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# Modeling the impact of climate change on water resources and soil erosion in a tropical catchment in Burkina Faso, West Africa

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## ABSTRACT

Soil erosion is recognized as one main reason for soil degradation in West Africa. However, predictions on the impact of climate change on soil erosion are rare for most West African countries including Burkina Faso.

This study assesses the impact of climate change on water resources and soil erosion in a small catchment ($126\ km^2$) in southwestern Burkina Faso. Climate data from an ensemble of six regional (RCM) and global (GCM) climate models were used to run the physically based spatially distributed hydrological and soil erosion model SHETRAN. The Representative Concentration Pathways (RCPs) 4.5 and 8.5 were selected as future climate scenarios.

Bias corrected precipitation and temperature required for the calculation of potential evapotranspiration were used as input for the SHETRAN model to simulate total discharge and specific suspended sediment yield (SSY). Discharge and SSY from simulations run with climate data were able to reproduce discharge and SSY from a simulation that used observed precipitation and temperature from the historical period (1971–2000).

The impact of climate change on hydrology and soil erosion was assessed by comparing the historical period with the future climate scenarios (2021–2050). Most of the used climate models predict an increase of temperature between 0.9 °C and 2.0 °C. The bias correction did not alter the climate change signal of temperature. Large uncertainties among the RCMs-GCMs exist regarding the climate change signal of future precipitation. Some climate models predict an increased (5.9%–36.5%) others a decreased (6.4%–10.9%) or mixed signal. The applied bias correction did not reverse the climate change signal in most cases but it influenced magnitude and timing of precipitation. The ensemble mean suggests an increased discharge between 19.5% (RCP 8.5) and 36.5% (RCP4.5) and an increased SSY of the same order. In general, the climate change signal and the corresponding discharge and SSY predictions are afflicted with large uncertainties. These uncertainties impede direct conclusions regarding future development of discharge and erosion. As a consequence of the mixed signals, potential increase and decrease of future discharge and soil erosion have to be incorporated in climate change adaption strategies.

## 1. Introduction

Hydrological and soil erosion processes are substantially driven by the atmosphere through rainfall and evapotranspiration. Rising temperatures are frequently predicted by regional (RCM) and global (GCM) climate models and are considered to change spatial and temporal rainfall pattern. Changing rainfall patterns and temperature have distinct effects on water resources and soil erosion (Field and Barros, 2014; Mullan et al., 2012; Nearing et al., 2004). The West African region is severely exposed to the effect of climate change due to the high vulnerability of the predominantly agricultural societies (Serdeczny et al., 2016). Analyzing the impact of climate change on hydrological and soil erosion processes is hampered by the lack of adequate data in terms of spatial and temporal resolution especially in a data scarce region as West Africa. Hydrological and soil erosion models are necessary to estimate past, present, and future development of water and soil resources. The modeled output can be used to provide guidance to decision makers regarding the implementation of climate change adaptation strategies (Beven, 2008; de Vente et al., 2013; Pandey et al., 2016). However, adaptation strategies necessary to mitigate the

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**Table 1**
Selected studies on the impact of climate change on water resources in West Africa (changed after Yira, 2016).

| Study | Location/seize | GCM/RCM | Scenario | Reference period | Future period | Precipitation change (%) | Discharge change (%) | SSY change (%) |
|---|---|---|---|---|---|---|---|---|
| Hiepe (2008) | Upper Oueme/14,500 $km^2$ | REMO-ECHAM5/MPI-OM | A1B, B1 | 1960–2000 | 2001–2050 | − 3 to − 8 | − 6 to − 23 | − 5 to − 27 |
| Itiveh and Bigg (2008) | Niger/1,471,000 $km^2$ | HadCM3, PCM, CGCM, CSIRO | A1, A2, B1, B2 | 1950–2000 | 2070s | Mixed trend | − 15 to + 20 | – |
| Kunstmann et al. (2008) | Volta Basin/94,000 $km^2$ | ECHAM4 | IS92a | 1991–2000 | 2030–2039 | − 20 to + 50 | − 10 < to > +20 | – |
| Ardoin-Bardin et al. (2009) | Sassandra, Ivory Coast/62,173 $km^2$ | HadCM3-A2 | – | 1971–1995 | 2036–2065 | 11.4 | 38 | – |
| Kasei et al. (2010) | Volta Basin/400,000 $km^2$ | MM5WRF and REMO-ECHAM5/MPI-OM | B1 | 1991–2000 and 1961–2000 | 2030–2039 and 2001–2050 | + 12 and − 6 | + 40 and − 5 | – |
| Ruelland et al. (2012) | Bani catchment, Mali/100,000 $km^2$ | MadCM3 and MPI-M | A2 | 1961–1990 | 2041–2070 | − 2 to − 10 | − 30 to − 46 | – |
| Oguntunde and Abiodun (2013) | Niger/2.27 Mio $km^2$ | RegCM3 | A1B | 1980–2000 | 2030–2050 | − 13 to + 32.6 | − 33 to + 35 | – |
| Cornelissen et al. (2013) | Térou Catchment, Benin/2344 $km^2$ | REMO-ECHAM5/MPI-OM | B1 | 2001–2010 | 2031–2049 | − 11 | − 11 | – |
| Aich et al. (2014) | Niger Basin/2,156,000 $km^2$ | HadGEM2-ES, IPSL-5 CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, NorESM1-M | RCP8.5 | 1970–1999 | 2070–2099 | Mixed trend | − 50 to + 50 | – |
| Bossa et al. (2014) | Ouémé catchment, Benin/ 49,256 $km^2$ | REMO-ECHAM5/MPI-OM | A1B | 2000–2009 | 2010–2029 | − 10 | − 18 | 0 |
| Mbaye et al. (2015) | Upper Senegal Basin, Senegal-Mali-Mauritania/218,000 $km^2$ | REMO-MPI-ESM-LR | RCP4.5 and RCP8.5 | 1971–2000 | 2071–2100 | Negative trend | Up to − 80 | – |

possible effects of climate change on hydrology, soil erosion and accordingly agriculture are challenging in the context of uncertain future climate change signals (Muerth et al., 2013).

The impact of climate change on the rainfall pattern and temperature in West Africa is difficult to assess due to differences between climate models regarding amplitude and direction of changing temperature and precipitation (Kasei et al., 2010; Niang et al., 2014). This is mainly attributed to the difficulties of simulating convective rainfalls and the rainfalls generated by the West African Monsoon (WAM) which is attributed to the incomplete knowledge of the involved processes, a lack of observations and the natural climate variability in the region (Cook, 2008; Druyan et al., 2010; Field and Barros, 2014; Klein et al., 2015; Niang et al., 2014). Consequently, climate model comparison studies report a large spread () of rainfall projections (Table 1). A trend towards the increase of frequency and magnitude of extreme precipitation events is debated and differs from region to region (Aguilar et al., 2009; Hounkpè et al., 2016; Mouhamed et al., 2013; New et al., 2006; Sylla et al., 2016b).

The effect of climate change on hydrology and soil erosion is difficult to assess using RCMs and GCMs due to their large uncertainty and biases regarding predicted rainfall patterns (Ehret et al., 2012; Hagemann et al., 2011; Muerth et al., 2013). Therefore, precipitation is frequently bias corrected to avoid unrealistic simulations and to enable correct impact assessment (Johnson and Sharma, 2015; Teutschbein and Seibert, 2012). Nevertheless, the application of bias correction is criticized because some assumptions of climate models are violated and the climate change signal may be changed (Ehret et al., 2012; Muerth et al., 2013). Because of this, a clear presentation and discussion of used data, differences between bias corrected and uncorrected results are necessary (Ehret et al., 2012). To account for the uncertainty in climate model predictions it is recommended to perform a multi-model assessment (Field and Barros, 2014). Therefore, in this study an ensemble of six RCMs-GCMs from the Coordinated Regional climate Downscaling Experiment project (CORDEX-Africa, http://www.cordex.org/) were used to evaluate the impact of climate change on hydrology and soil erosion in the Dano catchment.

Most of the available studies that used climate predictions for environmental models are focused on hydrological simulations. Studies that used climate change predictions of a multi-model ensemble as input to simulate the impact on hydrology and soil erosion are rare for the West African region (Li and Fang, 2016; Walling, 2009) but necessary as the effect of climate change on hydrology and soil erosion in this region is quite unclear (Niang et al., 2014). Mixed signals of discharge change are frequently reported by different studies in the region and may be attributed to the high uncertainty of precipitation projections for West Africa (Niang et al., 2014; Yira et al., 2017). A negative signal is reported to range from − 80% to − 11% (Table 1) for different climate models. Hiepe (2008) and Bossa et al. (2014) report negative signals for discharge in the Ouémé catchment in Benin as well as Ruelland et al. (2012) for the Bani catchment in Mali. Further negative discharge trends were found out by Mbaye et al. (2015) and Cornelissen et al. (2013). A positive trend is indicated by Ardoin-Bardin et al. (2009) for the discharge of the Sassandra catchment in Ivory Coast.

Among the listed studies only two deal with the impact of climate change on soil erosion. Both studies used the SWAT modeling system which is semi distributed and whose erosion module is based on the empirical MUSLE approach which does not consider gully and river bank erosion (Neitsch et al., 2011). Furthermore, the cited studies were conducted on a much larger scale ($\geq 2344\ km^2$).

Based on the described challenges, we aim to provide additional knowledge on the future impact of climate change on water and soil resources in West Africa with a focus on the Dano catchment in Burkina Faso. In this study we use the physically based spatially distributed hydrological and soil erosion model SHETRAN for the simulation of catchment discharge and soil erosion. SHETRAN was already tested in the Dano catchment (Op de Hipt et al., 2017) and was used to study the