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Monitoring water turbidity and surface suspended sediment concentration of the Bagre Reservoir (Burkina Faso) using MODIS and field reflectance data

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ABSTRACT

Monitoring turbidity and Surface Suspended Sediment Concentration (SSSC) of inland waters is essential to address several important issues: erosion, sediment transport and deposition throughout watersheds, reservoir siltation, water pollution, human health risks, etc. This is especially important in regions with limited conventional monitoring capacities such as West Africa. In this study, we explore the use of Moderate Resolution Imaging Spectroradiometer data (MODIS, MOD09Q1 and MYD09Q1 products, red (R) and near infrared (NIR) bands) to monitor turbidity and SSSC for the Bagre Reservoir in Burkina Faso. High values of these parameters associated with high spatial and temporal variability potentially challenge the methodologies developed so far for less turbid waters. Field measurements (turbidity, SSSC, radiometry) are used to evaluate different radiometric indices. The NIR/R ratio is found to be the most suited to retrieve SSSC and turbidity for both in-situ spectoradiometer measurements and satellite reflectance from MODIS.

The spatio temporal variability of MODIS NIR/R together with rainfall estimated by the Tropical Rainforest Measuring Mission (TRMM) and altimetry data from Jason-2 is analyzed over the Bagre Reservoir for the 2000–2015 period. It is found that rain events of the early rainy season (February-March) through mid-rainy season (August) are decisive in triggering turbidity increase. Sediment transport is observed in the reservoir from upstream to downstream between June and September. Furthermore, a significant increase of 19% in turbidity values is observed between 2000 and 2015, mainly for the July to December period. It is especially well marked for August, with the central and downstream areas showing the largest increase. The most probable hypothesis to explain this evolution is a change in land use, and particularly an increase in the amount of bare soils, which enhances particle transport by runoff.

1. Introduction

Monitoring turbidity and Surface Suspended Sediment Concentration (SSSC) in inland waters is important for several reasons. Turbidity and SSSC are related to the suspended sediment fluxes in rivers lakes, and reservoirs, and can help monitoring the sediment discharge, and more generally the sediment budget within catchments, seasonal variability and evolution over time. In turn, the sediment budget is controlling the silting of the dams, which impacts the sustainability of hydroelectric structures and the supply of water for treatment plants. SSSC in inland waters also contributes to pollution and public health issues. Indeed, a significant correlation exists between the concentration of parasites and bacteria and several water quality parameters including SSSC and turbidity (Santé Canada and Ottawa, 2004; Randall et al., 2006). Suspended particles can carry viruses and bacteria pathogenic to humans (Brock, 1966; Stotzky, 1966) and foster their development (Galès and Baleux, 1992; Palmateer et al., 1993; Santé Canada and Ottawa, 2004). High SSSC and turbidity can therefore be considered as a vector of microbiological contaminants which cause diarrheal diseases.

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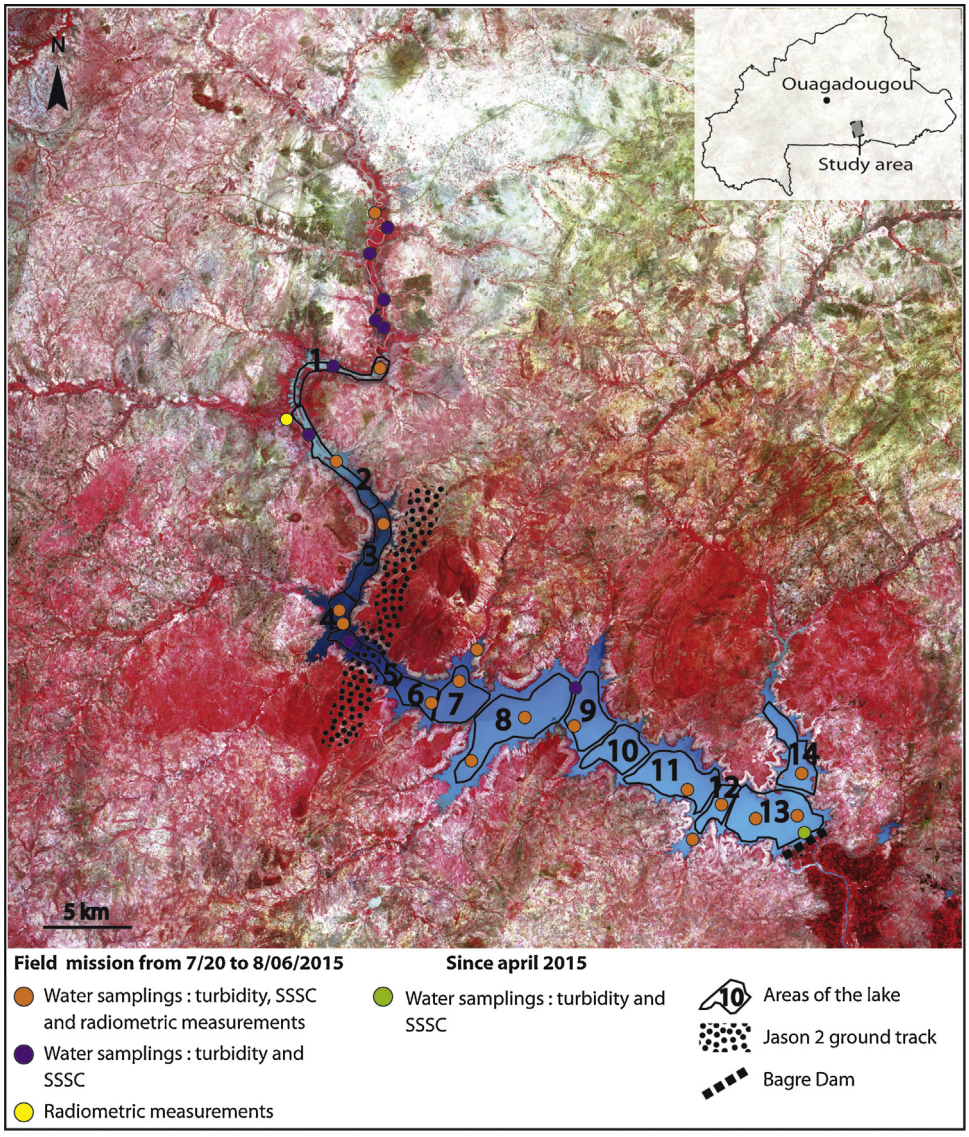

Fig. 1. Location of water samples, radiometric measurements and Jason-2 ground track in the Bagre Reservoir. Source: SPOT5 (SPOT5 TAKE5 program, ESA)

Water turbidity and SCCC in lakes or reservoirs may evolve through time, for instance in response to land use changes, modification of soil erosion, transport and deposition over the watershed, as well as exceptional rainfall events.

The quality of in-situ monitoring networks depends on the number of sampling stations, their spatial representativeness and the frequency of the measurements. In many regions of the world, monitoring networks are decreasing (Van der Bliek et al., 2014), and in some regions, such as West Africa, they are very poor or non-existent.

The Surface Suspended Sediments (SSS) absorb and scatter light, thereby affecting the spectral response of surface waters. Turbidity refers to optical properties of water and has been shown to impact water reflectance in the visible and near-infrared domain. In that context, remote sensing may be a solution in mitigating the data gaps or lack of in-situ network in many areas worldwide.

The "water color" remote sensing community was historically focused on ocean waters (Morel and Prieur, 1977; Morel and Gentili, 1996; Morel et al., 2007; Nechad et al., 2010; Neukermans et al., 2012) or coastal areas (Babin et al., 2003; Hu et al., 2004; Miller and McKee, 2004; Chen et al., 2007; Snyder et al., 2008; Doxaran et al., 2009; Petus et al., 2010; Barnes et al., 2014; Gernez et al., 2015). However, monitoring continental turbid waters by remote sensing is increasingly addressed (Kirk, 1976; Whitlock et al., 1981; Wang et al., 2004; Ma and Dai, 2005; Knight and Voth, 2012; Costa et al., 2013; Martinez et al., 2015; Moreno-Madrinán et al., 2015) as results of the environmental challenges listed above. Recent works show that medium resolution sensing imagery (like the Moderate Resolution Imaging Spectroradiometer – MODIS) can be efficiently used to monitor suspended sediments in large rivers (Martinez et al., 2009; Wang and Lu, 2010) and lakes (Wu et al., 2013). Martinez et al. (2009) found robust empirical relationships between suspended particulate matter and surface reflectance when matching MODIS 250 m images and field samples. Espinoza Villar et al. (2012) integrated satellite data and field data for monitoring tributaries of the Amazon River in Peru, and found that MODIS images could be used to study the SSSC and, combined to river discharge data, to assess the sediment discharge. However, the African continent remains very poorly studied. An exception is the work by Kaba et al. (2014) on the Tana Lake, who analyzed the relationships between the NIR reflectance (from MODIS images, 250 m) and total suspended solids (ranging from 10 mg/l to 30 mg/l), turbidity (rang-