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Water balance of small reservoirs in the Volta basin: A case study of Boura reservoir in Burkina Faso

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ABSTRACT

Effective water resources development and management is crucial for sustainable economic growth and poverty reduction in many developing countries. In West Africa, large numbers of small reservoirs with volumes from 10^4 to 10^7 m^3 play a considerable role in maintaining and developing activities in remote areas and in providing irrigation water for agriculture and supply water for both livestock and people. The lack of baseline data on reservoir operation hinders their optimal management. The objective of this study was to enhance the knowledge of water resources of the small reservoirs in order to improve their management in the context of multiple uses. This study was carried out on a small reservoir located in Southern Burkina Faso which was monitored for 2 years (from April 2012 to April 2014). A simple approach based on the mass conservation equation was developed for estimating reservoir fluxes. For a short hydrological monitoring period, the rainfall, evaporation and reservoir filling patterns revealed a different hydrological balance of the reservoir between these 2 years. A decrease of 32% in the annual rainfall leads to a 50% reduction in the annual runoff coefficient. The results showed that about 60% of water was lost by evaporation, whereas less than 20% of water caught in the reservoir was withdrawn for various uses. The available water resources in the studied system are largely sufficient to satisfy the current demands. There are still possibilities for developing uses of water storage and for enhancing the irrigation potential of the small reservoir. This analysis indicates that small reservoirs are underperforming. The results highlighted that estimating water fluxes in a reservoir is a central task to support water management authorities and stakeholders in operational strategies for water supply and irrigated agriculture.

1. Introduction

In many sub-Saharan Africa countries, water resources are an important limiting constraint for economic growth and development. The West African landscape is today characterized by the presence of large numbers of small reservoirs. Most of the small reservoirs were built in the Sudano-Sahelian zone to overcome water shortage problems due to severe droughts of the 1970s and 1980s which had a dramatic effect on agriculture and livelihoods (Cecchi et al., 2009; Druyan, 2011; Venot and Krishnan, 2011). These hydraulic infrastructures have been identified as a promising option for water resources development in regions with few perennial rivers and where access to other water sources is difficult (de Fraiture et al., 2014; Venot and Cecchi, 2011). There are more than 1700 small reservoirs scattered across Burkina Faso and Northern Ghana in the Volta basin (Cecchi et al., 2009; Venot and Cecchi, 2011).

Small reservoirs are always in high demand among local communities, because reservoirs improve food security by providing irrigation water for agriculture during the dry season, by providing water for livestock and by enabling fish production, small enterprises and other beneficial uses (Fromageot et al., 2006; Faulkner et al., 2008; Boelee et al., 2009; Cecchi et al., 2009). Their implementation in remote areas is often linked to local initiatives and reflects the desire of inhabitants to have a perennial water reserve in the vicinity of their residences. More recently, governments and donors in West Africa have been promoting small reservoirs to enhance irrigated cereal production downstream from the reservoirs (Venot and Krishnan, 2011). However, the irrigation potential of small reservoirs is underutilized, despite substantial investments

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in infrastructure (de Fraiture et al., 2014). Small reservoirs have been largely neglected in hydrological research. They receive less attention and lack management, while large reservoirs have traditionally been managed and monitored (Mustapha, 2009).

Generally located in headwater of large rivers, small reservoirs do not have enough information to assess and to understand their hydrological processes (Adwubi et al., 2009; Liebe et al., 2009; Rakhmatullaev, 2010). A fundamental challenge in agricultural water reservoir management lies in understanding the reservoir operation and improving management to satisfy water demands without compromising the system. Therefore, estimating the water balance and its components is a necessary precondition for this challenge. Many of water balance components (seepage, runoff and evaporation) are difficult to estimate directly even at the local scale, and are often assumed to be in the residuals of the water balance equation (Kampf and Burges, 2010).

Furthermore, the upstream catchments of these reservoirs are poorly gauged or ungauged. There are no measurement campaigns of the flow in small rivers since the investigation in West Africa at the end of the 1970s on representative catchments. The lack of information about inflows (surface runoff) into these reservoirs and the lack of knowledge of water dynamics in small reservoirs impedes efficient decision making for planning and optimal management (Liebe et al., 2005; Peel and Blöschl, 2011; Salami and Nnadi, 2012). In order to better manage, the knowledge on evolution of water storage within these reservoirs is required.

One way to increase knowledge is to analyze water levels recorded in the reservoir using methods that require a minimum of field measurements (Dubreuil, 1966; FAO, 1996).

This paper is focused on the hydrological operating of a small reservoir located on a tributary of the Black Volta River (Mouhoun) in Southern Burkina Faso. The general objective of the study is to enhance the knowledge of water resources of these small reservoirs in order to improve their management in the context of multiple uses. Specifically, the paper aims to identify and estimate the current water fluxes (inflows and outflows) with associated errors in order to establish the water balance of the small reservoirs in a data scarce environment. The study is conducted during a short monitoring period of 2 years, from April 2012 to April 2014.

2. Materials and methods

2.1. Site description

The study was conducted on the small reservoir of Boura (latitude 11.05° and longitude −2.49°), named the Boura reservoir located in Center-West Burkina Faso near the Ghanaian border. The Boura dam, built on the Kabarvaro River (tributary of Black Volta River) in 1983, is the single perennial source of water in the Boura district that covers 1145 km^2. The reservoir was equipped with irrigation infrastructure in 1985. The main features of the Boura reservoir are shown in Table 1. At the local elevation of 100 m corresponding to full storage, the reservoir covers 200 ha, and the maximum depth from the dam crest is 6.25 m. ONBI ("*Office National des Barrages et de l'Irrigation*"), in 1982 (unpubl.), carried out a feasibility study of the Boura reservoir, and estimated its full supply capacity at 4.2 million cubic meters (MCM) and its dead storage at 0.34 MCM. Boura reservoir is replenished by direct rainfall and runoff inflows during the rainy season. Water of this reservoir is mainly used for irrigation, and also for livestock watering and for domestic uses. Moreover, the Boura reservoir is also used for fish breeding which is not a consumptive water use.

An irrigation scheme, named CORIKAB ("*Coopérative des Riziculteurs Kama Nadié de Boura*"), was developed in 1985 downstream of the dam, covering initially 40 ha and expanding afterward in 1993 and 2006, up to 78 ha. It is irrigated by a gravity canal and is used for rice cultivation during the dry and rainy seasons. Another irrigation scheme, named PIAME ("*Projet d'intensification agricole pour la maîtrise de l'eau*"), was started by FAO in 2009 on the right bank of the Boura reservoir. It covers 20 ha and is irrigated by the semi-Californian system with 2 motor-pumps. The semi-Californian irrigation system is a water distribution technology composed by a motor pump, a primary supply canal, a PVC pipe distribution and drainage network. In this system, water is pumped directly from the reservoir or from the primary supply canal and pushed back at the head of the scheme, from where its flows by gravity to irrigate the plots.

Table 1
Morphometric characteristics of the Boura dam and its contributing catchment.

Feature	Quantity
Full supply capacity [MCM]	4.2
Reservoir surface area [ha]	200
Length of dam wall [m]	750
Maximum height of dam wall [m]	6.25
Dam crest elevation [m]	101.25
Crest width [m]	3.5
Full supply level [m]	100
Spill length [m]	35
Minimum operational level [m]	97
Catchment area [km^2]	150
Maximum elevation [m]	349
Minimum elevation [m]	270
Global slope index [m km^{-1}]	4
Specific elevation [m]	37.24

Source: Adapted from ONBI (1982, unpubl.).

In the PIAME scheme, water is devoted to irrigate vegetable cropping in dry season. Finally, individual or "informal" plots on the reservoir banks are irrigated manually with buckets or using small motor-pumps. They cover about 10 ha and water is mainly used to irrigate vegetable cropping in the early dry season when the reservoir level is still high.

The catchment area of about 150 km^2 is located in a region defined by the latitude range 10.94–11.07° and longitude range −2.50° to −2.37°, lying between the Center-West Region of Burkina Faso and the Upper West Region of Ghana (Fig. 1). The geology of the catchment is composed of pedestal rocks of Precambrian D (antebirrimian) in the North and Precambrian of Dahomeyan in the South-East. The landscape is dominated by gently undulating plains with weak slopes. The vegetation of the catchment is part of the Sudanese savannah area with arboraceous and scrubby savannah vegetation.

The local climate condition is characterized by a single rainy season from May to October, with a peak rainfall measured in August, and a dry season from November to April. The basin receives an average annual rainfall of 920 mm but exhibits a strong inter-annual variability. The annual rainfall in Boura varies approximately from 572 mm to 1368 mm over the period from 1961 to 2010 (data provided by the meteorological service in Burkina Faso). The mean daily air temperatures throughout the year range from 21.5 °C to 34.3 °C, and annual potential evapotranspiration is approximately 1900 mm.

2.2. Hydrological monitoring devices

The hydrological variables such as rainfall, evaporation, and reservoir water level were measured with devices installed in March 2012 (Karambiri et al., 2012). Rainfall was monitored after each rain event while evaporation was measured twice each day (at 06:00 am and at 06:00 pm) using a rain gauge with a 400 cm^2 cone and an evaporation pan (Colorado pan adapted by ORSTOM) respectively. Water level was logged at intervals of 15 minutes