Journal of Hydrology: Regional Studies 4 (2015) 386–397

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

journal homepage: www.elsevier.com/locate/ejrh

Hydrological predictions for small ungauged watersheds in the Sudanian zone of the Volta basin in West Africa

Ibrahim B.[a,*], Wisser D.[b], Barry B.[a], Fowe T.[c], Aduna A.[a]

[a] West African Science Service on Climate Change and Adapted Land Use (WASCAL), Competence Center, 06 BP:9507 Ouagadougou, Burkina Faso
[b] Center for Development Research, University of Bonn, Bonn, Germany
[c] International Institute for Water and Environmental Engineering (2iE), 01 BP:594 Ouagadougou, Burkina Faso

ARTICLE INFO

Article history:
Received 7 February 2015
Received in revised form 8 July 2015
Accepted 17 July 2015
Available online 6 August 2015

Keywords:
Hydrological prediction
Hydrological modeling
GR2M
WatBal model
Volta basin
West
Africa

ABSTRACT

Study region: Hydrological observation networks in the West African region are not dense and reliable. Furthermore, the few available discharge data often present significant gaps. The Volta basin, the second largest transboundary basin in the region, is a typical example of a basin with inadequate hydrological networks.
Study focus: In this study, a prediction approach to determine monthly discharge in ungauged watersheds is developed. The approach is based on the calibration of two conceptual models for gauged watersheds and an estimation of models' parameters from the physical and climatic characteristics of the watersheds. The models' parameters were determined for each ungauged watershed through two different methods: the multiple linear regressions and the kriging method. The two methods were first validated on five gauged watersheds and then applied to the three ungauged watersheds.
New hydrological insights for the region: The application of the two hydrological models on the eight watersheds helped to produce relevant monthly runoff and to establish the annual hydrological balances from 1970 to 2000 for both gauged and ungauged watersheds. The developed method in this study could therefore help estimate runoff time series, which are of crucial importance when it comes to design hydraulic structures such as small reservoirs.

1. Introduction

Water resources management under continuous drought conditions (Karambiri et al., 2011; Le Barbé et al., 2002; Nicholson, 1981) in West Africa requires a reliable assessment of water availability (Acreman and Hollis, 1996; Leemhuis et al., 2009; Taylor et al., 2006). The assessments of water resources are performed through observations of hydrological processes (runoff, surface water, groundwater levels, and evapotranspiration) and hydrological modeling. However, the current hydrological network of the region is limited to a few stations representing large areas of thousands square kilometers (Schuol et al., 2008). Most of the stations of the national hydrological networks are installed at outlets of large basins. Hence, many small watersheds of less than one thousand square kilometers are not monitored. This lack of discharge data for most of the watersheds makes the assessment of water resources availability a difficult task for many areas in the region (Amisigo et al., 2008; Gyau-Boakye and Schultz, 1994; Taylor et al., 2006). However, with the development of the computing

* Corresponding author.

http://dx.doi.org/10.1016/j.ejrh.2015.07.007

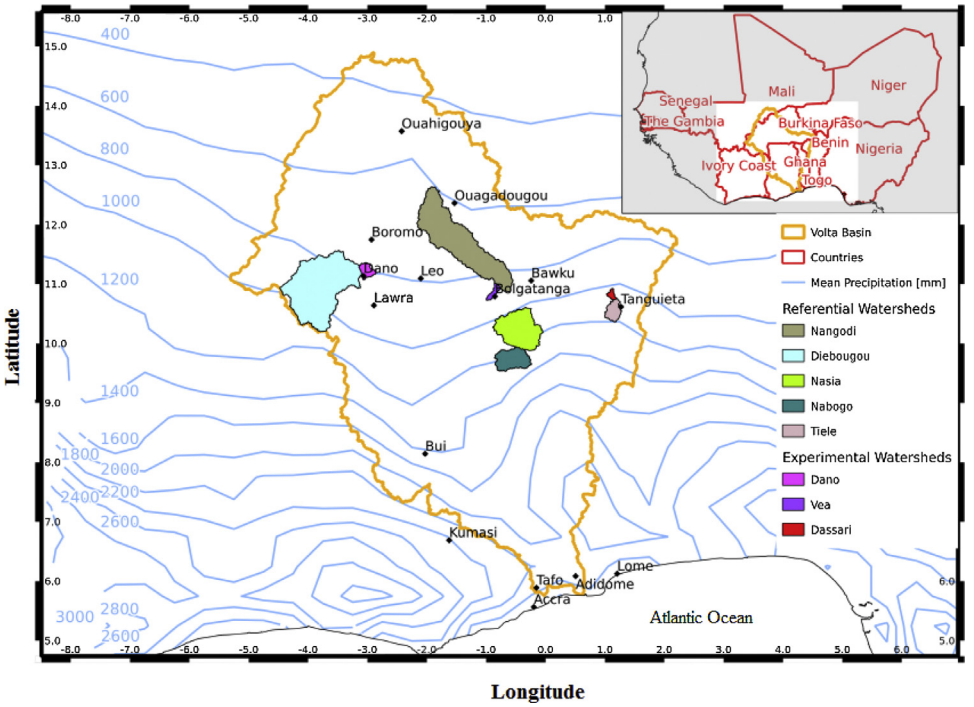

Fig. 1. Geographic position of the Volta basin in West Africa.
The isohyets represent the mean annual rainfall in mm/y for 1961–1990 from CRU data.

tools, the assessment of water resources with limited data could be addressed through hydrological modeling (Amisigo et al., 2008; Hongxia et al., 2009; Oudin et al., 2008; Schuol and Abbaspour, 2007). For many basins, hydrological models are implemented with conceptual climate/or physical parameters in order to reproduce the hydrological response of the basin based on water budget simulations (Parajka et al., 2013). Several methods have been developed for hydrological predictions in ungauged watersheds (Kim and Kaluarachchi, 2008). Typically, the predictions with hydrological models for ungauged watersheds are based on the determination of the conceptual parameters through regionalization approaches (Parajka et al., 2013). The regionalization approaches consist on transferring models' parameters from monitored watersheds to ungauged basins based on watersheds' physical (area, slope, land cover, etc.) and climatic (rainfall, potential evapotranspiration) characteristics. Oudin et al. (2008) made an assessment of three regionalization approaches (the regression-based approach, an approach based on physical similarity and the spatial proximity approach) for runoff prediction on ungauged watersheds using two conceptual hydrological models (GR4J and TOPMO) and 913 gauged watersheds in France. Hongxia et al. (2009) made also some predictions of runoff for 210 catchments in the south-east Australia from a set of three hydrological models. These studies have helped to determine relevant models parameters from two different regionalization methods: the spatial proximity method and the physical similarity method. On the other hand, Amisigo et al. (2008) made some monthly predictions of runoff for twelve Volta sub-basins (area ranging from 3000 to 134,000 km^2) with a NARMAX (non-linear auto regressive moving average with exogenous input) model. Many regionalization approaches for hydrological predictions in ungauged watersheds have been developed. However, Kim and Kaluarachchi (2008) concluded from an assessment of regionalization methods for six parameters of different models that the relevance of the predictions depends more on the hydrological model structure.

In this study, we used two different hydrological models, GR2 M (Mouelhi et al., 2006) and the water balance model (WatBal) developed by Yates (1997), to predict the three components of the hydrological balance (runoff, evapotranspiration and groundwater recharge) for three ungauged watersheds located in the Sudanian climate zone of the Volta basin in West Africa. The five gauged watersheds selected in the Volta basins around the three ungauged watersheds are considered as the reference watersheds.

2. Study area and datasets

The Volta basin is the second largest basin in West Africa with an area of about 400,000 km^2 (Taylor et al., 2006). It is a trans-boundary basin that crosses six countries: Benin, Burkina Faso, Ghana, Cote d'Ivoire, Mali and Togo (Fig. 1). The basin extends from the Sahelian zone (annual rainfall amount lower than 600 mm/y) in the North to the Guinean zone (annual rainfall amount higher than 1200 mm/y) in the south where the river drains into the Atlantic Ocean (Fig. 1).