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Analysis of hydrological variability over the Volta river basin using in-situ data and satellite observations

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ABSTRACT

By combining satellite altimetry with Gravity Recovery and Climate Experiment derived terrestrial water storage-TWS (2002–2014), this study used a two-step procedure based on spherical harmonic synthesis and statistical decomposition to support the understanding of the Volta basin's natural hydrology and its freshwater systems. Results indicate that Lake Volta contributed 41.6% to the observed increase in TWS over the basin during the 2002–2014 period. The statistical decomposition of TWS over the basin (after removing the Lake's water storage) resulted in a statistically significant ($\alpha = 0.05$) loss of 59.5 ± 8.5 mm/yr of TWS in the lower Volta region of the basin between 2007 and 2011. This trend is attributed to a base flow recession resulting from the negative trends in precipitation around the lower Volta (2002–2014) and limited river flows of the Volta river system. While it also coincides with observed decline in net precipitation (−15 mm/yr), the long dry periods in the basin (2001–2007) also contributed to this storage depletion. The Lake Volta shows sensitivity to incoming flows of the Volta river system with a lag spanning between less than one and up to two years. In addition to this, a 4–5 year cycle in the clustering of dry and wet periods resulting from the impact of climate variability on the basin was noticed.

1. Introduction

Lake Volta, one of the highly esteemed projects from the period of Africa's decolonisation, is the largest man-made reservoir by surface area in the world, covering a total area of approximately 8500 km^2. This Lake, which was built in 1964, has an estimated capacity of 150 km^3 with an installed hydropower generation capacity of about 912 MW (e.g., Owusu et al., 2008; Gyau-Boakye, 2001). Besides being one of the most important surface water in West Africa, the Lake, which is formed by the Akosombo dam in Ghana, is a symbol of high socio-economic importance and progress in the region, and remains a major source of livelihood and hydro-power to approximately 20 million people whose livelihood depends on the Volta river basin (hereafter the Volta basin, Fig. 1).

The impact of extreme climatic conditions on the Lake is a timely topical research issue of public-policy interest due to its implications on the people and local economy. For instance, Ghana suffered power rationing during the hydrological drought years of 1983, 1998, and 2006, leading to shortfalls in the production of goods, unemployment, and reduced gross domestic product (see, e.g., Bekoe and Logah, 2013). Apparently, in the wake of global climate change, the impacts of extreme climate conditions on Lake Volta

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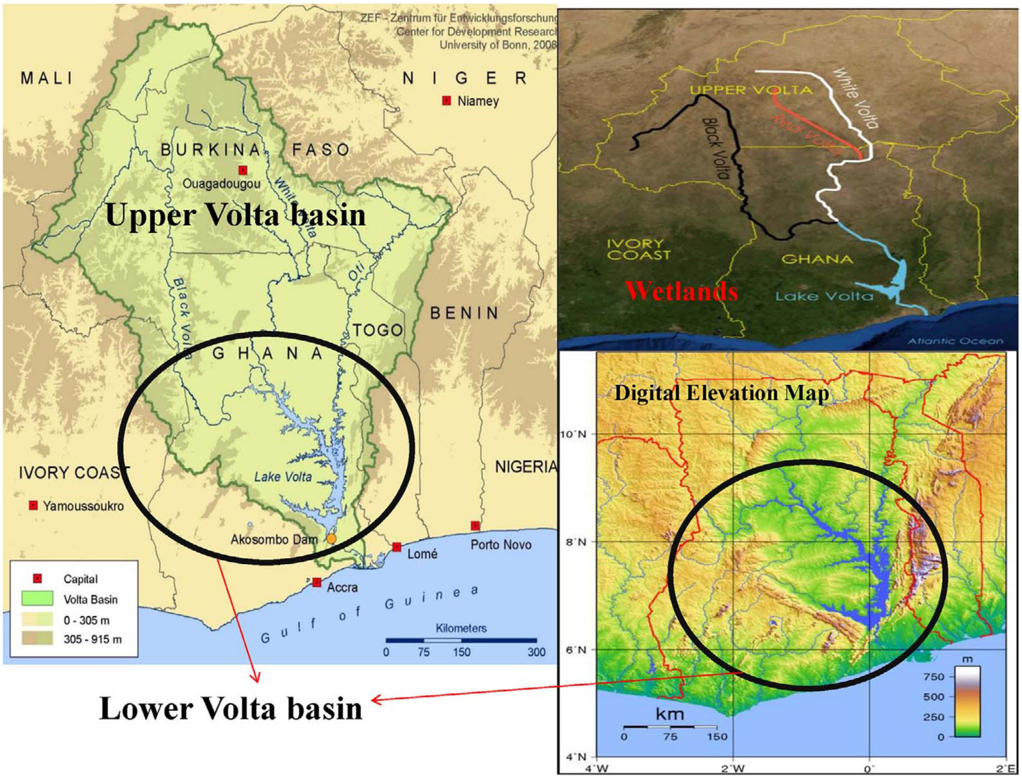

Fig. 1. Study area showing the Volta river basin. The riparian countries (Ghana, Togo, Benin, Burkina Faso, Mali, and Ivory Coast) of the basin are also indicated. The Lake Volta, the Volta river system (White Volta, Black Volta, and Oti rivers), and the location of the Akosombo dam have also been indicated. Original maps adapted from http://www.21stcentech.com/wp-content/uploads/2013/12/Volta-River-basin.jpg and https://en.wikipedia.org/wiki/Geography-of-Ghana.

could largely limit the generation of hydro-electric power in future, leading to untold hardship in the region. The low impoundment levels of Akosombo dam and the decline in Lake Volta's water level, owing to negative trends in rainfall (e.g., Owusu et al., 2008) are arguably indications of the region's vulnerability to the impacts of climate variability.

In the Volta basin, analysis of long term historical hydro-climatic conditions (1901–2002) have shown that large changes in water budget quantities (precipitation, river discharge, and evapotranspiration) have occurred (Oguntunde and Friesen, 2006). These changes, which impact on the local climate through feedback mechanisms and land atmosphere interactions, have the potentials of restricting the freshwater systems of the basin. As reported in earlier studies (e.g., Friesen et al., 2005; Andreini et al., 2000), the marked variability in rainfall and stream flow records in the pre and post construction periods of the Akosombo dam revealed the impact of damming on the basin. This inadvertently resulted in the non-linearity of hydrological processes, thereby complicating our understanding of the hydrological variability of the basin. One of such instance in the basin, is the observed decline in precipitation, which was inconsistent with observed increase in terrestrial water storage (TWS, i.e., the sum total of surface waters, soil moisture, and groundwater) derived from Gravity Recovery and Climate Experiment (GRACE, Tapley et al., 2004) during the 2003–2012 period (e.g., Ahmed et al., 2014; Moore and Williams, 2014). These observed trends in GRACE-derived TWS changes over the basin have been attributed to the impact of water ponding in the Akosombo dam (e.g., Ferreira and Asiah, 2015; Moore and Williams, 2014; Ahmed et al., 2014). Such impacts do have implications in water budget assessment and quantifying the impact of climate variability on the Volta basin's hydrology.

Although in some studies within the mainstream of water resources, droughts and GRACE-TWS have been reported in the Volta basin (e.g., Ndehedehe et al., 2016c; Bekoe and Logah, 2013; Ferreira et al., 2012; Owusu and Waylen, 2013; Kasei et al., 2010; Owusu et al., 2008; Oguntunde and Friesen, 2006; Friesen et al., 2005; Andreini et al., 2000, 2002; Giesen et al., 2001), the hydrological variability of the basin is largely unreported. In fact, the lack of clear perspectives regarding the impact of human activities on the hydrological changes of the basin have been partly and loosely attributed to increase in surface water storage in the reservoirs and decrease in soil moisture storage (e.g., Friesen et al., 2005). Although Giesen et al. (2010) argues that the causes of climate change in the basin remains unclear, however, the lack of in-situ data and existing data gaps in stream flow records of the region have particularly limited our understanding of the impacts of climate variability and the natural hydrology of the basin. The use of a non-physical based hydrological model to study the water balance of the basin as reported in Andreini et al. (2000) could be restricted as stream flow and rainfall could be affected by a number of factors, e.g., climate variability and human activities (e.g., water abstraction, land use change) amongst others (e.g., Bekoe and Logah, 2013; Owusu et al., 2008). Given the economic importance of the Lake Volta in hydropower generation for the southern catchment of the basin (Ghana) and the freshwater of the Volta river system for agricultural purposes in Burkina Faso, it is pertinent to understand the hydrological variability of the Volta