Physics and Chemistry of the Earth 34 (2009) 225–235

Contents lists available at ScienceDirect

Physics and Chemistry of the Earth

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

Water balance estimation of a poorly gauged catchment in West Africa using dynamically downscaled meteorological fields and remote sensing information

Sven Wagner [a,*], Harald Kunstmann [a], A. Bárdossy [b], C. Conrad [c], R.R. Colditz [c]

[a] *Forschungszentrum Karlsruhe, Institute for Meteorology and Climate Research IMK-IFU, Kreuzeckbahnstraße 19, 82467 Garmisch-Partenkirchen, Germany*
[b] *Institute for Hydraulic Engineering, University of Stuttgart, Germany*
[c] *Department of Geography, University of Wuerzburg, Germany*

ARTICLE INFO

Article history:
Received 26 November 2007
Received in revised form 27 March 2008
Accepted 2 April 2008
Available online 20 April 2008

Keywords:
Joint meteorological–hydrological simulations
MM5
TRMM
MODIS
Decision support
Western Africa
Volta basin

ABSTRACT

Scientifically sound decisions in sustainable water management are usually based on hydrological modeling which can only be accomplished by meteorological driving information. Especially in regions with weak infrastructure this task is hampered by limited hydro-meteorological information in sufficient spatial and temporal resolution. We investigated three approaches to provide required meteorological fields driving the distributed hydrological model: the results of the mesoscale meteorological model MM5 which are available near real time, the TRMM product 3B42 available with approximately one month delay, and station data available with a delay of one year or more. The study site is the White Volta catchment in the semi-arid environment of West Africa. The results for 2004 show that the meteorological model is able to provide meteorological input data for near real time water balance estimations. In this study the TRMM product does not improve the simulation results. Besides missing important meteorological data, also gridded information on land surface properties (albedo, LAI, etc.) is usually difficult to obtain, albeit it is an essential input for distributed hydrological models. This information is commonly taken from "static" tables depending on the land use. Satellite remote sensing provides worldwide spatially detailed information on land surface properties which is particularly suitable for large regions in remote settings. Therefore the MODIS products for albedo and LAI were processed to annual time series including the identification and replacement of low quality observations by interpolation. The impact using MODIS data on the spatial distribution of water balance variables occurs mainly on local scale. The hydrological simulations using MODIS LAI and albedo values result in higher annual evapotranspiration and lower total discharge sums for 2004. Altogether it is concluded that hydrological decision support systems in regions with weak infrastructure can benefit significantly from the integration of atmospheric modeling and satellite-derived land surface data.

© 2008 Elsevier Ltd. All rights reserved.

1. Introduction

Sustainable decisions in water resources management require scientifically sound information on water availability, which includes the quantification of the spatial and temporal changes of water balance variables. Central support in hydrological decision making arises from hydrological modeling which, in turn, depends on meteorological input. In poorly gauged basins this task is hampered by the fact that only little hydro-meteorological information is available. Station data are only available with a considerable temporal delay and therefore unsuitable for specific questions in water resources management, where basin-wide near real time and short-term monitoring is required to support stakeholders and water management authorities in operational irrigation water supply or running hydro-power strategies. Therefore other data sources for the meteorological driving information for hydrological simulations have to be used. In this study three data sources, available with different temporal delay, are applied with a special focus on precipitation, which is the basic component of the water balance. For near real time estimations the hydrological simulations are driven by the output of the mesoscale meteorological model MM5. The integration of atmospheric sciences and hydrology for the development of decision support systems in sustainable water management was performed by Kunstmann et al. (2007) for the Volta basin. Furthermore, this technique was applied by, e.g. Marx (2007) and Kleinn (2002) for catchments in Europe. Using joint atmospheric–hydrological simulations, the water balance estimations are available within two days. The second data source is a product of the Tropical Rainfall Measuring Mission (TRMM) which is available with approximately one month delay. Station data are used as a third

* Corresponding author.
E-mail address: sven.wagner@imk.fzk.de (S. Wagner).

1474-7065/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.pce.2008.04.002

meteorological data source. Especially in regions with weak infrastructure, where no automatic data recorders are used, the delay can increase up to one year or more until data are collected, digitized, and become available to the public.

Independent of the meteorologically driving data, land surface properties, like albedo and leaf area index (LAI), are essential input data for distributed hydrological modeling. This information is usually taken from standard literature values and incorporated into hydrological modeling through tables depending on the land use. But standard literature values can be imprecise, especially in regions with few field measurements. In particular in such regions, satellite-based data can improve the available information on land surface properties. Space-borne remote sensing systems such as MODerate resolution Imaging Spectroradiometer (MODIS) acquire full global coverage within 1–2 days. A large suite of land surface properties is made available free of charge as composites of daily, 8-day, or 16-day periods with a spatial resolution of 1000 m or less. Remote sensing techniques in hydrological studies and water resources management for the quantification of surface parameters are used in several studies. For example, Chen et al. (2005) used remote sensing data to characterize the distributions of vegetation types and LAI. Sandholt et al. (2003) integrated vegetation dynamics from remote sensing data in a distributed hydrological model for the Senegal river basin. In this study the MODIS products of the leaf area index (LAI, MOD15A2) and albedo (MOD43B3) are imported into the hydrological model and simulation results using tabulated literature- and MODIS values are compared.

This work will show the application and performance of hydrological simulations driven first by different meteorological input data sources which are available with specific delays and second by different land surface data sources derived from standard literature and multi-temporal MODIS remote sensing data. The study site is the White Volta catchment in Western Africa and the simulations were exemplarily carried out for the year 2004.

2. The White Volta catchment

The study area is one of the main tributaries of the Volta basin, the White Volta catchment (94,000 km^2) situated upstream of Lake Volta in northern Ghana and Burkina Faso (Fig. 1). Lake Volta is one of the largest artificial lakes in the world, and hydropower generation at the Akosombo dam is the major energy source in Ghana. In the basin rain-fed agriculture is the major source of livelihood. Due to increasing demographic pressure, the demand for water, food production, and energy increases continuously, which intensifies the competition for water resources. However, not the precipitation rate itself but also its variability determines the living in this area.

In general, precipitation intensities and total annual rainfall show a strong inter-annual and inter-decadal variability in Western Africa (Hayward and Oguntoyinbo, 1987). Mean annual precipitation in the White Volta catchment ranges from less than 500 mm (North) to more than 1500 mm in the South, of which around 80% occurs between July and September. The spatial precipitation distribution in the White Volta catchment is characterized by a strong latitudinal dependence. Furthermore, small-scale rainfall variability is very high. Friesen (2003) estimated the coefficient of variation of 9×9 km^2 intra-scale rainfall variability to be between 0.25 and 0.4 in northern Ghana. The main agro-ecological zones of the White Volta catchment include the Sudan Savannah (400–1000 mm year^{-1} precipitation) in the northern and Guinea Savannah (around 1200 mm year^{-1} precipitation) in the southern part of the catchment, both with a rainy season from May to October. Climatologically, the White Volta catchment is situated in the semi-arid climate zone with a mean annual temperature between 27 and 36 °C. The mean annual potential evaporation ranges between 2500 mm in the North and 1500 mm in the South. Approximately 80% of the precipitation is lost to evapotranspiration during the rainy season (Oguntunde, 2004).

The topography of the White Volta catchment is very flat, in particular in the southern part (<0.1%). The main geological systems of the catchment are a Precambrian platform and a sedimentary layer. The predominant soil types are lixisols in the southern and arenosols in the northern part (VBRP, 2002). Since 1993, the natural flow regime of the White Volta catchment has been disturbed by a dam and hydropower generation in Bagré in southern Burkina Faso. Due to the strong dependence of downstream hydrographs on the management strategies of the Bagré dam, the simulated runoff was replaced by the measured runoff at the next gauging station in Yarugu to avoid the transmission of errors to the downstream catchments. For this reason and data availability,

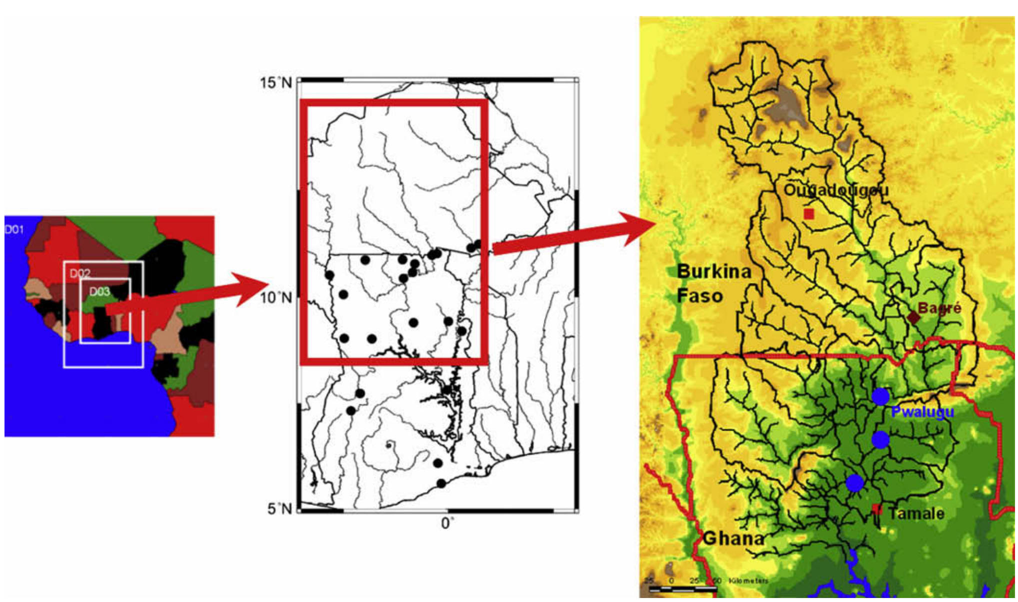

Fig. 1. Nesting strategy for the meteorological modeling (left), location of the 22 available meteorological stations (centre) and set-up of the White Volta catchment for the hydrological simulations (right).

Download English Version:

https://daneshyari.com/en/article/4721562

Download Persian Version:

https://daneshyari.com/article/4721562

Daneshyari.com