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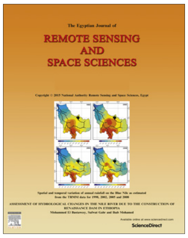

RESEARCH PAPER

Assessment of hydrological changes in the Nile River due to the construction of Renaissance Dam in Ethiopia

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Abstract This paper assesses impact of the Renaissance Dam on Ethiopia; on the Nile discharge ultimately reaches Egypt downstream. The Landsat-8 satellite images of 2013 were obtained and interpreted to identify locations for the construction sites for the Renaissance Dam. Then the Shuttle Radar Topography Mission (SRTM) data were obtained and processed to create a digital elevation model (DEM) for the Blue Nile upstream areas that will be submerged. Different scenarios for the dams' heights and resulting storages were simulated to estimate the resulting abstraction of the Blue Nile flows until completion of the project and the annual losses due to evaporation thereafter. The current site (506 m asl) for the Renaissance Dam allows the creation of a 100 m deep reservoir with a total storage of 17.5 km^3; overflows will occur at that lake's level (606 m asl) from the north western part of the developed lake into Rosaires downstream. Construction of the spillway dam to control the overflow area can allow the creation of a 180 m deep lake that store up to 173 km^3 in a lake that will cover 3130 km^2. The analysis of Tropical Rainfall Monitoring Mission (TRMM) suggests that the variation of total annual rainfall could reach 20%, thus the resulting hydrological fluctuations could affect the estimated filling time, the operational functions and discharge downstream. The negative hydrological impacts of the Renaissance Dam will increase by increasing the height of its spillway dam, as increasing the storage capacity could affect the strategic storage for the reservoirs in Egypt and Sudan. It is strongly recommended that an agreement should be reached to compromise the storage capacities and water supplies for all dams on the Nile to thoroughly satisfy the necessary needs.

1. Introduction

It is understood that the hydrology of large transnational river basins not only receive intensive academic research, but also

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attract widespread public, political, and economical concern (Beschorner, 1992; Allen, 2002). Yet, the countries of the Nile basin have not fully ratified a common water master plan, due to the conflict of interest, current and projected needs of water, lack of data, cooperation, etc. The diversity of hydrological processes within the Nile basin makes it extremely difficult to implement a common master plan for the entire basin (Said, 1993). The Nile is composed of several tributaries draining the Ethiopian Plateau and the Equatorial Lake Plateau (Williams et al., 2006). Interestingly, the Ethiopian catchments of the Nile (i.e. the Blue Nile and Atbara River) are contributing most of the annual flow to the Nile, and the net discharge of the Equatorial catchments into the White Nile is comparatively low, however receiving more or less similar rainfalls and covering greater surface areas (Tate et al., 2009). Moreover, the Nile course north of Atbara in Sudan receives no tributary flows. Thereafter, hydrology is dominated by abstraction due to infiltration, evapo-transpiration and different human activities such as irrigation. Therefore, the substantial management of the River Nile upstream is critical for downstream countries, particularly Egypt where the demand for water is increasing rapidly (El Bastawesy et al., 2013a; Ali, 2014; El Bastawesy, 2014). The gap could be narrowed by the implementation of regional agreements, which integrate research, social and economic strategies. For example, 11 riparian States (including South Sudan as of July 2011) of the Nile system are working toward a new agreement (the Nile Basin Initiative) which calls for the fair and just utilization of the Nile water resources across the basin and for the maximization of efficient management of the river basin.

In situ observations of hydrological parameters in the Nile basin are sparse. For example, measurements of rainfall are not available for large areas, and this is a major problem because of the very high spatial variability of rainfall in the basin (e.g. Yin and Nicholson, 1998), limiting the accuracy of estimates of hydrological inputs to the system. The discharges are available at a few key stations along the Nile, but the releases from several dams (particularly those recently constructed) are not published. The fluctuations of rainfall, lake and swamp levels, and resulting discharge are not uncommon, and the successful management of the Nile water needs a better understanding and more measurements of these hydrological variables (e.g. Sutcliffe and Parks, 1999; Said, 1993). These in situ measurements can be complimented by remote sensing – observations that are temporally and spatially homogeneous. Straightforward, the variable Landuse and landcover parameters are increasingly being determined by remote sensing techniques (Xinmei et al., 1995). Many of the existing platforms have been founded for measuring hydrological variables. These include the estimation of rainfall using multitude of sensors and platforms such as the Tropical Rainfall Monitoring Mission (TRMM) (e.g. Almazroui, 2011; Nicholson et al., 2003). The estimation of lake level fluctuations can also be achieved using satellite altimeter data such as the Topex/Poseidon mission, and the Gravity Recovery and Climate Experiment (GRACE) satellite mission (e.g. Awange et al., 2007; Birkett, 1995; Sutcliffe and Petersen, 2007; Swenson and Wahr, 2009). Therefore, multitude of remote sensing data can be elaborated to estimate quantitative hydrological variables for the catchments.

Additionally, the availability of semi-global digital elevation models (DEM) with moderate resolution such as the Shuttle Radar Topography Mission (SRTM) has allowed for the first time the extraction of drainage networks for the trans-boundary Rivers that almost lack coverage of consistent topographic maps with appropriate scale (Yang et al., 2011). The automatic delineation of catchment-hydrographic parameters from the DEM has gradually replaced the traditional manual delineation of these parameters from the conventional topographic maps regardless of the technical issues that may arise from the processing techniques or resolution of the DEM (Band, 1986; Chorowicz et al., 1992; Zhang and Montgomery, 1994; Wolock and Price, 1994; El Bastawesy, 2007; El Bastawesy et al., 2008).

The aim of this study is to develop a scenario of the reservoir of the dam being constructed on the Blue Nile in Ethiopia near the Sudanese border. This simulation will help assess impact of the dam on the net annual discharge downstream as other dams are being towered and constructed on the Nile, and additional agricultural areas are being irrigated from the Nile in Sudan as well as Egypt. There are three objectives required to achieve this goal. Firstly, to analyze the hydrology and rainfall of the Blue Nile basin, and to investigate the geomorphology of the reconnaissance dam's area. Secondly, to create the rating curves for the lake at different possible elevations given the appearance of construction sites on the satellite images and the availability of DEM for the area that will be flooded by the Reconnaissance Lake. Thirdly to use this model to simulate and assess the effect of various scenarios on water balance downstream, and to recommend alternative options to enhance the water security of the downstream countries in the Nile basin.

2. Study area

The Nile is the world's longest river, with a total length of 6670 km and draining a catchment area of 3.2 million km^2. The Equatorial Lakes plateau in Uganda is drained by tributaries forming the White Nile, which joins the Blue Nile (originating from the Ethiopian Highlands) at Khartoum. River Atbara is another major tributary of the Nile system, which also has its headwater on the Ethiopian plateau and joins the main Nile course at Atbara to the north of Khartoum. Thereafter, the Nile flows through the Saharan Desert without any significant tributaries (Fig. 1) (Williams, 2009).

The catchment of the Blue Nile and its tributaries covers approximately 250,000 km^2 in the Ethiopian Plateau, and it captures further tributaries of the Sudan and thus equates 324,000 km^2 at its confluence with the White Nile in Khartoum. The Blue Nile is carved into the Ethiopian plateau, which rises at elevations of 2000–3000 m above mean sea level, with several peaks up to 4000 m or more. Geologically, the Ethiopian Plateau constitutes a major part of the East African Rift System, which began at the end of the Cretaceous, and led to the formation of the Red Sea and the Main Ethiopian Rift (McConnel, 1972). The oldest rocks exposed in the Blue Nile basin are the Precambrian basement rocks, which are mainly acidic to basic rocks including quartzites, granites, granodiorite gneisses, diorite, metasediments and metavolcanics (Wolela, 2012). These are overlain unconformably by a Permo–Triassic "Karroo" succession which is around 450 m thick, interpreted as a succession of alluvial fan and fluviatile deposits. The Karoo succession is unconformably overlain