Assessing the Impacts of Climate Changes on the Eastern Nile Flow at Aswan

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Abstract: The Eastern Nile River Basin is currently experiencing new developments of 13 dams and reservoirs; both in Ethiopia and in Sudan to full utilize the basin for electricity generating and irrigation to face the population growth. These dams are 5 dams (Gambella, Baro1, Baro 2, Geba A and GebaR) on Baro-Akobo- Sobat-White Nile, 3 dams (Metema Dam, Rumela Dam and Humera Dam) on Tekeze-Setit-Atbara and 4 dams (Mandaya, Karadopi, Beko Abo and Grand Ethiopian Renaissance Dam) on Blue Nile and one dam (Kajbar Dam) on Main Nile. Egypt and Sudan are hot arid and semiarid countries, almost vitally relying on the Nile water as water source, with water demand in Egypt alone set to increase. These developments will strongly affect the water flow at Aswan. Therefore, it is needed to take into account these developments for Egyptian water right. In addition, the impacts of climate change for the whole basin development and management for near future (2011-2040), intermediate future (2041 – 2070) and far future (2071 – 2100) on the inflow, evaporation and energy production at High Aswan Dam have been taken into consideration. RIBASIM Model has been used in this study to simulate the water system in the Eastern Nile Basin. The model has advanced flexible features in operating goals for several different types of demand (hydro-power, irrigation, etc.) and the option to manage the system with priority to different demands. The baseline models is configured with the existing infrastructure and calibrated with historical hydrological regime. The model performed very well and satisfactory simulates the monthly flow distribution. The Nash-Sutcliffe efficiency and coefficient of determination accuracy were 0.95 for most of the gauge stations, Where, Mean Relative Bias (PBAIS) and Root Mean Square error (RMSE) varies between 0.015-28, 29-555m^3/s, respectively. 32 scenarios have been considered to assess the impacts of climate change on the Eastern Nile River. These scenarios comprise baseline scenario, 14 development scenarios, 18 combined / management scenarios (17 individual covering basin and 1 overall basin) during the current century and 4 climate change scenarios 2011–2040 (near future), 2041-2070 (intermediate future) and 2071-2100 (far future), respectively. 10 dams out of the 13 have a negative impact to the inflow at Aswan, The development and management of 10 dams on the Eastern Nile would reduce average annual the inflow, evaporation and energy production at Lake Nasser/ HAD by 18%, 4% and 4%, respectively. However, climate change can force these Lake Nasser to be drier. The average annual inflow reductions at High Aswan Dam due to climate change are estimated to be 24%, 35% and 36% for near future (2011-2040), intermediate future (2041-2070) and far future (2071 -2100), respectively.

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1. Introduction

The Nile River is longest river in the world by most accounts, flows through eleven countries along 6,800 km *[Said, 1993 and Ibrahim, 1984]*. It is the sixth largest Basin in the world area-wide encompassing most of the northeastern Africa. The total surface area of its basin is 3.11 million km^2, covers approximately 10% of the area of the African continent *[Gleick 1991 and NBI, 2012]*, 2.3% of the world's land surface area *[Mohamoda and Dahilon, 2003]*, and hosts nearly 20 per cent of the African population, mainly dependent on crop and livestock-keeping agriculture for their livelihoods. The combined runoff water coefficient of the Nile is 3.9%, which is very low compared to other rivers *[NBI, 2012]*. Its main sources are found in Ethiopia and the countries around Lake Victoria *[Hurst et al, 1959]*, where the water supply sources are the Eastern Nile (Ethiopian Highlands) which contributes almost 86% of the flow of the Nile and Eastern equatorial Nile or White Nile, which contributes 14% of the flow. The sources of the White Nile are Equatorial Lakes Plateau (Victoria, Kyoga and Albert Lakes). While, 86% originates from the Ethiopian Highlands: 59% through the Blue Nile (Abay), 14% Baro-Akobo (Sobat), and 13% Tekesse (Atbara) *[Swain, 1997 and Shahin 1985]*.The White and Blue Nile rivers converge in Khartoum. The combined rivers are then joined by the Atbara to form the Main Nile that flows northwards. It eventually discharges into the Mediterranean Sea through its Delta *[NBI, 2012]*.

Moreover, the Nile Basin with its majority situated in dry and semi-dry region is facing a number of challenges including high water demand, high variability, uneven distribution of resources coupled with the complications introduced by the trans-boundary nature of the river, and climate change is likely to worsen matters. Climate change is therefore a clear risk for the Nile Basin Countries due to the uncertainty of its impacts on rainfall and flows within the Nile basin. The Eastern Nile countries (Egypt, Ethiopia, Sudan and South Sudan) also suffering from diminished technical, insinuation and economic capability to manage the impacts of frequent climate extremes of floods and drought.

The downstream countries, Egypt and Sudan almost completely depend on the Nile water as water source, with water demand in Egypt alone set to increase. 97% of Egypt's total annual water resources are produced outside its borders of approximately, 87% of the water reaching Lake Nasser flows from the Ethiopian Highlands, principally through the Blue Nile, but also through the Atbara and Sobat rivers. These rivers exhibit considerable seasonal and interannual variability, with 80% of flows in the Blue Nile and Atbara following rainfall in Ethiopia during between July and October *[Soliman et al 2009]*. This is considered to be the main challenge for water policy and decision makers in the country as the Nile River provides the country with 97% of its various water requirements *[MWRI, 2005]*. Climate change impact on the water resources is likely to affect irrigation system and water supply in Egypt. Different activities of upstream Eastern Nile Courtiers / Nile basin Countries would affect Nile flow at Lake Nasser. The impacts will be seen in climatic factors such as temperature, precipitation, wind speed, humidity. The impact of interest here is on river flow, which is the resource for hydropower.

The Eastern Nile Basin including the Blue Nile Sub Basin is currently experiencing new developments in Ethiopia such as Mandaya Dam, Beko-Abo Dam, Karadobi Dam and the Grand Ethiopia Renaissance Dam (GERD). These developments will strongly affect the water flow at Aswan. Therefore, it is needed to take into account these developments for Egyptian water right.

2. Study Area

The Eastern Nile is one of the main sub-basins of the Nile basin. It lies between latitudes 7º N and 31º N. The Eastern Nile Basin is considered the Nile Basin without the Equatorial Lake Basin. The Eastern Nile Basin is divided into four sub-basins: the Baro-Akobo-Sobat-White Nile in the west, the Abbay-Blue Nile, the Tekeze-Atbara on the east and the Main Nile from Khartoum to the Nile delta, as shown in Figure 1. The Main Nile considered the largest sub-basin of the ENB covering 44% of its total area, followed by Baro-Akobo-Sobat covering 26% of its total area, then Abby-Blue Nile with 17%, while the Tekeze-Atbara-Setite is the smallest sub-basin covering 13% of the area, as shown in Table 1.

Figure 1. Eastern Nile Basin with Main Sub Basins and Reservoirs

The Eastern Nile Basin is constituted of four riparian countries along the Eastern Nile namely Egypt, Ethiopia and Sudan and South Sudan. The Eastern Nile Basin covers an area of 1,809,606 km^2 of which Egypt contributes 4% (72348 km^2), Ethiopia 22% (389113 km^2) the Sudan 13% (1111460 km^2) and South Sudan 61% (227648 km^2), as seen in Figure 2. While, the mean annual inflow of the four eastern Nile sub basin and their proportion of Nile inflow at Aswan Dam are presented in Table 1. However, the Blue Nile Basin is the major one, where it contributes 54 BCM of the mean annual flow and corresponding to around 64% of the flow that arrives at Lake Nasser, followed by Baro-Akobo-Sobat-White Nile Basin contributes 28.5 BCM and accounts 34% of the Nile flow at Aswan. While, Tekeze-Setit-Atbara Basin contributes 12 BCM and corresponding to 14 % of the Nile flow at Aswan.

Table 1. Eastern Nile Sub-basin Area and Flow

Sub-basin	Area (km) (%)	Flow (BCM) % at Aswan (%)	Annual rainfall (mm)
Baro-Akobo-Sobat-	205,775 (11.5%)	13.5 (16%)	500-1750
White Nile	262,441 (14.5%)	15 (18%)	< 300 – 500
Abbay-(Blue Nile)	311,548 (17%)	54 (64%)	500 – 1800
Tekeze-Setit-Atbara	227,128 (13%)	12 (14%)	200 – 1500
Main Nile	789,660 (44%)	84 (100%)	0 – 200

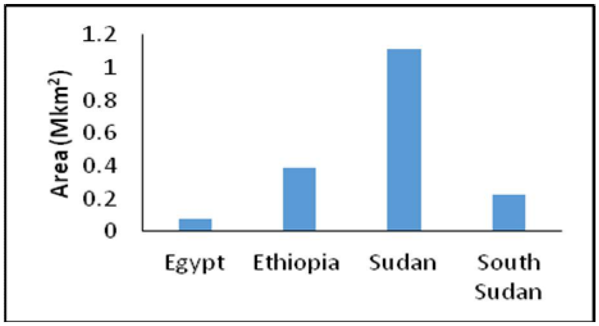

Figure 2. Sub-basin Area Percentage in the ENB System

According to FAO, 2015, the average annual rainfall precipitations in 2011 for Ethiopia, Sudan, South Soudan, and Egypt are 848, 250, 900 and 51 mm/year respectively.

3. Material and Methods

3.1 Model Description and Setup

A zero D model called RIBASIM developed by Deltares *[Wil, 2008]*, merely contains information on the water balance have been used to simulated the Eastern Nile Basin and its sub basins with a monthly time steps and a hydrological time series for the period January 1900 to December 2002 have been used. The existing infrastructures have been integrated to the model.

The models solve water balance per time step for each node in downstream order (simulation sequence):

$S_{t1} - S_{t0} + c * \{Qin_{t1} - Qout_{t1}\} = 0$ 1

Where:

t_0, t_1= simulation time steps e.g. monthly

S_{t1} = storage at end of time step t_1 (Mm^3)

Qin_{t1}= flow into the node during time step t_1 (m^3/s)

$Qout_{t1}$= flow out of the node during time step t_1 (m^3/s)

c = conversion factor

Considered water related elements that are included and quantified: supply side (rainfall, surface runoff, groundwater, water quality), demand side (domestic, municipal and industrial water, agriculture, aquaculture, hydro-power demand, navigation, environment, etc), Infrastructure (rivers, canals, reservoirs, weirs, pipelines, hydropower stations, pumps, including operational management).

3.2 Input Data

A historical monthly rainfall and temperature data over a 102 period (1900-2002) were obtained from CRU TS 2.0 (Climatic Research Unit, University of East Anglia) with spatial analysis $0.5^{\circ} \times 0.5^{\circ}$ *[Mitchell et al., 2004]*. However, reference evapotranspiration ET_0 data were obtained from the CLIMWAT data set of FAO *[FAO, 2012]*.While, hydrological discharge data were collected from Eastern Nile Technical Regional Office (ENTRO); Ministry of Water Resource and Irrigation (MWRI), Egypt; Ministry of Water Resources and Electricity (MWRE), Sudan and Ministry of Water Resources (MoWR), Ethiopia. Climate Scenario A2 for HADGEM model (Met Office Hadley Centre, UK) about future precipitation and temperature for were obtained the global coupled atmosphere ocean general circulation models made available by the World Climate Research Program (WCRP) Coupled Model Inter-comparison Project phase 3 (CMIP3) *[Meehl et al., 2007]. Kim et al., 2008* equation was used for developing the relationship between the prediction changes in runoff and the changes in precipitation and temperature, as given below:

$\Delta Q = 2.2\ \Delta P - 7.5\ \Delta T$ 2

where: Δ Q is the percentage change in mean annual runoff; Δ P is the percentage change in mean annual precipitation; Δ T is the °C change in mean annual temperature; and the coefficient of determination of this equation is 0.97.

3.3 Calibration and Validation

4 stations, namely Dongola, High Aswan Dam, Khartoum and Malakal have been chosen for calibration 10 years (1961-1970), while another 10 year (1971-1980) for Validation. The performance assessment was based on the water balance closure of the watershed and the value of the statistical performance indices such the Nash-Sutcliffe Efficiency (NSE), Coefficient of determination (R^2), Mean Relative bias (PBAIS) and Root Mean Square error (RMSE). These performance measures have been used with data based on daily and/or monthly time steps.

Nash–Sutcliffe Efficiency

Nash–Sutcliffe Efficiency measures the fraction of the variance of the observed flows explained by the model in terms of the relative magnitude of residual variance to the variance of the flows; the optimal value is 1.0 and values should be larger than 0.0 to indicate 'minimally acceptable' performance *[Nash and Sutcliffe, 1970]*. It is computed as follows:

$$NSE = 1 - \sum_{t=1}^{n}(Q_{sim} - Q_{obs})^2 / \sum_{n=t}^{n}(Q_{obs} - \overline{Q_{obs}})^2 \quad 3$$

where Q_{obs} is observed values and Q_{sim} is modelled values at time/place t.

Root-Mean Square Error

The root-mean square error computes the standard deviation of the model prediction error which is the difference between measured (Q_{obs}) and simulated values (Q_{sim}). The smaller the RMSE (m^3/s) value, the better the model performance is. It is computed as follows:

$$RMSE = \sqrt{\frac{1}{n}.(\sum_{t=1}^{n}((Q_{sim})_t - (Q_{obs})_t)^2} \quad 4$$

PBIAS

Percent bias measures the tendency of the simulated flows to be larger or smaller than their observed counter parts; its optimal value is 0.0, positive values indicate a tendency to overestimation, and negative values indicate a tendency to underestimation. It is estimated as follows:

$$PBIAS = \frac{\sum_{t=1}^{n}((Q_{sim})_t - (Q_{obs})_t)^2}{\sum_{t=1}^{n}(Q_{obs})_t} X100\% \quad 5$$

Pearson Correlation Coefficient (r)

Correlation – often measured as a correlation coefficient – indicates the strength and direction of a linear relationship between two variables. A number of different coefficients are used for different situations. The best known is the Pearson product-moment correlation coefficient (also called Pearson correlation coefficient or the sample correlation coefficient), which is obtained by dividing the covariance of the two variables by the product of their standard deviations.

$$r = \frac{\sum_{i=1}^{n}(Q_{sim} - \overline{Q}).(Q_{obs} - \overline{Q})}{\sqrt{\sum_{i=1}^{n}(Q_{sim} - \overline{Q})^2 . \sum_{i=1}^{n}(Q_{obs} - \overline{Q})^2}} \quad 6$$

The square of the Pearson correlation coefficient (R^2), known as the coefficient of determination, describes how much of the variance between the two variables is described by the linear fit. The ranges of models' performance ratings, RMSE, NSE and PBIAS reported by *Moriasi et al., 2007* were based on monthly time step data. Models' performances are poorer for shorter time steps than for longer time steps *[Legates and McCabe, 1999, Gupta et al., 1999 and Engel et al., 2007]*. Thus, it was decided to use Moriasi's performance ratings for this research (Table 2).

Table 2. General Performance Ratings for a Monthly Time Step (Moriasi et al., 2007).

Performance rating	NSE	PBIAS (%)
Very good	$0.75 < NSE \leqslant 1.00$	$PBIAS < \pm 10$
Good	$0.65 < NSE \leqslant 0.75$	$\pm 10 \leqslant PBIAS < \pm 15$
Satisfactory	$0.50 < NSE \leqslant 0.65$	$\pm 15 \leqslant PBIAS < \pm 25$
Unsatisfactory	$NSE \leqslant 0.50$	$PBIAS > \pm 25$

3.4 Scenarios Development

32 scenarios have been considered to assess the impacts of climate change on the Eastern Nile River. These scenarios comprise baseline scenario, 14 development scenarios, 18 combined / management scenarios (17 individual covering basin and 1 overall basin) during the current century and 4 climate change scenarios 2011–2040 (near future), 2041-2070 (intermediate future) and 2071-2100 (far future), respectively (Table 3). The baseline model/ scenario is developed to represent the current simulation of the existing conditions in the Eastern Nile Basin including current major infrastructure. The existing situation is based on the measured data obtained in 2012. This baseline model/ scenario comprises the Chara Chara Weir, Koga Dam and Finchaa Dam at Bahir Dar/Lake Tana. The model scenario comprises also Jebel Aulia Dam and Abobo Dam on Alwero River/White Nile, Roseries Dam and Sennar Dam on the Blue Nile, Tana-Beles Hydropower diversion for the Tis Abbay; the TK5/ Tekeze Reservoir, Small Scale Irr Dam on Tekeze Basin, Khashm El Girba Dam on Atbara River; and the Merowe Reservoir on the Main Nile.

Table 3. Scenarios Development

ID	Scenario	Scenarios Definition
1	Baseline	Existing condition
2	BASW-DS1	Existing condition + Gambella
3	BASW-DS2	Existing condition + Baro1

4	BASW-DS3	Existing condition + Baro 2
5	BASW-DS4	Existing condition + Geba A
6	BASW -MS1	Existing condition + Gambella + Baro1
7	BASW -MS2	Existing condition + Gambella + Baro1 + Baro 2
8	BASW -MS3	Existing condition + Gambella + Baro1 + Baro 2 + Geba A
9	BASW -MS4	Existing condition + Gambella + Baro1 + Baro 2 + Geba A + Geba R
10	TSA-DS1	Existing condition + Metema
11	TSA-DS2	Existing condition + Rumela
12	TSA-DS3	Existing condition + Humera
13	TSA-MS1	Existing condition + Metema + Rumela
14	TSA-MS2	Existing condition + Metema + Humera
15	TSA-MS3	Existing condition + Rumela + Humera
16	TSA-MS4	Existing condition + Metema + Rumela + Humera
17	BN-DS1	Existing condition + GERD
18	BN-DS2	Existing condition + Mandaya
19	BN-DS3	Existing condition + Karadobi
20	BN-DS4	Existing condition + Beko Abo
21	BN-MS1	Existing condition + GERD + Mandaya
22	BN-MS2	Existing condition + GERD + Karadobi
23	BN-MS3	Existing condition + GERD + Beko Abo
24	BN-MS4	Existing condition + GERD + Mandaya + Karadobi
25	BN-MS5	Existing condition + GERD + Mandaya + Karadobi+ Beko Abo
26	BN-MS6	Existing condition + GERD + Karadobi+ Beko Abo
27	BN-MS7	Existing condition + Mandaya + Beko Abo
28	BN-MS8	Existing condition + Mandaya + Karadobi+ Beko Abo
29	MN-DS1	Existing condition + Kajbar
30	EN-MS1	Existing condition + Gambella + Baro1 + Baro 2 + Geba A+ Rumela + GERD + Mandaya + Karadobi+ Beko Abo + Kajbar
31	EN-CC1	Existing condition + Gambella + Baro1 + Baro 2 + Geba A+ Rumela + GERD + Mandaya + Karadobi+ Beko Abo + Kajbar + CC1 (2020)
32	EN-CC2	Existing condition + Gambella + Baro1 + Baro 2 + Geba A+ Rumela + GERD + Mandaya + Karadobi+ Beko Abo + Kajbar + CC1 (2050)
33	EN-CC3	Existing condition + Gambella + Baro1 + Baro 2 + Geba A+ Rumela + GERD + Mandaya + Karadobi+ Beko Abo + Kajbar + CC1 (2080)

4. Result and Discussion

Model Calibration and Validation

The calibration and validation results for short periods of 10 years are shown in Table 4 and Table 5, respectively. These tables indicate clearly lower model performance for Dongola and High Aswan Dam stations and higher model perform for Khartoum and Malakal stations, respectively in the validation period compared to the calibration period. Both NSE and R^2 indicate very good model with more than 0.9, while the Mean Relative bias (PBAIS) are satisfactory. Whereas, the Root Mean Square Error (RMSE) varies between 93.91 and 49.64 m^3/sec, showing a reasonably good agreement between observed and simulated stream flows. Moreover, the model parameters performance for the whole period NSE and R2, PBAIS, RMSE are 0.977, 0.951, 0.015 and 555.08 m3/sec, respectively.

Table 4. Model Performance for Calibration of River Discharge for Different Station

Station	NSE	R^2	PBAIS (%)	RMSE (m^3/sec)
Dongola	0.977	0.965	10.05	454.97
Aswan Dam	0.993	0.981	18.297	310.62
Khartoum	0.993	0.986	18.33	233.877
Malakal	0.975	0.900	15.11	124

Table 5. Model Performance for Validation of River Discharge for Different Station

Station	NSE	R^2	PBAIS	RMSE (m^3/sec)
Dongola	0.95	0.952	17.09	479.64
Aswan Dam	0.992	0.948	25.977	96.43
Khartoum	0.996	0.994	26.68	128.60
Malakal	0.988	0.878	27.76	93.91

Water Balance

Figure 3 represents the mean and standard deviation annual inflow volume. It is observed, that the standard deviation of theses sub-basins is mostly half of the mean. However, the flow contribution from sub basins resulted, 58% (49.5 Mm^3) for Blue Nile, 33 % (28.5 Mm^3) for BASW and 14% (11.82 Mm^3) for TSA of the Main Nile. As shown in Figure 4, the monthly water level in Lake Nasser at High Aswan Dam has reached its minimum 147.78 m in July 1980. HAD reached its dead storage level in winter 1960s such as October to December 1961, November to December 1962, November to December 1963, September to December 1964, December 1965, November to December 1967,…etc.

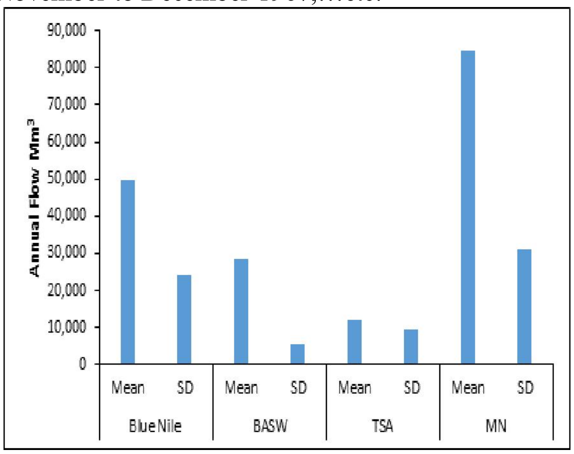

Figure 3. Annual Inflow in Over ENB

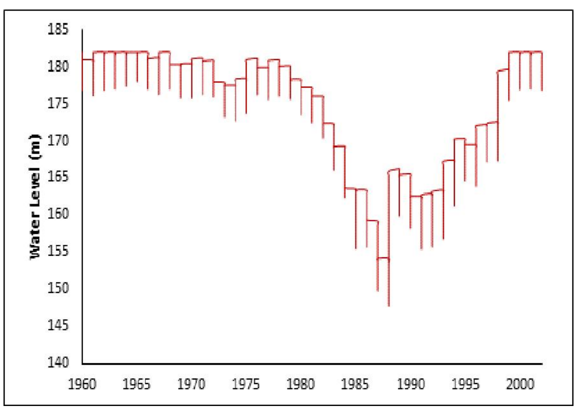

Figure 4. Monthly Water Level at HAD

Inflow and Evaporation

The monthly and annual average inflow of the 33 scenarios has been compared with the baseline scenario at Aswan. The Impact of developing Eastern Nile Basin Dams has been plotted as shown in Figure 5 and Figure 6. It is noticed that, monthly inflow is low from January to June, then the inflow rises to reach its peak in September, after that the inflow decline from September to December. The maximum monthly inflow incretions and reductions of Lake Nasser (HAD) was observed +69% in June and -55% in August for the full basin development (overall scenario), as shown in Figure 5. Moreover, the maximum annual inflow reduction was 22.53% for scenario TSA-DS2 (Rumela), while the inflow reduction for overall scenario was 18% (Figure 6). However, the maximum monthly inflow reductions observed at Khartoum, Kesie and Ed Deim are 49% in December, 35% in March and 71% in August, respectively. In spite of the average annual inflow at Kessie increases with 0.3%, the average annual inflow at HAD, Khartoum and Ed Deim decrease by 18.12%, 33.8% and 8.9%, respectively (Figure 7).

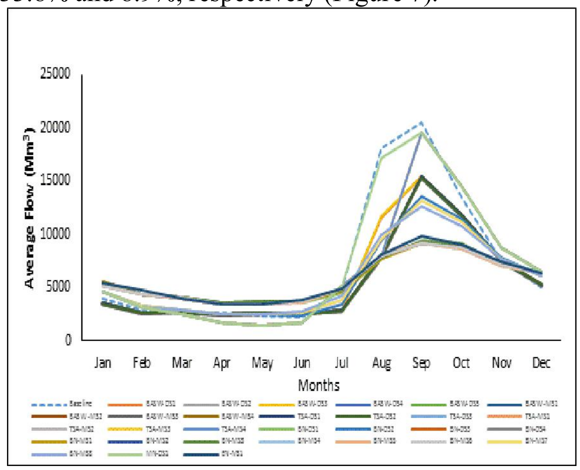

Figure 5. Monthly Inflow at HAD

The average annual evaporation at HAD varies between 10626 Mm^3 and 14114 Mm^3. The minimum and maximum reductions recorder at HAD are 0.045% and 21.5% for scenario BASW-MS4 (Geba A) and scenario BASW-DS1 (Gambella), respectively. While the maximum evaporation increment were 4.57% for scenarios TSA-DS3, TSA-MS1, TSA-MS, TSA-MS3 andTSA-MS4. However, the overall development of the basin required a reduction of 2.4% (Figure 8). Despite the average annual evaporation loss decrease at HAD by 4.1%, the evaporation losses at Khartoum, Kessie and Ed Deim increase by 19.5%, 46.6% and 60.6%, respectively (Figure 9).

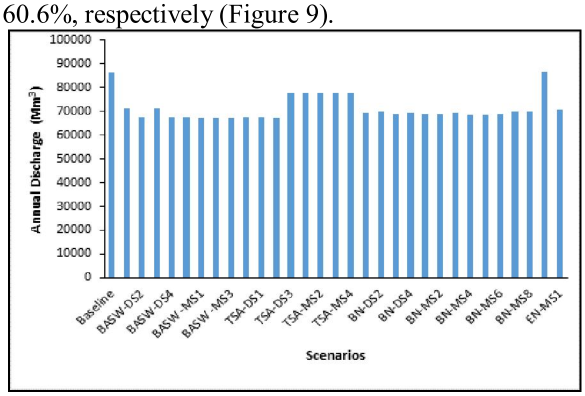

Figure 6. Annual Inflow at HAD

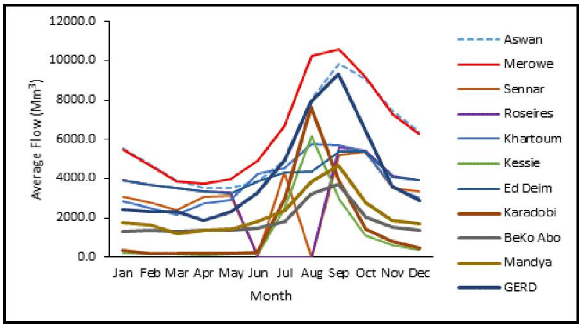

Figure 7. Monthly Inflow at various Stations for overall Scenario

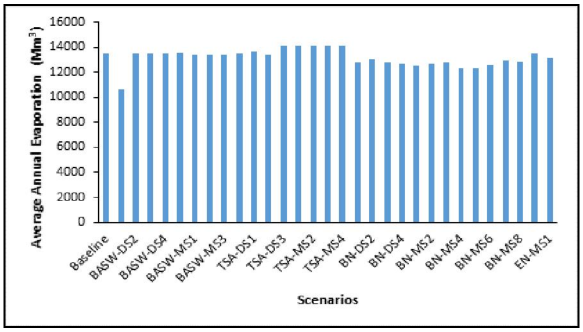

Figure 8. Annual Evaporation at HAD

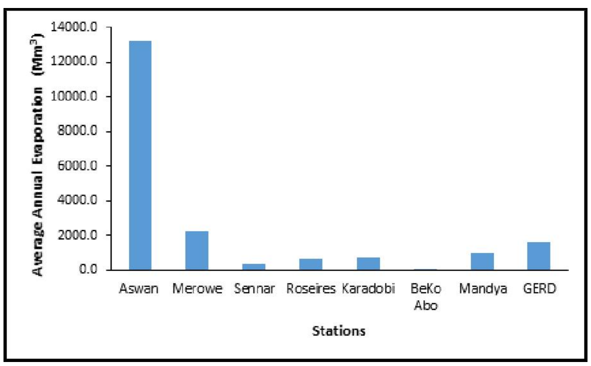

Figure 9. Annual Evaporation at various Stations for the overall Scenario

Energy Generation

Figure 10 illustrates the energy generation at HAD due various scenarios. It is clearly seen that the energy generation was increased by 7% for 5 scenarios corresponding development and management of TSA basin, theses due increase inflow in the sub basin. However, the energy reduction varies between 0.8% and 11%, the maximum reduction observed at scenario BASW-DS2 (Baro1).

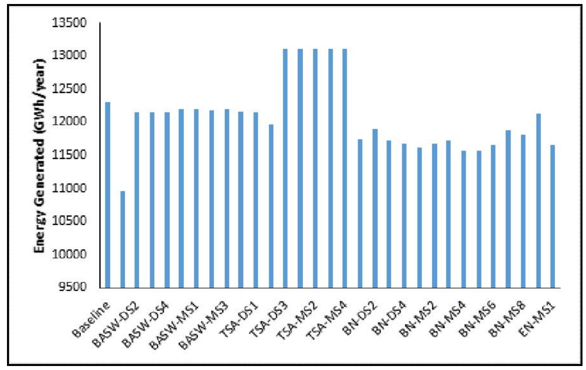

Figure 10. Annual Energy Generation at HAD

Inflow Prediction

The results in Table 6 suggest that the mean annual runoff over the Blue Nile at the first projection period 2010-2039 was simulated as -9.3% by HADGEM which is a 1.86% decrease in mean annual rainfall and 2°C increase in mean annual temperature. Where the runoff decreases to -3.9% and increase to 4.3 in the middle and end of the 21st century. However, the runoff decreases to 23% and 24% for the whole basin. The maximum average monthly decline due to climate change at HAD is estimated to be 10.8% in September, 33.3% in July and 34.1% in August for near future, intermediate future and far feature, respectively, as shown in Figure 10. It is observed that the average monthly and annual inflow for the intermediate future has not changed compared to the near future that mean that the average inflow is almost stable in the intermediate future. The average annual inflow decline is plotted in Figure 11. The average annual inflow reductions at High Aswan Dam are estimated to be 6.95%, 20.5% and 21.4% for near future, intermediate future and far future, respectively. While these reductions are higher as 18% (1970-200), 24%, 35% and 36% with respect to the baseline scenario (existing condition). However, the average annual inflow reductions at Ed Deim are estimated to be 8.3%, 8.3% and 25.2% for near future, intermediate future and far future, respectively.

Table 6. Changes in Climate Variables and Runoff Projected over the Eastern Nile Basin

Period	BN			WN			MN			EN		
	ΔP	ΔT	Δ Q	ΔP	ΔT	Δ Q	ΔP	ΔT	Δ Q	ΔP	ΔT	Δ Q
2010-2039	-1.86	2	-9.3	-1.158	1	-10.05	6	1.5	1.97	0.99	1.5	-5.6
2040-2069	1.62	1	-3.9	-13.58	2.5	-48.64	2.73	3	-16.49	-3.07	2.16	-23
2070-2099	4.7	2	4.3	-14.77	3.2	-56.50	5.15	4.2	-20.17	-1.64	3.13	-24

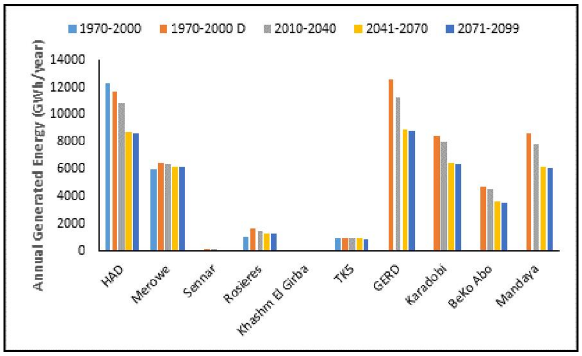

Figure 10: Impact of Climate Change of Developing Eastern Nile Dams on the Projected Average Monthly Inflow at HAD

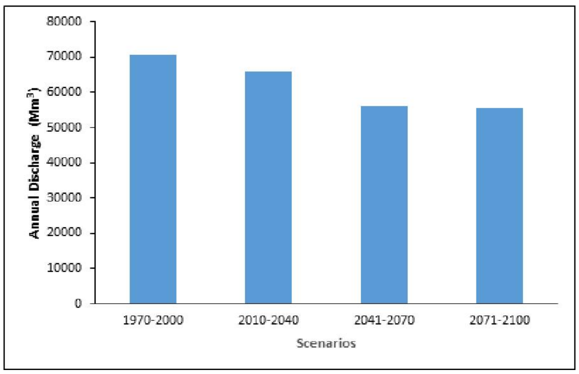

Figure 11: Impact of Climate Change of Developing Eastern Nile Dams on the Projected Average Annual Inflow at HAD

Figure 12 displays the average annual evaporation at HAD. The average annual evaporation reductions are estimated to be 26%, 59% and 61% for near future, intermediate future and far future, respectively. While these reductions are higher as 4% (1970-200), 29%, 62% and 63% with respect to the baseline scenario (existing condition).

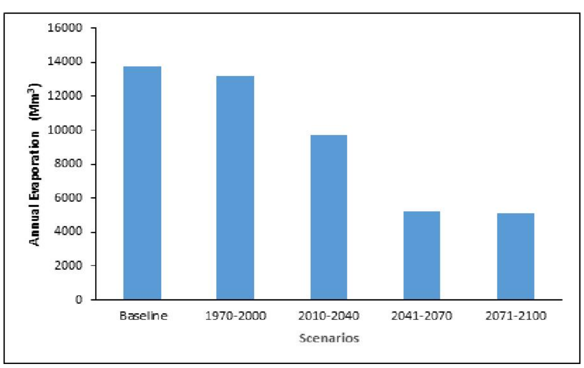

Figure 12 Impact of Climate Change of Developing Eastern Nile Dams on the Projected Average Annual Evaporation at HAD

Energy Generation Prediction

The projected annual generated energy for 10 dams are illustrated in Figure 13. The percentage in indicates that, the generated energy could be reduced as an impact of climate change due to inflow reduction. The reduction increases with increases time horizons. It is clearly seen that the impact of climate change has no effect on production of Khashm El Girba Dam. However, the energy production at HAD will be reduced due to climate change by 7.4%, 25% and 26% for near future, intermediate future and far future, respectively.

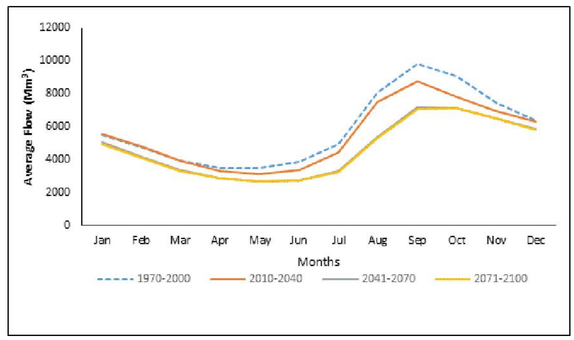

Figure 13 Impact of Climate Change on Eastern Nile Development Dams

5. Conclusion and Recommendation

The development and management of 10 dams on the Eastern Nile would reduce average annual the inflow, evaporation and energy production at Lake Nasser/ HAD by 18%, 4% and 4%, respectively. However, climate change can force these Lake Nasser to be drier. The average annual inflow reductions at High Aswan Dam due to climate change are estimated to be 24%, 35% and 36% for near future (2011-2040), intermediate future (2041-2070) and far future (2071 - 2100), respectively. Whereas, the average annual evaporation reductions due to climate change are increased from 4% to 29%, 62% and 63% for near future, intermediate future and far future, respectively. Increase of evaporation losses will affect at the Nile water by increasing the Nile water salinity. Moreover, the energy production at HAD would decrease due to climate change from 4% to 12%, 28% and 29% for near future, intermediate future and far future, respectively. These reductions induce superficial effects on the drinking water stations, industrial pump station irrigation, navigation and energy generation.

Egypt should implement the following climate change adaptation strategy to cope with impact of climate change such as:

- Impose irrigation limitation and shift to modern irrigation system (Sprinkler/Drip) whenever possible and the uncertainty in the types of crops that might be used in the future.

- Use of non-convention water resources, such as reuse of agricultural drainage water for irrigation, in situ wastewater treatment, optimum use of rainwater harvesting and implement seawater and brackish water desalination in the coastal regions.
- Use automation of the gate on the canal control structures.
- Canal and drains rehabilitation.
- Increase individual awareness.

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