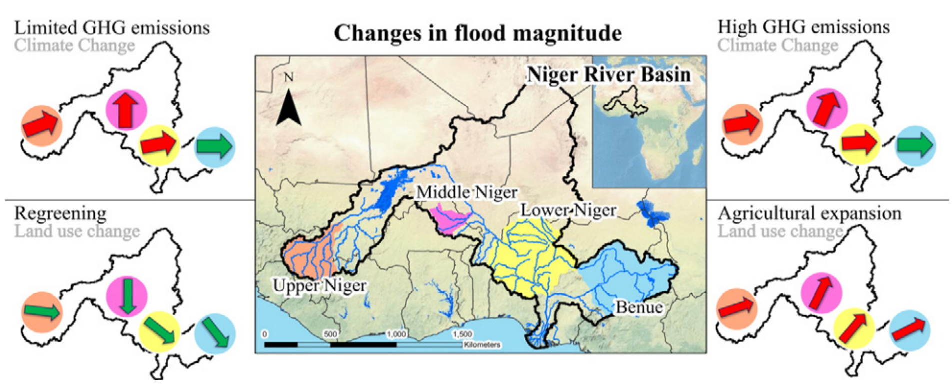

Fig. 1 Projected changes in flood magnitudes in the Niger River Basin between a near future period (2021–2050) and the base period (1976–2005 driven with 18 Regional Climate projections. The results of a limited emission (RCP 4.5) (top left) and a high emission (RCP 8.5) (top right) scenario are depicted as medians for each sub-region as arrow, with red for increasing and green for decreasing trends. The angle of the arrows are relative to the highest increase (Middle Niger limited emission: +30.4% ≙ 90°). For land use and land cover changes a regreening scenario (bottom left) and a business as usual scenario (bottom right) with strong agricultural expansion are depicted as changes from the mean of both climate scenarios. The angles of the arrows are relative to the highest decrease (Middle Niger regreening: −21.2% ≙ −90°).

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ABSTRACT

This study assesses future flood risk in the Niger River Basin (NRB), for the first time considering the simultaneous effects of both projected climate change and land use changes. For this purpose, an ecohydrological process-based model (SWIM) was set up and validated for past climate and land use dynamics of the entire NRB. Model runs for future flood risks were conducted with an ensemble of 18 climate models, 13 of them dynamically downscaled from the CORDEX Africa project and five statistically downscaled Earth System Models. Two climate and two land use change scenarios were used to cover a broad range of potential developments in the region. Two flood indicators (annual 90th percentile and the 20-year return flood) were used to assess the future

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flood risk for the Upper, Middle and Lower Niger as well as the Benue. The modeling results generally show increases of flood magnitudes when comparing a scenario period in the near future (2021–2050) with a base period (1976–2005). Land use effects are more uncertain, but trends and relative changes for the different catchments of the NRB seem robust. The dry areas of the Sahelian and Sudanian regions of the basin show a particularly high sensitivity to climatic and land use changes, with an alarming increase of flood magnitudes in parts. A scenario with continuing transformation of natural vegetation into agricultural land and urbanization intensifies the flood risk in all parts of the NRB, while a "regreening" scenario can reduce flood magnitudes to some extent. Yet, land use change effects were smaller when compared to the effects of climate change. In the face of an already existing adaptation deficit to catastrophic flooding in the region, the authors argue for a mix of adaptation and mitigation efforts in order to reduce the flood risk in the NRB.

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1. Introduction

Catastrophic flooding in the Niger River Basin (NRB) is increasingly perceived as a major threat, affecting people at a scale of millions (Aich et al., 2014a; Tarhule, 2005; Tschakert et al., 2010). Simultaneously increasing vulnerability, population growth and discharges in absolute terms were identified as reasons for this augmented flood risk (e.g. Aich et al., 2014a; Descroix et al., 2012; Di Baldassarre et al., 2010). A study of Jury (2013) for the entire Sub-Saharan African region found a general return to wetter conditions when looking at streamflows during the last decades, including the Niger River. More specifically for the Niger River, Tarhule et al. (2015) found increasing flows in all parts since the extremely dry period of the 1970s and 1980s. However, for most regions of the NRB, the water levels do not reach the levels observed before this dry period (e.g. Paturel et al., 2003). Hydrological projections for the West African region have recently been reviewed by Roudier et al. (2014). For the NRB, they found a tendency towards increasing river flows with a mean increase among all studies above 5%, yet with strong variability and high spatial heterogeneity. Roudier et al. (2014) concluded that a general agreement exists on the region's high vulnerability to climate change. However, this vulnerability analysis lacks projections of future floods. In addition, they state that there is an urgent need to take into account other factors influencing runoff, especially water consumption and land use changes, in order to acquire a more comprehensive flood risk assessment. Especially for the drier parts of the basin, in the Sahelian Zone, Amogu et al. (2010) and Descroix et al. (2013) and Séguis et al. (2004) identified Land Use Land Cover (LULC) change as the main driver of the increasing flood magnitudes. To assess these past changes, Aich et al. (2015) used a modeling attribution approach to quantify the share of LULC change and climatic variability responsible for the recent flood increases and concluded that LULC and climatic changes have approximately equal shares affecting the flood increase. Future flood projections for the NRB should therefore include both drivers, climate and LULC, in order to support the elaboration of sound flood mitigation and adaptation strategies.

The present study intends to assess this research gap by addressing the question of how flood magnitudes in the Niger basin will evolve under the influence of expected climatic and LULC changes. In order to answer this question, projected changes in LULC and climate dynamics are analyzed first and, based on these scenarios, a process-based, ecohydrological model is employed to assess future high flows. The number of modeling studies focusing on floods has increased in the recent past (Bellu et al., 2016; Chen et al., 2012; Kundzewicz et al., 2013; Vansteenkiste et al., 2014), as has the corresponding methodology for calibration and validation with its specific focus on high flows (Crochemore et al., 2015; Giuntoli et al., 2015; Hattermann et al., 2014; Kay et al., 2015; Vetter et al., 2015; Westerberg et al., 2011). The selected Soil and Water Integrated Model (SWIM) has proved to be generally able to simulate high flows (95th and 99th percentile discharges), flood events (10- and 30-year return periods) and even extreme floods (50-year return period) well ((Hattermann et al., 2011; Krysanova et al., 2015). However, regional characteristics and data scarcity can impede or hinder such exercises. In order to judge the model's efficiency for high flows and floods, a thorough validation for this specific feature of the flow regime is necessary. Crochemore et al. (2015) and Kay et al. (2015) recently provided measures for a sound validation of model ability which are also applied in this study.

The experimental setup includes two scenarios for the climate and LULC, respectively, which have been combined in the study. In addition to these four scenario combinations, stable LULC as of 2005 has also been combined with both climate scenarios, allowing a quantification of the impact of climate on its own. In total, this results in six different scenario combinations. Due to the huge extent and diversity of the study area, four different example regions of the NRB are analyzed (Fig. 1). The projections concentrate on the near-future period of 2021–2050, because of its specific relevance for adaptation measures. In particular, the near-future period considered for the analysis corresponds approximately to the occurrence of +2 °C global warming with respect to the pre-industrial period. The +2 °C global temperature increase is still considered a critical guidance for mitigation strategies, in order to avoid the most severe socio-economic impacts of climate change. The results are being discussed and interpreted, taking into account the uncertainties. Finally, implications for the management of future flood risks in the NRB are discussed.

2. Methodology

2.1. Study area

The NRB in West Africa covers an area of approximately 2,156,000 km^2, of which only approximately 1,270,000 km^2 contribute to the river discharge (Fig. 1). Guinea, Ivory Coast, Mali, Burkina Faso, Benin, Niger, Chad, Cameroon and Nigeria fall within this active basin. These countries are members of the Niger Basin Authority, an intergovernmental body which coordinates the management and development of the NRB's water resources, including the development and implementation of a joint flood policy.

The basin comprises sub-regions with very different hydrographic and/or climatic conditions: The Upper, Middle and Lower NRBs, the Benue and the Niger Delta all have individual topographic and drainage characteristics. This study focuses on exemplary catchments in all sub-regions but the Delta (Table 1). Discharge data from individual catchments in the Lower NRB was not available for the study. The drainage area of the analyzed gauge Lokoja in the Lower NRB comprises the other sub-regions. In the Upper NRB, headwaters of the Niger accumulate on low-altitude plateaus with annual precipitation of up to >1500 mm (all precipitation magnitudes derived from Hijmans et al., 2005). These headwaters flow into the Inner Niger Delta, a vast wetland. The catchment up to the gauging station Koulikoro (approximately 120,800 km^2) has been selected to represent the discharge in the Upper NRB.

The middle part is the driest sub-region of the NRB and ranges from the Inner Niger Delta to the border of Nigeria, including the Sahel and the northern part of the Sudan zone of the basin. The climate is arid to

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