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Modelling of flood hazard extent in data sparse areas: a case study of the Oti River basin, West Africa

Kossi Komi[a,*], Jeffrey Neal[b], Mark A. Trigg[c], Bernd Diekkrüger[d]

[a] West African Science Service on Climate Change and Adapted Land Use (WASCAL), University of Abomey-Calavi, Republic of Benin
[b] School of Geographical Sciences, University of Bristol, Bristol, United Kingdom (UK)
[c] School of Civil Engineering, University of Leeds, Leeds, LS2 9JT, United Kingdom (UK)
[d] Department of Geography, University of Bonn, Meckenheimer Allee 166, 53115 Bonn, Germany

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ABSTRACT

Study region: Terrain and hydrological data are scarce in many African countries. The coarse spatial resolution of freely available Shuttle Radar Topographic Mission elevation data and the absence of flow gauges on flood-prone reaches, such as the Oti River studied here, make flood inundation modelling challenging in West Africa.

Study focus: A flood modelling approach is developed here to simulate flood extent in data scarce regions. The methodology is based on a calibrated, distributed hydrological model for the whole basin to simulate the input discharges for a hydraulic model which is used to predict the flood extent for a 140 km reach of the Oti River.

New hydrological insight for the region: Good hydrological model calibration (Nash Sutcliffe coefficient: 0.87) and validation (Nash Sutcliffe coefficient: 0.94) results demonstrate that even with coarse scale (5 km) input data, it is possible to simulate the discharge along this region's rivers, and importantly with a distributed model, derive model flows at any ungauged location within basin. With a lack of surveyed channel bathymetry, modelling the flood was only possible with a parametrized sub-grid hydraulic model. Flood model fit results relative to the observed 2007 flood extent and extensive sensitivity testing shows that this fit (64%) is likely to be as good as is possible for this region, given the coarseness of the terrain digital elevation model.

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* Corresponding author at: WASCAL, University of Abomey-Calavi, Republic of Benin.
E-mail address: kossik81@yahoo.fr (K. Komi).

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1. Introduction

During the last two decades, many damaging floods have occurred in West Africa (Di Baldassarre et al., 2010). In September 2007, intense rainfall caused the worst floods this region had faced for many decades. The worst affected countries were Ghana, Burkina Faso and Togo with 56, 46 and 23 persons killed respectively (Tschakert et al., 2010). In order to improve the provision of flood hazard information in the study area and across West Africa generally, we require both hydrological and hydraulic models to first simulate the peak flows or high water level and then simulate inundation of this peak to identify flood-prone areas. Unfortunately, the lack of appropriate data availability (type and resolution) in the region prevents the application of standard engineering flood models. Recently, the research community have begun to tackle this challenge. For instance, when modelling flood inundation at the reach scale in data scarce environments, one of the difficulties is the coarse resolution of the freely available Digital Elevation Model (DEM) compared to the narrow width of the river channel. To tackle this issue, one solution developed by Neal et al. (2012) is to develop a sub-grid channel hydraulic model. Incorporated in the LISFLOOD-FP model, this approach provides a means of representing any river channel whose width is narrower than the spatial resolution of the topography data on low resolution terrain data where river geometry survey data are absent. This model was successfully validated for the Niger River in Mali (Neal et al., 2012). Other studies aiming at simulating flood inundation and propagation in a data sparse regions have also been carried out. Yan et al. (2014) use design floods derived from African envelope curves and a physical model chain to simulate flood extent with the LISFLOOD-FP model on the Blue Nile. The results of Yan et al. (2014) highlight the difficulties in modelling flood inundation extent in data scarce areas, particularly in generating realistic flood flows. Moreover, Sanyal et al. (2013) use the same raster-based hydrodynamic model (LISFLOOD-FP) to simulate flood inundation in a large ungauged river of the Damodar River in India. The authors highlighted the difficulties in performing hydrodynamic modelling in developing countries because of the lack of data but showed that even a few 'well-designed' field surveys can provide additional information to the free DEMs in order to improve flood routing. Although, the majority of these previous studies revealed the obstacles in modelling flood in developing countries, they do demonstrate the usefulness of the freely available DEM in accurately simulating flood dynamic in data scarce areas.

Given the absence of river geometry observations and the need to use globally available digital elevation data, the main objective of this study is to investigate the ability of the methods developed for data scarce areas to simulate the flood extent for the Oti River. This case study will further evaluate the sensitivity of inundation predictions to some key input variables that have not previously been examined in enough detail on the Oti River or elsewhere in Africa. Specifically, *(i)* how sensitive are the model results to the Manning's friction coefficient of the channel? *(ii)* How sensitive are the model results to river channel geometry parameters? And *(iii)* does changing floodplain DEM resolution have a substantial effect on water surface elevation and floodplain inundation simulation?

2. Study area and datasets

This study focuses on the Oti River basin which is a sub-basin of the Volta River basin of West Africa. In the present work, we consider approximately 140 km of the Oti River starting from the Mandouri gauging station (Fig. 1) and ending just downstream of Mango gauging station. Both gauges are currently abandoned.

The average width of the river in the study reach is 60 m and the model domain is between latitudes 10.20 and 10.84 degrees North and longitudes 0.02 and 1.15 degrees East. The study area is a rural catchment which is mainly characterized by agricultural land use with floodplain elevations from 103 m to 559 m over the model domain (Fig. 2a). The mean water level at Mango gauge station is about 5 m (Moniod et al., 1977).

In addition to the severe flood of 2007, the study area has experienced substantial events in the years 2010, 2008, 1999 and 1998. Further back in time, major floods also occurred in the Oti River basin on October 6, 1957 (10 m of water level at Mango gauge station) and September 21, 1962 with 10.64 m of water level at Mango (Moniod et al., 1977).