

Assessment of Hydrological Changes in the Nile River Due to the Construction of Renaissance Dam in Ethiopia

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Abstract: This paper investigates the hydrological scenarios of the Renaissance Dam being constructed on the Blue Nile within Ethiopia and its impact on water balance downstream. The Landsat-8 satellite images of 2013 were obtained and interpreted to identify locations for the Renaissance Dam and its spillway dam. The Shuttle Radar Topography Mission (SRTM) data were also obtained and processed to create a digital elevation model (DEM) for upstream areas. The DEM was analyzed to estimate water volumes that will fill the reservoir at various operational levels. The estimations were computed by filling the DEM to certain heights equivalent to the arbitrary barriers added to the original DEM at locations of the dams and the stored volumes were computed from the resulting surface extent and spatially variable depths for the lakes. Different scenarios for the Dams heights and resulting storages were proposed 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 km³; 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 upto 173 km³ in a lake that will cover 3130 km². The negative hydrological impacts of the Renaissance Dam will increase by creating the 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.

Key words: Blue Nile • Renaissance • Dam • Remote Sensing • GIS • Water balance

INTRODUCTION

Recently, the hydrology of large transnational river basins receive an intensive academic research and also attract widespread public, political and economical concern [1; 2]. There is a growing awareness of the societal importance of hydrological processes, such as fluctuations of river flows, water management strategies, climate change scenarios and the impact of these on sensitive and heavily populated deltaic systems, such as the international rivers is governed by the existing ties and treaties among the nations sharing same trans-boundary basins. So far the riparian 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 and 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 [3]. The Nile is composed of several tributaries draining the Ethiopian Plateau and the Equatorial Lake Plateau [4]. 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 [5]. Moreover, the Nile course north of Atbara in Sudan receives no tributary flows. Thereafter, hydrology is dominated by abstraction due to infiltration, evapotranspiration and the 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 [6]. The gap could be narrowed by the implementation of regional agreements, which integrate research, social and economic strategies. For example, the 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 [7], 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, lakes and swamps levels and resulting discharge are not uncommon and the successful management of the Nile water needs better understanding and more measurements of these hydrological variables [8 ; 3]. These in situ measurements can be complimented by remote sensing- observations that are temporally and spatially homogeneous. Straightforward, the variable Land use and land cover parameters are increasingly being determined by remote sensing techniques [9]. 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) [10; 11]. 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 [12-15]. Therefore, multitude of remote sensing data can be elaborated to estimate quantitative hydrological variables for the catchments.

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 [16]. 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 [17; 18]. The manual method is a tedious and error-prone technique particularly

when the active longitudinal channel courses are not marked on topographic maps. The major issues associated with the derivation of surface drainage networks from DEM are related to the quality, source and resolution of the DEM and to the processing techniques and algorithms employed [19; 20]. However, the delineation of various morphometric parameters (for a typical dryland catchment) was not very sensitive to the change of DEM resolution (from 20 m to 90 m) [21].

The dynamic changes within large water bodies have widely been monitored and observed using different remote sensing platforms [22]. The 2D fluctuation of lakes and inundated playas can be easily estimated using the visual interpretation and change detection of multi-temporal satellite images. The 3D change detection of artificial lakes and reservoirs can be also estimated by integrating depths data (i.e. bathymetry) with the surface extent of those lakes. The availability of topographic maps or DEM produced prior the formation of enormous water bodies allows the simulation of storage capacities at different levels [22]. Again, the accuracy of water budget scenarios will be directly related to the quality of DEM, which can be examined by comparing measurable derivatives with their counterparts on the satellite images such as drainage networks and shorelines configurations.

The aim of this study is to scenario the reservoir of the Dam being constructed on the Blue Nile in Ethiopia near the Sudanese border. This simulation will help assessing 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 analyse the hydrology 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.

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 km². 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

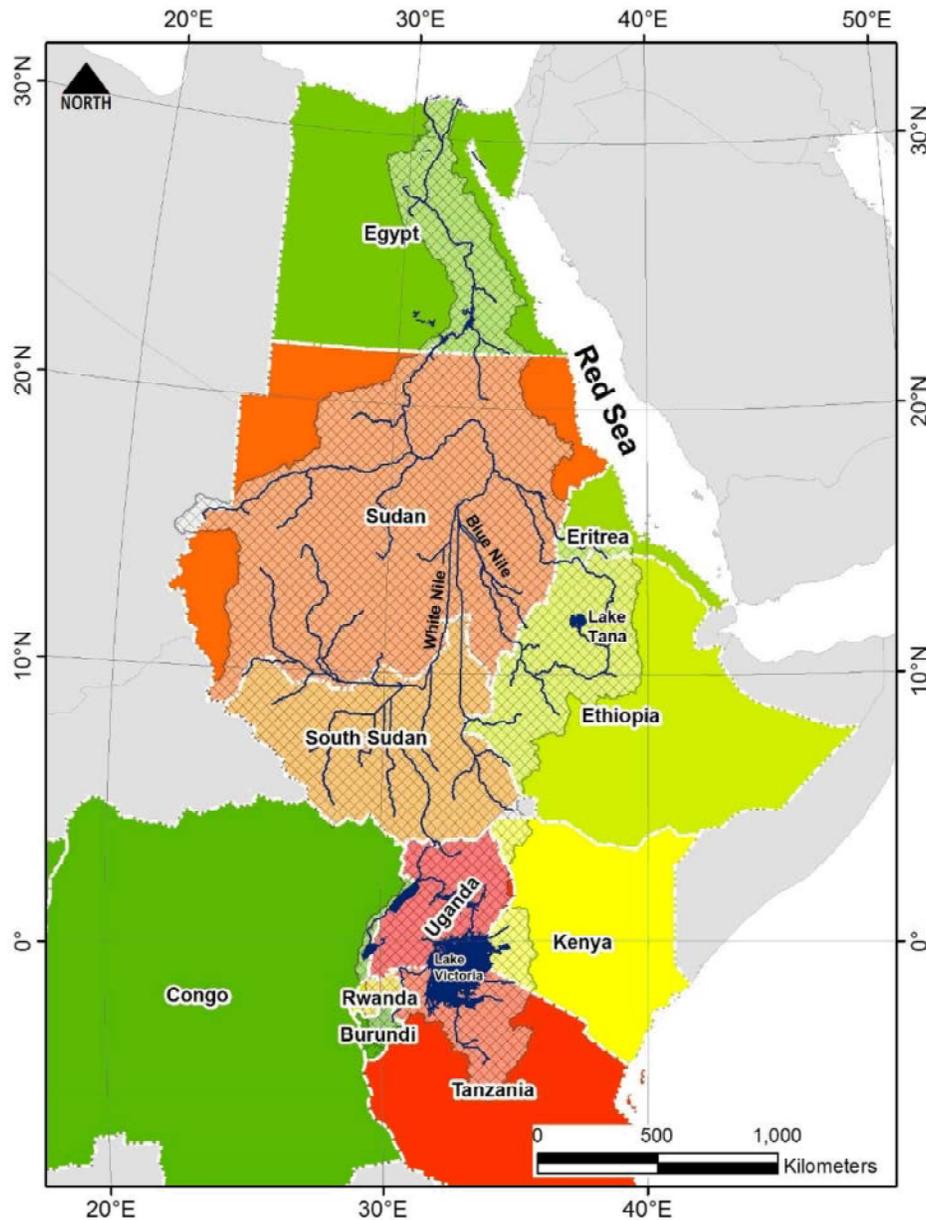


Fig. 1: Location map of the study area, catchment of the Nile Basin is indicated by cross-hatching pattern; the catchment morphometry is derived from the GTOPO30 data (www.eros.usgs.gov).

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) [23]. It flows from the equatorial plateau of East Africa through the tropical plains of Sudan, to the deserts of Sudan and Egypt. Lake Victoria is the main equatorial lake feeding the Nile and the Kagera River is

the largest stream debouches into Victoria. The outlet is now controlled by a dam constructed on the Rippon Falls. After passing Lake Kioga the Nile leaves the equatorial plateau at the Murchinson Falls and it enters the Albert Lake. The Nile emerges from Albert as “Albert Nile” in Uganda and it known as Bahr El Jebel in South Sudan. After being joined by the Bahr El Ghazal and Sobat, the river called the White Nile. At Khartoum, the River is joined by the Blue Nile rising in Lake Tana.

The catchment of the Blue Nile and its tributaries covers approximately 250,000 km² in the Ethiopian Plateau and it captures further tributaries of the Sudan and thus equates 324,000 km² 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 [24]. 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 [25]. These are overlain unconformably by a Permo- Triassic "Karoo" succession which is around 450 m thick, interpreted as a succession of alluvial fan and fluvial deposits. The Karoo succession is unconformably overlain by up to 750 m of the Lower Triassic fluvial- sediments (i.e. Adigrat Sandstone Formation) mainly composed of conglomerates, sandstones, siltstones and mudstones. Overlying the Adigrat Sandstone Formation is a 50 m thick transition zone of alternating shales, limestones, sandstones, dolostones and evaporites. This is overlain by the transgressive limestone formations of the Middle Jurassic to the Lower Cretaceous, which reach a maximum thickness of 1140 m in the Blue Nile area [26]. The volcanic rocks of the Oligocene-Quaternary are laying unconformably on the Mesozoic and older rock units [27].

The plateau is mainly covered by grassland and some deciduous forests due to the seasonal nature of rainfall, while the main land use is dominated by grazing, ranching, cultivation and mixed farming. Lake Tana is also one of the main hydrological features on the Ethiopian plateau and it approximately cover 3000 km² and the fringes are occupied by swamps that are being affected by the seasonal fluctuation of the lake level. The Gilgil Abay is the main river feeding Lake Tana and the Blue Nile emerges from Tana Lake at Bahir Dar, where it makes a 150 km radius loop around the Oligocene -Quaternary volcanic shield of Mount Choke (4070 m asl) by flowing first southeast, then south, then southwest. For a long distance from Tana, the Blue Nile flows through a canyon (i.e. Gorge of the Nile), in some places 1200 meters deep. This canyon is carved into the Mesozoic sedimentary rocks, which constitute the flanks of Afar Depression and the Ethiopian Rift Plateau. Thereafter, the Blue Nile continues travelling northwestward towards the low land of the Sudan (i.e. El-Diem) where it is bordered by the

Precambrian basement rocks [28]. Overall, the Blue Nile is approximately 900 km long in Ethiopia and is augmented by several tributary rivers along its entire course. Most of these tributary streams are perennial though highly seasonal in their flows. For example, the Didessa and Dabus, draining the southwestern part of the basin adjacent to the Baro, contribute significant fractions (over a third) of the total flow, especially at the start and the end of the runoff season. The wetlands in the Dabus sub-basin occupy about 900 km² and have a considerable effect on the resulting runoff [29]. The lower part of the basin (downstream of the Rosaires, which is a main reservoir storing Blue Nile waters for irrigation within Sudan) in the Sudan is underlain by alluvium plain (The Gezira plain), which is largely covered with savannah and some shrubs. It generally slopes west with an average elevation of 700 m a.s.l. and the river is little below the surroundings, but some areas are usually inundated during the flood season. Nowadays, large areas of the Gezira plain have been converted into perennial irrigation. Two major seasonal tributaries (the Dinder and Wadi Medani) confluence with the Blue Nile in Sudan. The long-term mean annual flow of 48.658 km³ at Rosaires/el Deim, records also shows a considerable variation from low annual totals of 20.69 km³ in 1913 and 29.65 km³ in 1984, to high totals of 69.67 km³ in 1917 and 69.85 km³ in 1929.

The seasonal distribution of flows is very marked, with maximum monthly flows averaging 15.23 km³ in August contrasting with 0.32 km³ in April. The bulk of the runoff (84% on average) occurs between June and October. The average flow recorded at the mouth of the Dinder (1907-1960) is 3.086 km³ and the average flows for the Rahad are 1.145 km³ (1908-1960) and 1.044 km³ (1961-1997). There are considerable losses from these highly seasonal two rivers as the average upstream records for the Dinder during same period was 2.374 km³. This great variation in the produced flows from the Blue Nile System reflects a great deal of temporal and spatial changes in the climatic parameters, particularly precipitation. According to the data available for the 5 decades, it is estimated that annual variation of rainfall is about 20% [30]. The data available also suggests a strong seasonality in rainfall; the rainy season covers only 3-5 month of the year and 80% of the Blue Nile flows occur during this period. Most of the tributaries in the basin are drying out during the prolonged dry season [31]. Grossly, the seasonal fluctuation is more pronounced. Contrary to the November flood on the White Nile, the flood on the Blue Nile comes already in August and is more intense

because of the steep slopes of the basin. The average precipitation is 1082 mm and the runoff coefficient is 15% and evapotranspiration is 924 mm per year [8]. Due to the lack of spatially distributed hydrological data for the entire basin, the current study will utilize the abovementioned hydrological parameters for the numerical calculations of storage capacities for the Renaissance Dam and its impact on the hydrology and societies downstream, particularly in Egypt.

MATERIALS AND METHODS

Calculation of the storage capacities for a reservoir of the dam requires multiple datasets that approximately define location, height, the areal extent of the lake and its depths (i.e. bathymetry). Of course the surface extent and spatially variable depths for the developed lake will markedly vary at the different operational levels of the dam. Realistically, scenarios of different heights for the dam and the resulting lake levels should be modeled, in order to estimate the storage capacities and their impact on the hydrology downstream. But the estimation of maximum storage capacity for the reconnaissance dam receives a particular concern from the public as well as hydrologists, due to its anticipated affect on the Egyptian water supplies. The appearance of construction site for the dam on the Landsat 8 satellite image of the 28th of

May 2013 has provided the first key data on the dam location (Fig. 2). The SRTM DEM tiles were separately pre-processed and then mosaicked in order to be used for the analysis of the reservoir parameters. The pre-processing has started with assigning an elevation value for each pixel whose value is -32768. Then the DEM was 'filled' in order to modify values of the artifacts to their neighboring pixels, thus increasing the accuracy of deriving hydrologically-correct parameters from these DEM [32]. The extracted drainage networks from the DEM required the calculation of 'flow direction' from the 'filled' DEM and the calculated 'flow accumulation' from the 'flow direction' grid [17]. The resulting drainage networks and associated sub-catchments were overlaid on the satellite images to check that they correspond to visible wadis and streams [33]. This comparison is necessary to ensure the accuracy of DEM in simulating the topographic relief and thus, the resulting lake shapes and geometry at various levels [22]. Once the DEM was assured for its accuracy in the hydrological analysis, the main dam and the spillway dam were added as 'barrier' on the DEM and these barriers were assigned specific elevations at the various scenarios (Fig. 3). The rating curves for the reservoir were estimated and the resulting net annual loss due to evaporation from the lake surface was also estimated.

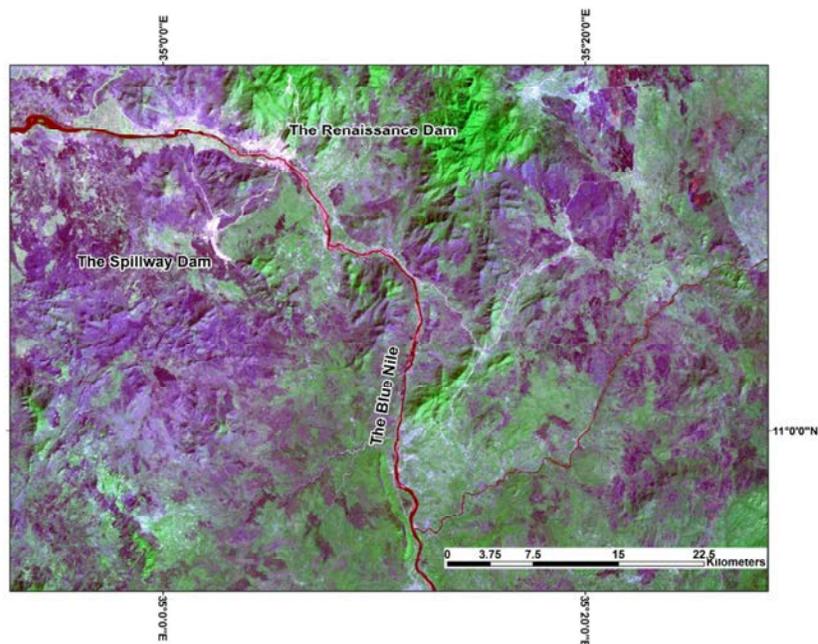


Fig. 2: A subset of landsat-8 composed of the multispectral bands (3,5,7) in (r,g,b) respectively shows locations of the "renaissance dam" and its spillway dam.

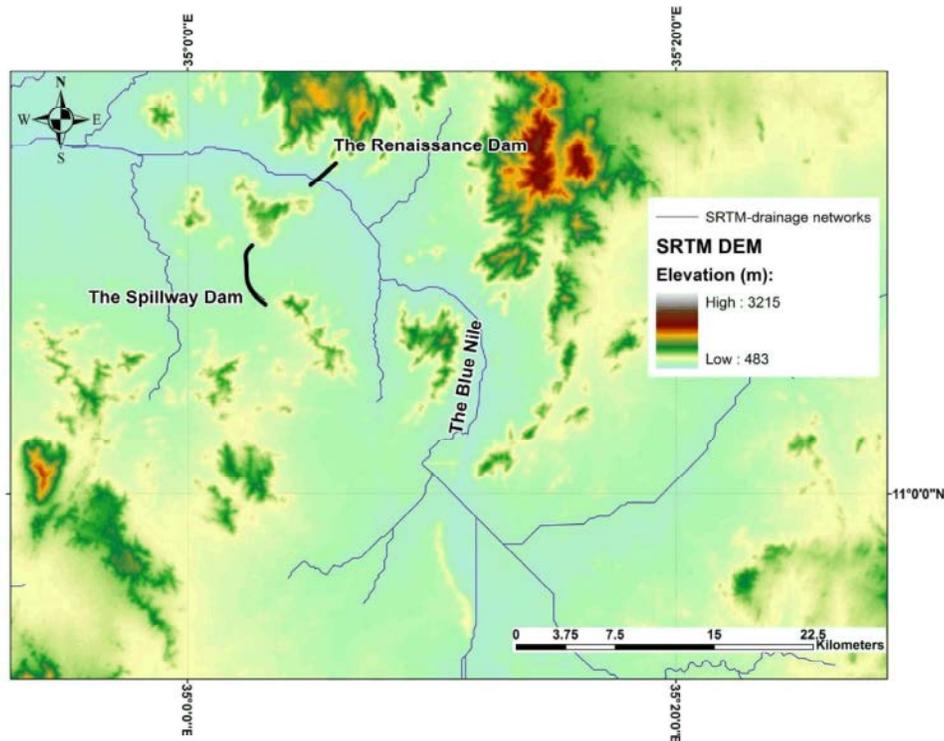


Fig. 3: The SRTM DEM for same area shown in Fig 2, it shows the main topographic reliefs and flow pathways composing the lower part of the Blue Nile.

RESULTS

The catchments of the Blue Nile were delineated from the SRTM3 DEM and location of the Renaissance Dam and its spillway dam being constructed were delimited from recent satellite images and hydrometric data averaged from the available literature. For the sake of simplicity, the estimated average annual runoff discharge at Rosaires was set to 49 km³ and the annual evaporation loss from the lake surface is 924 mm [8]. Topography of the Renaissance Dam area and its upstream varies in elevation from 506m to 1777m asl. The construction site of the main dam is a narrow floodplain area, which is bounded by two high shoulders (1222 and 945m asl) of the massive basement rocks. Basically, the construction of the dam at this site (506 m asl) can only support a lake with a maximum depth of 100 m (i.e. maximum lake level is 606m asl). This is because the lake at 606 m asl level will spill over its shore line into the Roseries downstream through a southwestern tributary wadi apart from the main course of the Blue Nile (Fig. 4). This is why the Spillway Dam is being constructed to the west of the Renaissance Dam to control the overflow and to raise the storage capacity of the main dam. Straightforward, the

Renaissance dam alone could not support the creation of a reservoir deeper than 100 m, but the construction of auxiliary dam in the saddle area between the hillslopes in the western side of the Blue Nile will allow the construction of a main dam taller than 100 m above the floodplain level. Again, the spillway dam can be 80 m tall at maximum, as another overflow will occur at the level of 686 m asl and thus require a second spillway dam at that site further upstream.

The GIS-simulated reservoir of the Renaissance Dam at the level of 606 m asl (i.e. maximum water depth is 100 m) showed that the lake will cover approximately 745 km² and the stored water volume would reach km³. Indeed, the abstraction of 17.5 km³ of water to fill the reservoir will affect the net annual discharge downstream that will continue until the completion of the dam. The impact will be directly related to the length of construction period and the strength of summer flooding seasons within the basin during the project duration. The impact downstream will be lesser with longer duration of construction and stronger flooding season and vice versa. Additionally, the construction of spillway dam will definitely increase the storage capacity and resulting net annual evaporation loss due to the increasing of surface area. For example,

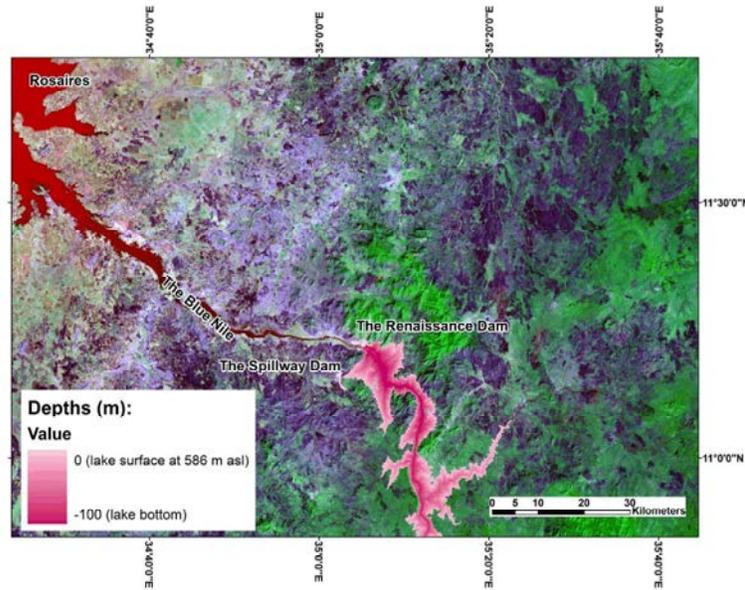


Fig. 4: Simulation of the resulting lake when the Renaissance Dam is approximately 100 m tall (i.e. maximum lake depth). The lake will store upto 17.5 km³ of water and it will cover 745 km².

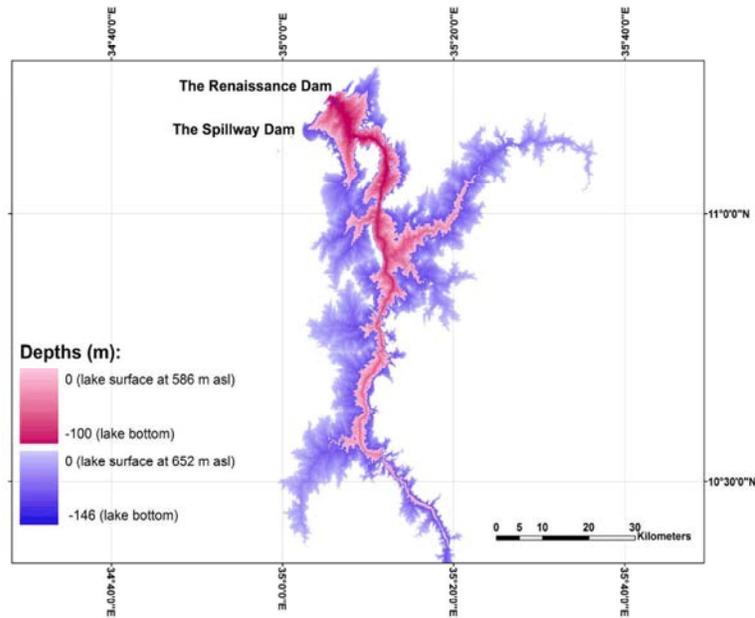


Fig. 5: Comparison of two scenarios for the resulting lake if the Renaissance Dam is constructed to 100 m tall (the red scale colours) and 146 m tall (the blue scale colours).

the erection of a 30 m tall spillway dam will allow the renaissance dam to reach 130 m tall, thus storing 56 km³ of water in the developed lake that will cover approximately 1560 km². According to the published information on the Renaissance dam by the Ethiopian Power Company, the

Renaissance Dam will stand at 147 tall and the Spillway Dam will be of 45 m tall and the storage capacity will reach 74 km³ [34] (Fig. 5). Table 1 shows the estimated storage capacity and surface extent of the resulting lake at selected scenarios.

Table 1: The estimated rating curves for some scenarios of the Renaissance Dam and its developed lake (the dam tall and maximum lake depth are considered equivalent).

Maximum lake depth (m)	Surface area (km ²)	Maximum storage capacity (km ³)	Average annual loss (km ³) due to evaporation (924mm/yr)
80	442	9.6	0.4
100	745	17.5	0.7
130	1560	56	1.4
146	1954	80.5	1.8
180	3130	173	2.9

DISCUSSION

A thorough understanding of hydrological processes is necessary for effective water management in trans-boundary river basins, but this is a real challenge for the Less Developed countries, such as those linked by the Nile system [6]. The riparian states of the Nile Basin are working toward a new agreement (the Nile Basin Initiative) which call for the fair and just utilization of the Nile water resources across the basin rather than to maximize efficient management of the river basin. Reaching a common framework of cooperation is hindered by lack of data, diversity of water use and need among different states and conflict of the interest. The announcement of any hydrological project such as building dam for hydropower generation and/or water storage in the upstream is always handled by the politicians due to the sensitivity of water issues particularly for downstream of the Nile. The hydrological assessment of these projects and their anticipated impact are therefore of utmost important to approximately identify the benefits and negative impacts [2].

Remote sensing and DEM data have proved significant for monitoring ongoing dynamic changes in large surface water bodies; extracting hydrological parameters and modeling the water balance [35; 22; 36]. The use of this approach has been driven by the increased availability of multi-temporal high and moderate resolution satellite data, during the past three decades. The accuracy of simulation and hydrological modeling is governed by the quality of used DEM, availability of lengthy discharge and rainfall data for calibration and ground trothing (e.g. 13). However, it should be noted that some limitations were encountered in the development of the herein designed GIS model. The SRTM DEM is the elevation data available for this area and it was acquired in 2001 and the reservoir is yet to develop. Therefore, simulated lake of the dam at various levels has to be examined somehow for accuracy. The SRTM is the most consistent elevation data

worldwide as it was collected during a single mission with same procedures [37]. Consequently, the quantitative assessment of SRTM quality in portraying the reservoirs the Nile Basin founded after 2001 is a significant measure for the accuracy of current simulation. There is a high degree of consistence and matching between morphometry of Marwa Dam on the main Nile River in Sudan and Takeze Dam on the upstream of Takeze River in Ethiopia as appears on recent satellite images of the Landsat 8 and their counterparts simulated from the SRTM (Fig. 6). Indeed, there is little discrepancy between the lake boundaries on both data sets as the vertical accuracy of the DEM is measured by integer meters, while the actual lake level stands at fractional units. However, this inevitable and minor discrepancy between lake surface area and level estimation from DEM and satellite images is slightly influencing the analysis. Nonetheless, the coincidence of lakes surface areas simulation from the DEM and their counterparts on satellite images exceeds 96%.

The anticipated negative impacts for the Dam on downstream will be more pronounced for Egypt as it almost relies on the Nile. The main concern is that the completion of this project could occur over short duration and during a low-flood seasons. Consequently, the net annual discharge of the Blue Nile downstream could be minimal and the Nasser Lake could also struggle to sustain the required water for all the Nile Valley and its delta in Egypt. The situation is very risky as the distributed data available and the utilized hydrological models cannot accurately assert the discharges during the coming seasons. These negative hydrological impacts can only be minimized if the dams are constructed over longer time period and/or being compromised on specifications particularly the tall parameter. On the other hand, the creation of Renaissance Dam will be beneficial in several economical and geo-environmental aspects. The clean and cheap hydropower energy will help develop the economy of Ethiopia and the entire region. The reservoir will act as a sediment trap, thus storage capacities and functionalities for the downstream reservoirs in Sudan and Egypt will be improved. The major benefit for creating an additional reservoir on the Blue Nile could be appreciated during the humanitarian crises arising from the recurrent drought [30].

Indeed the cooperation is the only way forward for the nations sharing the Nile in order to achieve sustainability and development [38]. The abstraction of huge water volume upstream of the Renaissance Dam on the Blue Nile could be supplemented from the White Nile

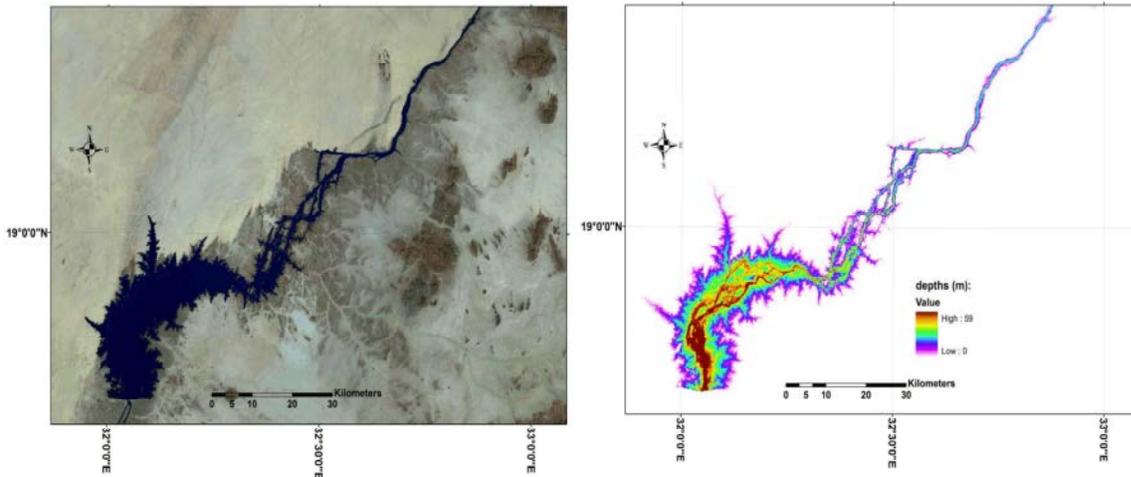


Fig. 6: The simulated lake of Marwa Dam in Sudan. The high coincidence between the lake as appear on the Landsat-8 image (top) and the SRTM-DEM simulation indicate the reliability of estimation.

catchments, which are occupied by immense and numerous swamps. Although the White Nile only contributes less than 30% of the total annual flows of the Nile River downstream at Lake Nasser, the hydrological potential of the basin is promising and can be developed [6]. One of the early pioneer projects known as "the Jonglei Canal Project" was initiated to save some of the water loss into the Sudd swamps of the White Nile basin. The aim was to construct a 280 km channel (in the first phase) to bypass the swamp area between Jonglei and Malakal, in order to save 4.7 billion cubic metres of water from loss into the Sudd. The digging of the canal began in June 1978, but unfortunately it came to a halt in 1983 as a result of civil war in the region [3]. An additional project was also proposed to improve the water discharge and optimize management of land resources in the Equatorial Lakes area for the benefit of the Nile Basin partners [6]. Lake Kioga has a very high potential for this scheme, it is a large shallow swamp, which covers an area of 6,270 km², with a catchment of 75,000 km². The total average rainfall is estimated at 1500 mm per year and the annual evaporation is 1290mm, while the net annual and unregulated overflow from the lake at Murchison falls into Lake Albert (including that received from Lake Victoria) is 22.5 km³. These swamps can be drained due to the large difference in elevation between Kioga upstream and Albert downstream. The resulting increase in discharge flows can be used to generate electricity at the Murchison Falls and providing more discharge downstream. Draining a considerable part of the Kioga swamp will also expand and improve agricultural productivity in the area as

drainage will be enhanced. Such a project would, however, demand more detailed feasibility studies, environmental impact assessments and enhanced international collaboration.

CONCLUSION AND RECOMMENDATIONS

This paper has presented hydrological scenarios of Renaissance Dam, which is being constructed on the Blue Nile at the Ethiopian border with Sudan. Estimation of water storage for the new lake is of utmost importance for downstream as the Blue Nile contributes approximately 60% of the annual water budget of the flows received at Aswan Dam in south of Egypt. Downstream of Atbara in Sudan the Nile no longer receives any tributary flows and is converted into a system for reservoirs, barrages and irrigation channels for perennial cultivations. Although, there will be a significant temporal reduction of flows from the Blue Nile until the reservoir is completed, but the anticipated shortage of net discharge downstream cannot be predicted with much confidence due to the annual variability of main streams constituting the Nile System and the absence of reliable data and models that can be used to determine the flow patterns in the next few years. Therefore, the impact of Renaissance Dam will be strongly felt downstream if its completion falls in a low-flood period as it will require longer duration for filling the reservoir and vice versa. Additionally, the hydrological impact of the dam and its spillway dam will be determined by their specifications such as the heights, dead storage capacity and the operational framework. On the other

hand, coordination among Ethiopia, Sudan and Egypt is necessarily required to ensure that the specific flows abstraction upstream of the Renaissance Dam will be not lower the reservoirs downstream (i.e. Rosaires, Marwa Dam, Aswan High Dam) to critical levels in such way affecting their functionality and capabilities to fulfill the required water budgets for the various activities. This can be achieved by constructing the Renaissance Dam and its spillway dam over longer duration or to lower their elevations to compromise the electric power going to be produced. It is clearly evident that Ethiopia will benefit from the Renaissance Dam as huge electro-power will be generated and it will retain a huge reservoir in its border area with Sudan. The downstream countries may get benefit from the storage of considerable amounts of sediments upstream, thus maintain the storage capacities of the downstream reservoirs for longer durations. Egypt needs to adapt new strategies with its Nile water particularly for the agricultural sector which consumes most of it. Using more-efficient techniques for irrigation and drainage system seems very necessary, but the ownerships are of small areas and highly disseminated thus the installation of new systems are always costly and met with local difficulties and conflict of interests. In the mean time, the cooperation among all the nations sharing the Nile should be more effective and consider the benefits for all parties. It is highly recommended to start considering the various proposed schemes to increase flows downstream thorough draining the swamps in South Sudan and Uganda and to substitute these wetlands for food production and grazing.

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