The Development of the Baro-Akobo-Sobat sub basin and its Impact on Downstream Nile Basin Countries

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Abstract

The Nile Basin, due to its size and varying climate, hydrology, topography and demography, constitutes one of the most complex and unique river basins. A great number of water resources development projects are being under planning and implementation phase on both national and transboundary levels in order to respond to rapid population growth, climate change impact, urbanization, industrialization, economic and food crises on both global and regional levels. The Baro-Akobo-Sobat sub basin is considered one of the most promising regions in the Eastern Nile Sub-basin and a number of water resources development projects are being planned for this purpose: TAMS Dam, Birbir A and Birbir R Dams, Baro-1 and Baro-2 Dams, Geba-A and Geba-R dams for hydropower production, Itang Irr Scheme, Gilo-2 Dam and Irr Scheme, , Dumbong Dam and Irr Scheme, Genji Scheme (Hydropower). The main objective of this study is to assess the positive and negative impacts of these projects on both national and regional levels. Different assumptions and approaches in proposed dams operation rules and irrigation schemes are used in order to reach an optimal solution for an integrated development of the sub basin while minimizing the negative impact on the basin level downstream. A series of development scenarios and relevant social, environmental and economic indicators on both local and downstream levels are measured and a multi criteria analysis is undertaken to evaluate these scenarios.
Based on the quantification of environmental, social and economic indicators and their comparative analysis, this study is presenting an optimized set of development projects within the Baro-Akobo-Sobat basin that can simulate the win-win regional approach, maximizing the regional benefit and minimizing the negative impacts. Therefore, the main output of this study is presented as a proposed master development plan of the BAS basin using the basin water resources as a major potential.

Key words: Nile Basin Decision Support System, Dams, Irrigation, Hydropower, Downstream Impact, Multi Criteria Analysis

1 INTRODUCTION

The Nile Basin, due to its size and varying climate, hydrology, topography and demography, constitutes one of the world's most complex and unique river basins. Given the rapid population growth, urbanization, industrialization, both economic and food crises, climate change and its possible impact on water resources in the Nile Basin, a great number of water resources development projects are being under planning and implementation on both national and transboundary levels within the Nile Basin in order to respond to these challenges and to achieve sustainable socio economic development on both national and regional levels. The Baro-Akobo-Sobat (BAS) sub basin is considered as one of the most promising regions in the Eastern Nile Sub-basin. The BAS sub basin is located in the central part of the Nile Basin and extends from the Equatorial forests near Gambella in Ethiopia at elevations of 2000 to 3000 masl into Sudan. Its total catchment area is about 481,000 km2. The basin includes a complex system of rivers and large wetlands.

The main river channels are the Baro, Gila and Akobo which originate from the Ethiopian Plateau, and the Pibor which originates in South Sudan. After the confluence of these rivers, the river is named the Sobat River. Large seasonal marches formed by spills from the Akobo, Baro, Sobat and other smaller rivers characterize the system along the border between Ethiopia and Sudan. The Sobat River joins the

White Nile at Malakal. Apart from the Abobo Irrigation Scheme, there are currently no major water users in the basin in the form of irrigation or hydropower installations (Sutcliffe and Parks, 1999).

The basin is under consideration for various hydropower and irrigation projects as shown in Figure 1 and Tables 1&2. The Nile Basin Decision Support System (NB DSS) is a comprehensive analytical framework that integrates Information management system, Water Resources Modeling system, Analytic tools (optimization, benefit-cost analysis, multi-criteria analysis...) and it is intended to serve as water resources-based DSS for use in the context of an international river basin in a user friendly graphical user interface (GUI). Consequently, the NB DSS is used in this study to assess the downstream impact of the development of the BAS sub basin from different perspectives taking into account the cumulative impact resulting from the development of the Equatorial Lakes as well.

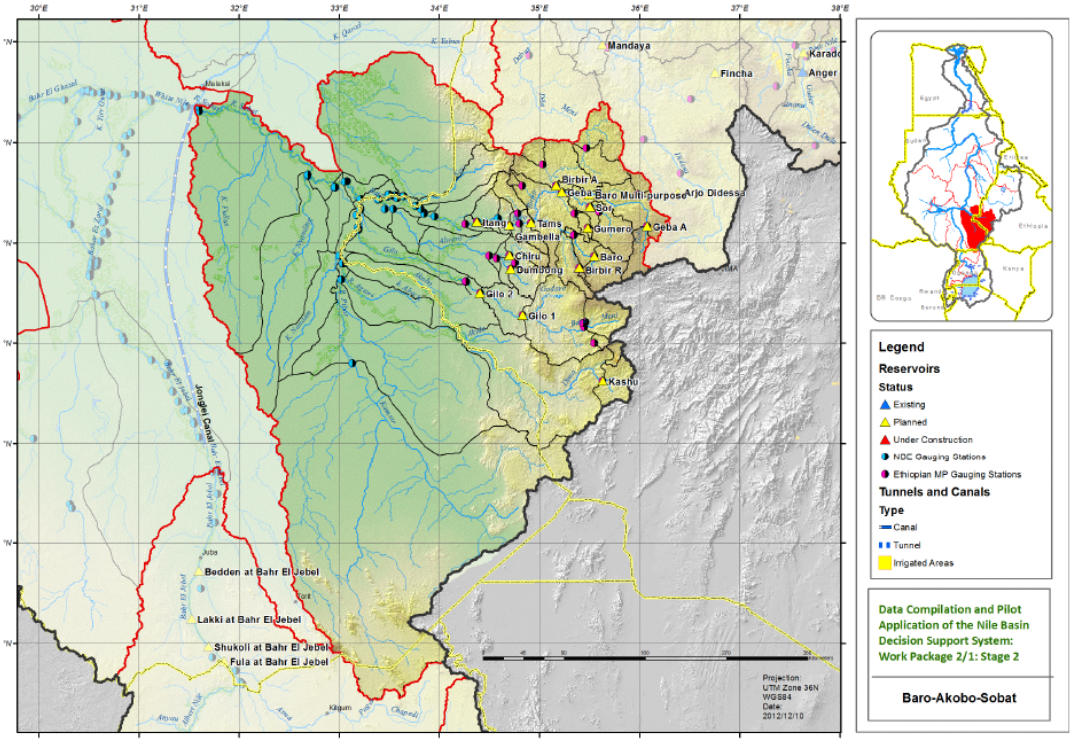

Figure 1: Baro-Akobo-Sobat Sub basin (study area) Existing and Proposed Projects

2 PROBLEM STATEMENT

The Nile River loses 95% of its water within its trajectory from source to mouth: out of the 1661 BCM of rains falling on the Basin, only 84 BCM reach Aswan upstream High Aswan Dam (HAD). The difference is lost in swamps and through evaporation and seepage. In the last decades, many water resources and hydropower development projects are being studied in order to benefit from the River for the welfare of its people. National water development plans and donors' funded projects lead to a series of prefeasibility and feasibility studies targeting the construction of a set of multipurpose and hydropower dams in addition to a number of irrigation schemes all through the Nile Basin . These projects need to be studied in an integrated manner in order to assess their impacts locally and regionally. The Baro-Akobo-Sobat (BAS) sub basin is considered as one of the most promising regions in the Eastern Nile Sub-basin and a number of water resources development projects are being planned for this purpose: Tams, Birbir A and Birbir R, Baro-1 and Baro-2, Geba-A and Geba-R Dams and Genji Scheme (for hydropower production), Gilo-2 and Dumbong (Dams and Irrigation Schemes) and Itang (Irrigation Scheme). Although different development scenarios have been studied within the preparation and case studies undertaken in the scenario analysis reports developed by the Nile Basin Initiative (NBI) and the consortium of consultants for the BAS sub basin, this development has not been studied on the total Nile basin level in order to assess the impact of the development of each sub basin alone and in a progressively cumulative manner on the downstream.

3 OBJECTIVE

The main objective of this study is to assess the positive and negative impacts of BAS projects on both national and regional levels in order to reach an optimal solution for an integrated development of the sub basin while minimizing the negative impact on the basin level downstream using the NB-DSS tool. This involves:

- Defining scenarios and a set of economic, environmental and social evaluation criteria (indicators) using the NB-DSS tool.
- Using the MCA tool and associated functionalities embedded in the NB-DSS to evaluate scenarios based on the quantification of economic, environmental and social indicators.

It is important to note that this work will be considered as a part of a wider research work aiming to study the cumulative impact of the development of each sub basin (Equatorial lakes, Bahr el Ghazal, White Nile, Blue Nile and Main Nile) using the same above mentioned approach .

4 METHODOLOGY

A Mike Basin model is used to simulate the Nile Basin: the present state of water resources development in the Equatorial Lakes, White Nile, Eastern Nile and Main Nile up to Aswan (Baseline) and the planned projects in the BAS and the Equatorial Lakes.

The model simulations' results are assessed under different scenarios: baseline, BAS projects (hydropower only), BAS projects (irrigation only), BAS projects (irrigation +hydropower), Equatorial Lakes' projects and BAS projects (irrigation + hydropower).

Relevant social, environmental and economic indicators on both local and downstream levels are measured and a multi criteria analysis is undertaken to evaluate these scenarios. Figure 2 presents a scheme of both irrigation and hydropower proposed projects in the BAS.

5 The NB DSS

The basic purpose of the NB-DSS is to provide a framework for sharing knowledge, understanding river system behavior, designing and evaluating alternative development scenarios, investment projects and management strategies. Its main goal is to support informed, scientifically based, rational cooperative decision making to improve the overall benefit from harnessing the Nile River, and to develop economically efficient, equitable, environmentally compatible and sustainable strategies for sharing the benefits. The NB DSS addresses the following priority concerns:

- Water Resources Development
- Optimal Water resources utilization
- Coping with floods and droughts
- Energy development (hydropower)
- Rain fed and irrigated agriculture
- Watershed and sediment management
- Navigation
- Climate change impacts and water quality issues are defined as cross-cutting issues.

MIKE Basin model representing the baseline scenario for the entire Nile Basin is being configured at appropriate temporal and spatial resolutions. The primary data sources for the Baseline Model were the Nile Encyclopedia (MWRI, Egypt), Ethiopian Master Plans and inflow records into Lake Victoria supplied by the riparian countries. Figure 3 shows the NBDSS layout and components.

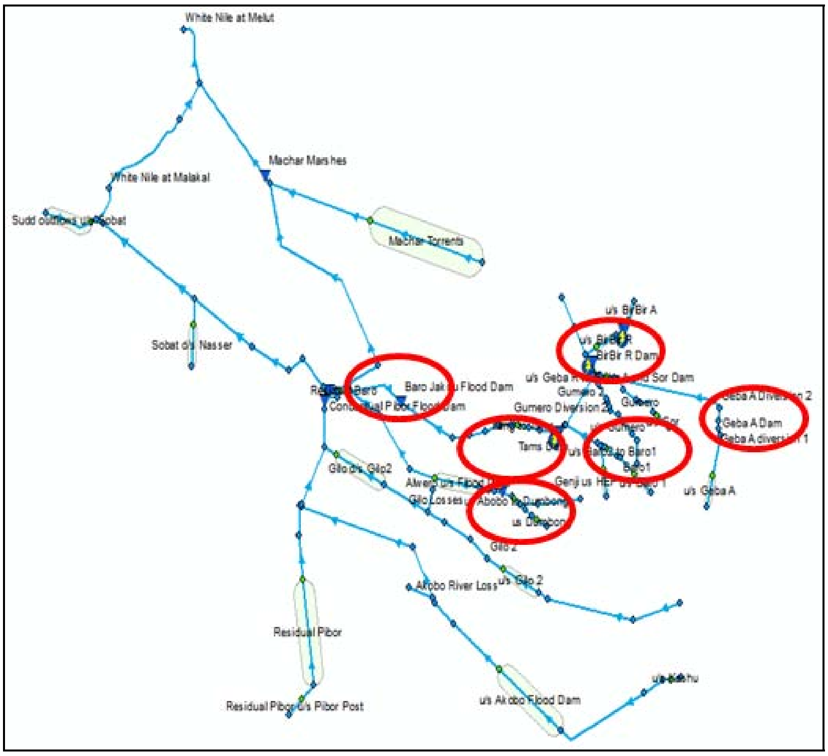

Figure 2: Irrigation and Hydropower proposed projects in the BAS

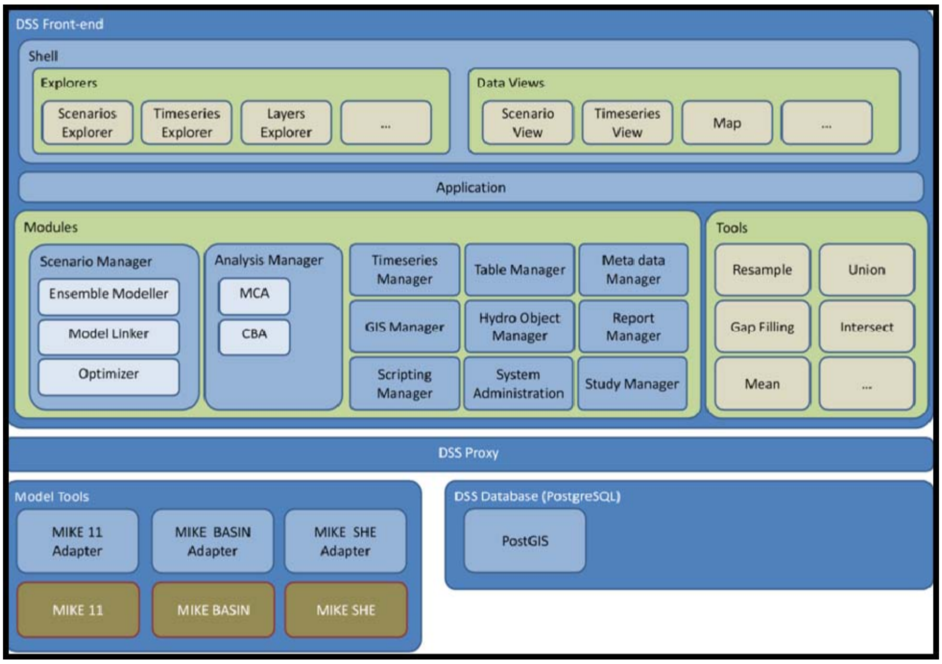

Figure 3: NBDSS Layout and Components

5.1 Scenario Definition

The approach adopted for scenario implementation involved the modification of the BAS baseline model within the entire Nile Basin for representation of the various development and management options (Irrigation, Hydropower, Irrigation +Hydropower). A baseline and four other scenarios for the development of BAS and its impact on downstream were identified. A simulation period of 1951 to 1990 was used for all scenarios. This short simulation period is due to the lack of complete data in all sites within a larger and later period. The scenarios are based on the full future development interventions in the BAS within the context of the entire basin as follows:

Scenarios	**Description**
S0	**Baseline: Current situation**
S1	**BAS planned projects(Irrigation +Hydropower):** **TAMS Dam (Hydropower)** **Birbir A and Birbir R Dams (Hydropower)** **Itang Irr Scheme** **Gilo-2 Dam and Irr Scheme** **Baro-1 and Baro-2 Dams (Hydropower)** **Geba-A and Geba-R dams (Hydropower)** **Dumbong Dam and Irr Scheme** **Genji Scheme (Hydropower)**
S2	**Integrated BAS and Equatorial Lakes projects :** **Scenario 1+** **Bugesera Irrigation in the Kagera** **Rusumo Falls run-of-river scheme, hydropower and irrigation** **Kakono Dam, hydropower and irrigation** **Karuma Dam and Hydropower** **Ayago Dam and Hydropower** **Kano Irrigation Scheme** **Magwagwa Dam and Hydropower** **Sondu Miriu Dam and Hydropower** **Nandi Forest Dam and Hydropower**
S3	**BAS Hydropower projects**
S4	**BAS Irrigation projects**

The following tables (Tables 1 and 2) represent some detailed information regarding the proposed hydropower dams and irrigation projects within the BAS sub basin. Hydropower project's data as well as estimated areas and crop water requirements for future irrigation schemes were based on the following sources of information"

- "Baro-Akobo River Basin Integrated development Master Plan Study .Annexure 1H - Irrigation Projects and Annexure 1J - Hydropower " TAMS (May 1997) and the main report of the "Baro 1 & 2 Multipurpose Projects including Genji Diversion Scheme". Feasibility Study (Norplan, Norconsult and Laymeyer International,2006 .
- ENTRO. 2007. Eastern Nile Power Trade Program Study. Prepared by EDF and Scott Wilson
- The series of reports named ".Data Compilation and Pilot Application of the Nile Basin Decision Support System (NB-DSS): Work Package 2: Stage 2: Scenario Analysis Reports" for: Integrated Nile Basin and Integrated Water Resource Development of the Baro-Akobo Basin. (NBI, 2012) represent the source of compiled information and model configuration for the BAS sub basin, the Equatorial Lakes Plateau and its planned projects, and the entire basin baseline configuration.

Table 1: BAS Planned HP Dams

	TAMS	Birbir A	Birbir R	Baro1	Baro2	Geba R	Genji
Dam Crest Level (masl)	760	1430	1158	1520	1320	2170	Run-of-River
Dead Storage (masl)	705	1410	1056	1485	1318	2160	
Bottom Level (masl)	500	1390	980	1439	1293	2130	
Flood Control Level (masl)	760	1430	1158	1520	1320	2170	
Installed Capacity (MW)	1060	95	465	180	500	1071	214
Target Power (MW)	633	95	275	94	253	1071	214
Total Installed Capacity (MW)	3585						
Total Target Power (MW)	2635						

Table 2: BAS Planned Irrigation Dams

	Dumbong	TAMS	Gilo2
Dam Crest Level (masl)	**513.5**	**760**	**473**
Dead Storage (masl)	**506**	**705**	**40**
Bottom Level (masl)	**480**	**500**	**440**
Flood Control Level (masl)	**513.5**	**760**	**473**
Installed Capacity (MW)		**1060**	
Target Power (MW)		**633**	

Proposed irrigation schemes are as follows: Itang Scheme (530 km^2), Gilo2 Scheme (470 km^2), as well as the development of an additional sugarcane irrigation scheme at Dumbong (150 km^2).

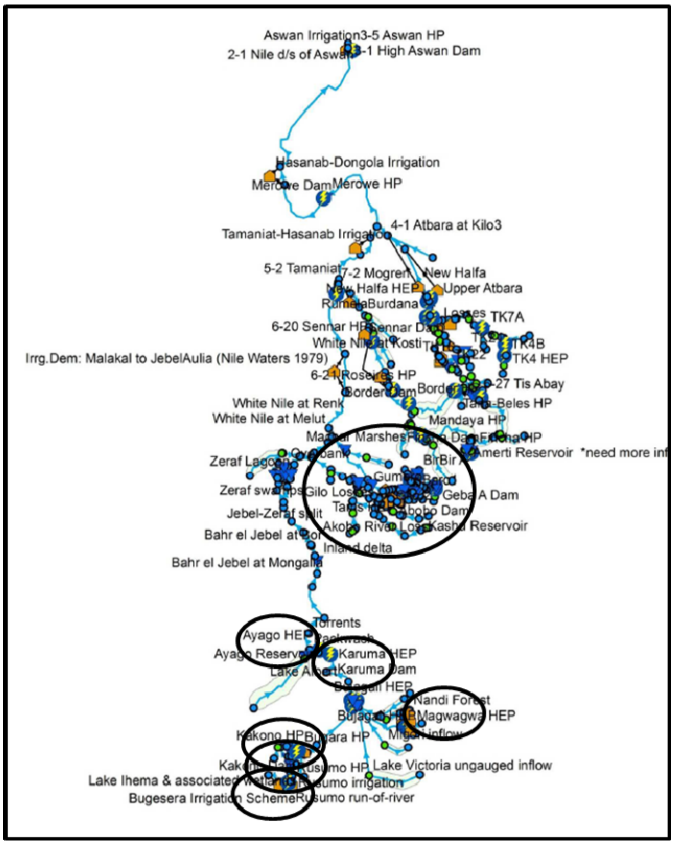

Figure 4: Irrigation and Hydropower Proposed Projects in the BAS and Equatorial Lakes (Scenario2)

5.2 Indicators' Selection and Results

Indicators quantify and simplify information in a manner that facilitates understanding of environmental, social and economic implications related to water resource interventions. Only Six basic environmental indicators **were** selected from a list of thirteen indicators installed in the NB DSS to describe possible changes that could be linked to the proposed development interventions as shown in Table 3.They were grouped into two categories viz. Footprint Areas and downstream.

Table 3: Environmental Indicators Definitions and Measurement Units

Indicator			
Category	**ID**	**Name**	**Units**
Footprint Areas	**EN3**	**Fisheries production**	**tons/a**
	EN4_1	**Floodplain Area Inundated (Recession Agriculture)**	**% change compared to baseline**
Downstream Areas	**EN4_2**	**Wetland Area Inundated**	**change compared to baseline (% or Area in km2)**
	EN5	**Ecological Stress**	**Index**
	EN6	**Biological Production: Wet season duration based on median monthly flows**	**% change compared to baseline**
	EN10	**Seasonal Shift**	**no weeks delay in onset of wet season**

Three different social indicators out of fifteen under the following two social categories were selected: water availability, community health and safety (Table 4)

Table 4: Social Indicators Definitions and Measurement Units

Indicator		
Category	**ID**	**Units**
Water Availability	**SO1**	**% Change from Baseline**
Community Health and Safety	**SO3**	**Prevalence of diseases resulting from pest species (index)**
	SO4	**Time of decay (h) to acceptable coliform concentrations**

Three out of ten economic indicators were derived. These typically included navigation and hydropower production as presented in Table 5. The reason behind the selection of these specific indicators for this case study in each sector (environmental, social and economic) is their clearness, simplicity, measurability and their possible comparability which can clearly reflect the expected impact of different interventions on the water resources availability and livelihood of the stakeholders within the footprint area as well as in the downstream.

Table 5: Economic Indicators Definitions and Measurement Units

Indicator			
Category	**ID**	**Name**	**Units**
Navigation	**EC1**	**Navigability – Vessels**	**Change from Baseline in days/year**
Energy	**EC21**	**Average Energy generated at specific HP node**	**GWh/a**
	EC22	**Total Average Energy generated – system wide**	**GWh/a**

5.3 Environmental Indicators Results

As shown inTable 6, the fishery production indicator (EN3) is calculated in both foot print area (Different Sudd locations and Mashar Marches) in addition to the downstream Dams on the White and Main Nile under all scenarios. The summation of all is configured as an evaluation criteria “Total Fish production”. Percentage change in the flood plain inundated area (indicator on recession agriculture-EN41) is also calculated in the lower BAS and in the main Nile downstream Khartoum being the key areas where change due to cumulative interventions could be measured. Percentage change in inundated wetland area (EN42) is calculated in Mashar Marches, while ecological stress index (EN5) was calculated in Sudd inflow, BAS outflow and the lower Main Nile in order to reflect the ecological stress taking place in response to different proposed scenarios. Percentage change in the biological production (EN6) represented by the wet season duration (based on median monthly flows) is calculated in the lower main Nile in order to assess the cumulative impact of different possible interventions. The seasonal shift represented with the number of weeks delay in onset of wet season (EN10) is calculated in Sudd inflow/outflow; BAS outflow and lower Main Nile since they represent key areas of change in the flow regime after different implementation of the different activities. Two other direct indicators are also considered due to their high importance in reflecting the magnitude and direction of impact: the mean annual outflow from Lake Victoria (i.e. impact of EL development) and mean annual inflow to Aswan (i.e. downstream impact of BAS and EL development).

Table 6: Environmental Indicators Results

Scenario	Baseline integrated (S0)	BAS integrated Irr-HP (S1)	BAS-EL integrated (S2)	BAS HP (S3)	BAS Irr (S4)
EN3 Jebel Aulia Dam	4970.90	3975.10	3975.10	3975.10	3975.10
EN3 Merowe Dam	1720.30	1720.30	1720.30	1720.30	1720.30
EN3 Aswan Dam	16712.30	16851.7	16845.8	16902.5	16777
EN3 Mashar Marshes	11128.00	6224.6	6220.8	6369.7	10984.7
EN3 Sudd557	32199.90	31446.1	28829.3	32205.7	32226.1
EN3 Sudd552	2026.50	2029.7	2034.4	2024	2024.5
EN3 Sudd553	38988.40	38896.6	38653.1	39017.7	39017.1
EN3 Sudd554	2063.00	2063.9	2061.7	2064	2062.8
EN3 Sudd555	37371.70	36894.7	34568.1	37452.7	37437.1
EN4_1 Lower BAS	0	-5.1	-0.3	2.3	0
EN4_1 Main Nile ds	0	19.8	18.7	22.7	21.2
EN4_2 Machar Marshes	0	-50	-50.1	-48.7	-1.6
EN5 Sudd Inflow	0	-1.00	-1.00	-1.00	-1.00
EN5 BAS outflow	0	-5	-4	-5	-3
EN5 Lower Main Nile	0	-2.00	-2.00	-2.00	-2.00
EN6 Lower Main Nile	0	9.2	9.6	10.2	8.1
EN10 Sudd Inflow	0	0.6	2	0.3	0.3
EN10 Sudd outflow	0	0.7	0.7	0.3	0.4
EN10 Lower Main Nile	0	0.3	0.3	0.1	0.3

Environmental indicators reveal reduction in fish production reaching 44 % in Mashar Marshes in all scenarios except scenario 4 where reduction reaches only 1% since water for irrigation will be available in the foot print area. In Jebel Aulia Dam, all scenarios show that fish production is reduced by 20% since it is directly impacted by the development of BAS and/or EL, while some of the Sudd region areas mark slight reduction not exceeding 10% under scenario 2 due to reduction in water levels resulting from dams’ construction and irrigation in the EL.

Recession agriculture practiced on flood plains will be slightly reduced in lower BAS by 5% under scenario1 due to irrigation and increased by 2% under scenario3 since hydropower dams release water after HP generation. No change occurs under scenarios 2 due to the independence of the two sub basins

(BAS and EL). Recession agriculture in Main Nile downstream Khartoum will increase ranging from 20 to 23% under all scenarios due to flow increase in both white and main Nile after using the losses usually wasted in the BAS, Mashar Marshes and EL. Mashar Marsh's wetlands will be reduced by about 50% under all scenarios. This reduction comes as a result of water regulation.

The developments associated with all Scenarios will significantly increase the ecological stress along the lower BAS with a negative index varying from-3 to -5 while lower main Nile displays a negative index of -2. The Sudd inflow will not be severely impacted and displays a negative ecological stress index of -1. Under all Scenarios, the wet season duration along the lower Main Nile will increase with about 8 to 10 % compared to baseline

A shift in the start of the wet season will be experienced along the Sudd inflow: 2 weeks (scenario 2), 4 days (scenario1) and 2 days (scenarios 3-4). Sudd outflow wet season will be shifted by 5 days (scenarios 1- 2), 3 days (scenario 4) and 2 days(scenario 3). But the only scenario which should be considered in the Sudd region is scenario 2 since the development of BAS will not have a direct impact on this region. Lower main Nile wet season is expected to have only a 2 days shift (Scenario 1-2-4).

5.4 Social Indicators Results:

Table 7 represents the Social Indicators Results under different scenarios.

Table 7: Social Indicators Results

Scenario	Baseline (S0)	BAS only integrated Irr-HP (S1)	BAS-EL integrated Irr-HP (S2)	BAS HP (S3)	BAS Irr (S4)
SC1 ds Equatorial Lakes	0	-1	-2.9	0.2	0.1
SC1 Lower BAS	0	154.6	148.9	175.7	-44.3
SC1 Lower Main Nile	0	15.5	10.5	17.2	-8.1
SC3 ds Equatorial Lakes	0	0	0	0	0
SC3 Lower Bas	0	-3	-3	-3	0
SC3 Main Nile ds Khartoum	0	0	0	0	0
SC3 Lower Main Nile	0	0	0	0	0
SC4 ds Khartoum	0	40.2	40.2	40.2	40.2
Mean Annual Outflow Lake Vic	945.27	946.88	915.72	946.88	946.88
Mean Annual Inflow to Aswan	2457.06	2569.42	2560.06	2592.27	2570.81

Water availability represented by the percentage change of Dry season low flow (Median flow during lowest consecutive 3 months in dry season) is reduced by 2.9% under scenario 2 downstream Equatorial Lakes due to development projects in the EL. Water availability increases by 155%, 149%, 175% (scenarios 1-2-3 respectively) due to increased flow regulation, and decreases by 44% (scenario 4)due to irrigation activity. In lower BAS, it also increases by 16%, 10% and 17% in lower main Nile (scenarios 1-2-3) and decreases by 8% (scenario4).

Prevalence of diseases resulting from pest species index reaches -3 in lower BAS due to water recession of Mashar Marshes. Time of decay to acceptable coliform concentration downstream Khartoum remains the same (40 hours) under all scenarios which indicates that different development scenarios have the same impact on water quality in the downstream.

Finally, the mean annual outflow from Lake Victoria diminishes by 3% (scenario 2) due to the development of the EL region and the mean annual inflow to Aswan increases by 4 to 5.5 % under scenarios (1-2-4) due to losses exploitation in the BAS wetlands.

5.5 Economic Indicators Results

Economic Indicators' Results are shown in Table 8.

Table 8: Economic Indicators Results

Scenario	Baseline (S0)	BAS only integrated Irr-HP (S1)	BAS-EL integrated Irr-HP (S2)	BAS HP (S3)	BAS Irr (S4)
EC1 Lower BAS	0	77	77	79	-27
EC1 Main Nile ds Khartoum	0	-8	-13	-5	-28
EC21 Jebel Aulia	188.43	187.5	187.5	192.0	183.1
EC21 Aswan	5047.97	5298.782	5277.953	5503.754	5101.896

Economic benefits are closely related to additional hydropower generation, improved navigation and increased food production. The economic indicators reveal a considerable increase in navigability on the lower BAS 77 to 79 days per year except in scenario 4where a reduction of 27 days per year takes place. On the other hand, a reduction in navigability will take place in the Main Nile downstream Khartoum by 8,13,5 and 28 days per year in scenarios 1-2-3-4 respectively. The considerable deterioration in navigation under scenario 4 in both regions is due to the water consumption for irrigation in the BAS which reduces the flow in the river system compared to baseline.

Average Energy generated at Aswan increases under all scenarios by around 200 to 300 GWh while it is very slightly negatively affected in Jebel Aulia under scenario 4 due to water consumption for irrigation and positively under scenario 3 due to upstream regulation by constructed dams.

5.6 Multi Criteria Analysis

In general, Multi Criteria Analysis (MCA) is used in order to assess how interventions affect the direction of change in environmental, social and economic performance, and to measure the magnitude of that change. MCA is concerned with structuring and solving decision and planning problems involving multiple solutions and criteria that don't have a unique optimal solution. It is a support tool where preferences are used to differentiate among solutions for decision makers who face such problems. Many MCA techniques exist. The NB DSS implements the MCA Decision Matrix which compares criteria for various solutions (aka scenarios), weighted by preferences in a matrix form. It allows comparison of multiple decision matrices that were created by different stakeholders. Figure 5 is a scheme which explains the MCA process and its application in the NBDSS.

5.7 Evaluation Criteria

The evaluation criteria were defined for a comparison of scenarios 1, 2, 3 and 4 along with their calculated values. The criteria were categorized into three groups representing the MCA sessions: Environmental, Social and Economic. Table 9 summarizes the evaluation criteria that were defined for a comparison of the four scenarios along with their calculated values.

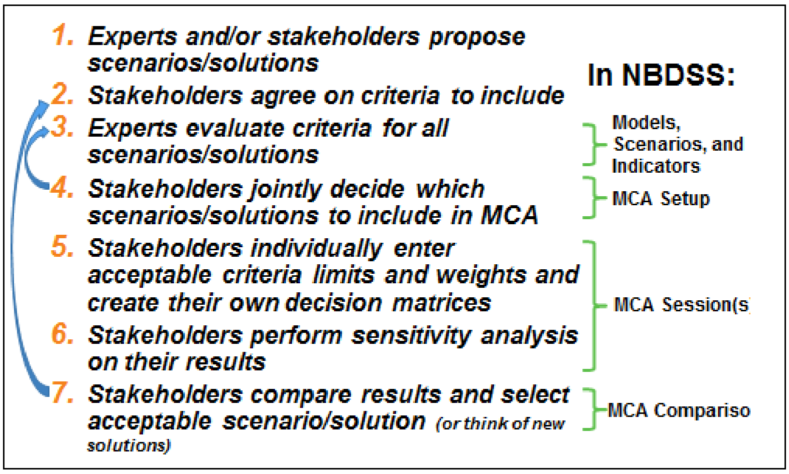

Figure 5: Scheme Explaining the MCA process and its application in the NB DSS

Table 9: Evaluation Criteria

Criteria	Group	Unit	Baseline (S0)	BAS only integrated Irr-HP (S1)	BAS-EL integrated Irr-HP (S2)	BAS HP (S3)	BAS Irr (S4)
Total Fish Production (Sum of EN3 in all sites)	ENV	ton/a	163164	150847	156070	157717	162209
Area Inundated US Sudd	ENV	% change compared to baseline	0	-3	-1	0	0
Inundated area Lower BAS	ENV	% change compared to baseline	0	0	-5	2	0
Area inundated DS Khartoum (Main Nile)	ENV	% change compared to baseline	0	19	20	23	21
Mashar Marshes inundated	ENV	% change compared to baseline	0	-50	-50	-49	-2
BAS Ecological stress	ENV	Index	0	-4	-5	-5	-3
Lower Main Nile Ecological stress	ENV	Index	0	-2	-2	-2	-2
Lower Main Nile Biological Production(wet season duration)	ENV	% change compared to baseline	0	10	9	10	8
Sudd Seasonal Shift (Average EN10 Sudd inflow and outflow)	ENV	weeks	0	1	1	0	0
Lower Main Nile Seasonal Shift	ENV	weeks	0	0	0	0	0
Water Availability in Lower BAS	SOC	% change compared to baseline	0	149	155	176	-44
Water Availability in Lower Main Nile	SOC	% change compared to baseline	0	11	16	17	-8
Prevalence of diseases (SC3 ds Equatorial Lakes+ Lower Bas+ Main Nile ds Khartoum+ Lower Main Nile)	SOC	index	0	-1	-1	-1	0
Mean Annual Outflow Lake Victoria	SOC	m3/sec	945	916	936	949	948
Mean Annual Inflow to Aswan	SOC	m3/sec	2457	2564	2571	2633	2514
Navigability DS kartoum	ECO	days/year	0	-13	-8	-5	-28
Average Energy gnerated at Jebel Aulia	ECO	GWh/a	188	187	188	192	183
Average Energy Generated at Aswan	ECO	GWh/a	5048	5278	5299	5504	5102

5.8 Weights

Five different groups of stakeholders where defined as MCA sessions, each having different priorities defined by weighted criteria: in the BAS (environment, social and economic) criteria were weighted for each MCA session, in addition to two down streamers in both Khartoum and Aswan with different weighted criteria. Table 10 summarizes the weights allocated to the different criteria for the five MCA sessions which were considered.

Table 10: Weights Allocated to Different MCA sessions

Criteria	BAS Env	BAS Soc	BAS Eco	Main Nile Khartoum	Main Nile Aswan
Total Fish Production	4	7	4	8	7
Area Inundated US Sudd	9	14	12	13	16
Inundated area Lower BAS	3	6	7	11	9
Area inundated DS Khartoum (Main Nile)	6	9	9	2	8
Mashar Marshes Inundated	2	5	6	12	10
BAS Ecological stress	1	4	5	10	11
Lower Main Nile Ecological stress	5	8	8	1	3
Lower Main Nile Biological Production(wet season duration)	7	10	10	3	4
Sudd Seasonal Shift	10	15	13	14	17
Lower Main Nile Seasonal Shift	8	11	11	5	5
Water Availability in Lower BAS	11	1	14	9	12
Water Availability in Lower Main Nile	14	3	15	4	1
Prevalence of diseases	12	2	16	15	13
Navigability DS Khartoum	18	18	2	6	14
Average Energy Generated at Jebel Aulia	16	17	1	7	15
Average Energy Generated at Aswan	17	16	3	17	6
Mean Annual Outflow Lake Victoria	15	13	18	18	18
Mean Annual Inflow to Aswan	13	12	17	16	2

5.9 Scenario Evaluation Results

The following matrices represents the ranks and scores resulting from different MCA sessions based on the weighted criteria previously selected for each session and under each scenario. The summary of the results shows that BAS HP scenario has the highest rank in all MCA sessions in both BAS and downstream. The baseline scenario is ranked second, BAS irrigation third, BAS Irr-HP fourth and BAS-EL last under all MCA sessions. Table 11 and Figure 6 represent the ranks and scores resulting from different MCA sessions.

Table 11: Ranks Resulting from Different MCA Sessions

	BAS eco	BAS soc	BAS env	Main Nile Aswan	Main Nile Khartoum
Baseline	**2**	**2**	**2**	**2**	**2**
BAS-EL	**5**	**5**	**5**	**5**	**5**
BAS Irr-HP	**4**	**4**	**4**	**4**	**4**
BAS HP	**1**	**1**	**1**	**1**	**1**
BAS Irr	**3**	**3**	**3**	**3**	**3**

	Main Nile Khartoum	Main Nile Aswan	BAS soc	BAS env	BAS eco
Baseline	1.066	0.960	0.960	1.054	1.525
BAS-EL	0.602	0.400	0.400	0.107	0.871
BAS Irr-HP	0.860	0.549	0.549	0.470	1.118
BAS HP	1.315	1.036	1.036	1.192	1.644
BAS Irr	1.003	0.817	0.817	0.966	1.447

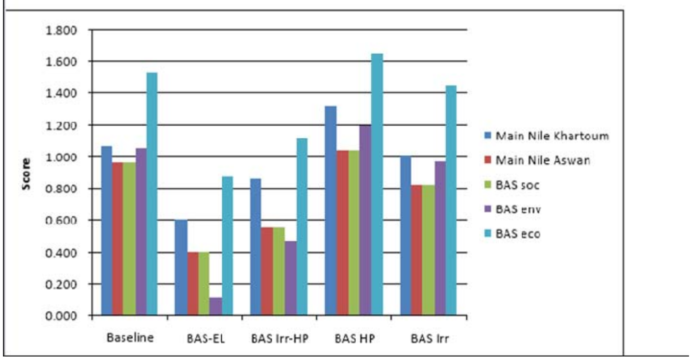

Figure 6: Scores resulting from different MCA sessions

6 CONCLUSION

- The study shows that HP development in the BAS is the best alternative under all scenarios and for all the stakeholders' from the BAS sub basin and downstream. This scenario is followed by the baseline one (current situation) while the irrigation development of the BAS is ranked third, followed by the integrated (Irrigation and hydropower development) and finally the accumulated hydropower and irrigation development in both BAS and EL combined.
- Environmental Impact:
  - Total fish production will be reduced under all scenarios. The reduction ranges from 0.5 to 7.5 %.

  - Inundated area upstream Sudd region will be reduced by 3% due to the development of the EL region while it will be reduced by 5% in the lower BAS (scenario2) and increased by 2% (scenario 3). Mashar marshes inundated area is severely affected since it is reduced by 50% under all scenarios except scenario 4.The inundated area in the main Nile downstream Khartoum increases in a range of 19 to 23% under all scenarios.
  - The developments associated with all Scenarios will significantly increase the ecological stress along the lower BAS with a negative index varying from-3 to -5 while lower main Nile displays a negative index of -2. The Sudd inflow will not be severely impacted and displays a negative ecological stress index of -1.
  - Under all Scenarios, the wet season duration along the lower Main Nile will increase with about 8 to 10 % compared to baseline
  - An average one week shift in the start of the wet season is expected along the Sudd region due to EL development.
- Social Impact:
  - Water availability represented by the percentage change of Dry season low flow is reduced by 2.9% compared to baseline due to development projects in the EL, while it increases in lower BAS by 149% to175% under all scenarios due to increased flow regulation, except the BAS irrigation scenario where it decreases by 44% due to irrigation activity. Water availability increases ranging from 10% to 17% in lower main Nile and decreases by 8% only in the BAS irrigation scenario.
  - Prevalence of diseases resulting from pest species index reaches -3 in lower BAS due to water recession of Mashar Marshes.
  - Finally, the mean annual outflow from Lake Victoria diminishes by 3% due to the development of the EL region and the mean annual inflow to Aswan increases by 4 to 5.5 % under all scenarios due to losses exploitation in the BAS wetlands.
- Economic Impact:
  - Navigability increases considerably in the lower BAS by77 to 79 days per year except in scenario 4where a reduction of 27 days per year takes place. On the other hand, a reduction in navigability will take place in the Main Nile downstream Khartoum ranging from 8 to 28 days per year. The considerable deterioration in navigation under BAS irrigation scenario in both areas is due to the water consumption for irrigation in the BAS which reduces the flow in the river system compared to baseline.
  - Average Energy generated at Aswan increases under all scenarios by around 200 to 300 GWh while it is very slightly negatively affected in Jebel Aulia under scenario 4 due to water consumption for irrigation and positively under scenario 3 due to upstream regulation by constructed dams.
  - From previous, it can be concluded that BAS sub basin has significant potential for hydropower and irrigation development and that there is a great opportunity to develop basin wide win-win solutions through regional planning and management of available resources.
  - The NB DSS is a good and promising tool to study all water resources development projects at both local and regional levels.

7 RECOMMENDATIONS

- There is a need to introduce and calculate more clear and direct indicators in order to correctly and accurately assess the development impact within the study area and its' downstream.
- More detailed information and longer time series can help in a better simulation of the Nile Basin. In this regard and on a wider scope, a solid updated and living database of water levels, discharges and water quality indices for the entire Basin is a crucial need.
- This work needs to be applied for the rest of the sub basins in order to study the impact of the development of each sub basin alone and the cumulative effect of development on the sub basin itself and downstream.

- In this case study, due to short time and for simplicity, optimization exercise was not applied. It is recommended that Future case studies include the application of optimization.

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