Water Energy and Food Nexus: Application in KhorKlabsha

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Abstract

Significant impact on Nasser Lake (NL) inflow is highly expected due to unilateral on-going development plans in some of Nile Basin countries and climate change negative impacts. For decades, NL is considered Egypt's fresh water Bank, where Nile water is stored during flood to be used during the recession for agriculture, industrial and municipal uses. The expected development activities will have adverse effects on Egyptian water resources, therefore new operation strategies and changes in infrastructure are needed to adapt with such effects. New creative ideas are suggested based on applying large scale Water-Food-Energy (WEF) nexus approach, to propose a development plan in KhorKlabsha a major water body within the lake. Using advanced tools to select the best scenario to implement the proposed plans, results show two main essential factors, namely the energy losses (between pumping and hydropower) and the limited capacity of Old Aswan Dam (OAD) reservoir. In addition to the economic feasibility of constructing renewable energy plants and the proposed infrastructure, the WEF nexus approach in KhorKlabsha offers an opportunity to meet future challenges. New operation strategies are proposed for NL to enable using water of dead storage zone (below 147 m AMSL) after considering its quality.

Keywords: Nile Basin,WEF Nexus, Nasser Lake (NL), KhorKlabsha, High Aswan Dam (HAD), Old Aswan Dam (OAD), Arc-GIS, RIBASIM 7, Pump Station, Run-of-River

1. INTRODUCTION

Nexus literally means "*connection between things in a series*", and the Water-Energy-Food (WEF) nexus focuses on the linkages between the three nexus themes. The main rationale for those promoting WEF nexus is that as the different nexus themes are so closely related, they should be looked at simultaneously to encourage win-win situations, avoid negative impacts and, ultimately, enhance sustainability. The nexus focuses on system efficiency rather than on the productivity of isolated sectors (Hoff, 2011). As an evaluation for WEF nexus in Egypt,harvesting synergies and reducing negative trade-offs across sectors and resources, including efforts to increase cross-resource efficiencies and subsequently to also increase water, energy, and food security, requires coordination across sectoral institutions, strategies, policies, and activities. Only a coordinated approach will ensure that efforts in one sector do not cause negative effects in another sector but complement each other and generate synergies (GIZ, 2017). This paper presents a new idea for applying large scale WEF nexus in Egypt, particle in KhorKlabsha in NL as one of the most promising area rich with energy potential, water and land.

Nasser Lake (NL) or High Aswan Dam Lake (HADL) is one of the promising regions in Egypt, where nexus approach is recommended to be applied to achieve sustainable development. Although NL considered as the valuable fresh water bank for Egypt, abundant natural resource is under development around, including renewable energy, land reclamation and mining. Development plans in the region started years ago including New valley project, Toshka Pump Station and recently Benban Solar Park (EgyptEnergy, 2018)

Linked to new road networks, ports and infrastructure to enhance the investment activities and trade with Sudan.

Future challenges expected to change the current situation of NL. Studies showed negative impacts on the Nile flow resulted from Climate Change and unilateral development plans of some Upstream Nile Basin countries (Eman Sayed, 2014). Equally important, renewable sources of energy have been developed extensively. These energy sources present new challenges in meeting the electricity demand because they are intermittent. The best option to deal with the stochastic nature of these renewable energy sources is constructing new pumped storage plants. It plays a key role in the development and penetration of renewable energy, as it facilitates a real-time balance between generation and demand.

There are many successful a well-known example for dealing with similar management problems of large dams and fresh water lakes, recently Los Angeles Department of Water and Power, the original operator of Hoover dam when it was constructed in 1930s, wants to equip it with a $3 billion pipeline and a pump station powered by solar and wind energy. The pump station downstream would help regulate the water flow through the dam’s generators, sending water back to the top to help manage electricity at times of peak demand (Scott, 2011). Consequently, and for the purpose of this research, KhorKlabsha was selected to apply a large scale WEF nexus approach in NL.

1.1. Study Area

The shoreline of the NL has numerous embayment which are called Khor, the total number of important khors are 85 of which 48 lie on the eastern side and 37 on the western one (Mola, 2014). KhorKlabsha is one of the major "khors" of the lake, located on the northern part of the lake with largest surface area and highest evaporation volume compared to the other khors.Khor Kalabsha is also known as Khor Abu Sinnah (getamap, 2016), Its coordinates are 23°33'0" N and 32°49'60" E in DMS (Degrees Minutes Seconds). Khor Kalabsha is the second largest khor in the lake. It is about 30 km upstream of the HAD, in the Western Desert. It has a surface area of 600 Km^2, about 10% of the lake’s entire area. It loses about 2700 mm of water annually, due to evaporation (Emad Elba, 2014).

Figure 1 shows a preliminary layout for the proposed development plan according to WEF nexus approach. A new management perspective is presented to turn challenges to opportunities through applying WEF nexus in KhorKlabsha as part of NL, available renewable energy around the lake could be used to pump a specific volume of KhorKlabsha water to a carrier transferring water to an advanced irrigation scheme, providing supplementary irrigation for new cultivated land, the major water volume would be converted to a proposed Run-of-River hydropower station to generate base-load energy for Egypt national grid. Despite of the energy losses and the possibility of regenerate same amount of the used energy according to hydropower stations design and characteristics (El-Bahrawy.A.N, 1999), proposed plan offers opportunity to pump water from NL dead storage zone below 147 m (AMSL) as worst case scenario expected for drought decades in future, Moreover, water will be provided for agricultural expansion to achieve new economic gain.

1.2. Available Tools

This reserach contains the description of different tools and assumption used to identify the possibility and preliminary limitation of the proposed plan. Based on historical survey maps before HAD construction and new bathymetric survey missions, Arc-GIS was used to create Digital Elevation Model (DEM) for KhorKlabsha to identifies water level, surface area and storage relationships (Godone, 2013). Furthermore, hydrological analysis was conducted to give an overview regarding KhorKlabsha water content and evaporation. Finally, Deltares-RIBASIM 7 simulation model for NL was used to exam different alternatives to find out the best management scenario for the proposed development plan (Krogt, 2015). Next sections will focus on the tools and analysis used in this study and the final conclusion.

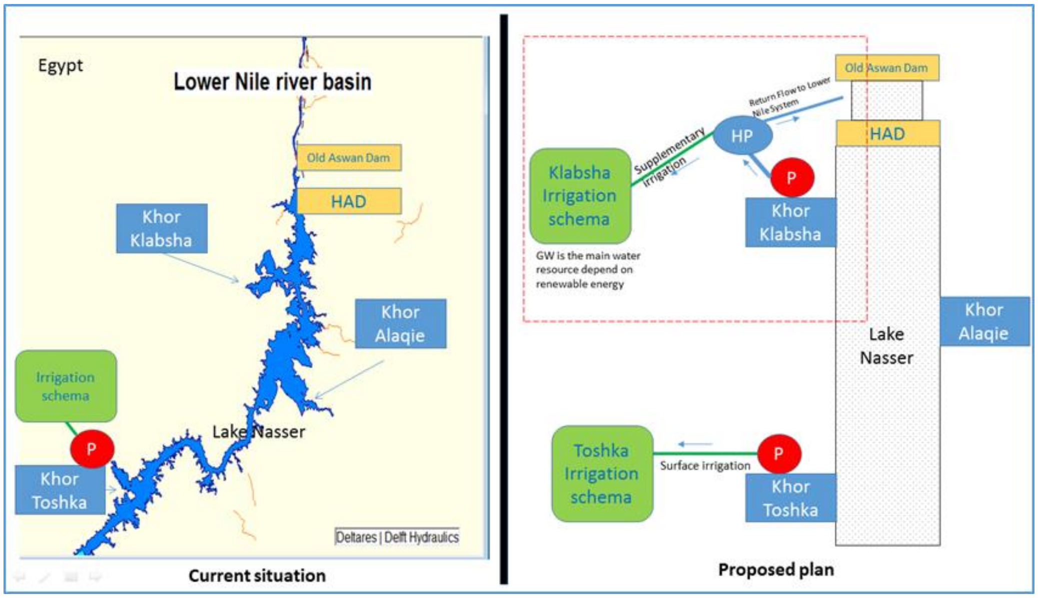

Figure 1: KhorKlabsha proposed plan preliminary layout (study area)

2. METHODOLOGY

2.1. Bathymetric Representation of KhorKlabsha

Digital Elevation models (DEM) are key tools in land analysis and management as they are directly employable in Geographic Information System (GIS) systems and other specific applications like hydraulic modelling, geotechnical analyses, road planning, telecommunication, and many others (Godone, 2013). In this study, Arc-GIS 3D-Analyst tool was used to process the available topographic data before HAD construction to create KhorKlabsha DEM, starting from level 87m (AMSL). The purpose of is to investigate the relation between: Water Level, Surface Area and Water Volume using the best interpolation technique to simulate KhorKlabsha topography. Projected (WGS-1984-UTM-Zone 36 N) contour lines and spot heights from different sources combined together to create initial raster image file with a pixel resolution of 1294m. Moreover, as an additional enhancement, many interpolation techniques have been examined to refine the relation and increase DEM resolution to 10m*10m.

2.2. Hydrological Analysis Of KhorKlabsha

Based on previous section, hydrological analysis has been conducted using the bathymetric representation to determine KhorKlabsha water volume of storage and evaporation, available NL upstream level time series historical record and average evaporation rate have been used to conduct the hydrological study. However, seepage losses in this study were neglected as it has a minor effect.

2.3. The WEF Nexus Model Of NL

2.3.1. Model description

River basin simulation models are important tools in water management studies of river basins. Such studies often pertain to complex water resources systems, and require the analysis of large amounts of data. In this part NL simulation model will be conducted using a computer program packages for simulation of river basin management developed at Deltares | Delft Hydraulics is the package called RIBASIM, acroznym for river basin simulation. Due to its good reputation and practical experience gained from study cases around the world, MWRI of Egypt consider RIBASIM as reliable software program tool for water management and planning efforts. An educational version of RIBASIM 7 has been used for the purpose of this study, different assumptions, conditions, inputs and scenarios were used to simulated the water balance of NL (Krogt, 2015), generated power and proposed alternatives. Results have been calibrated and validated with real data to examine the model quality. for the purpose of this study, NL schematization was developed to simulate the current situation in the lake and examine the new development plan as shown in Figure , the model scheme interface includes maps, nodes and links.

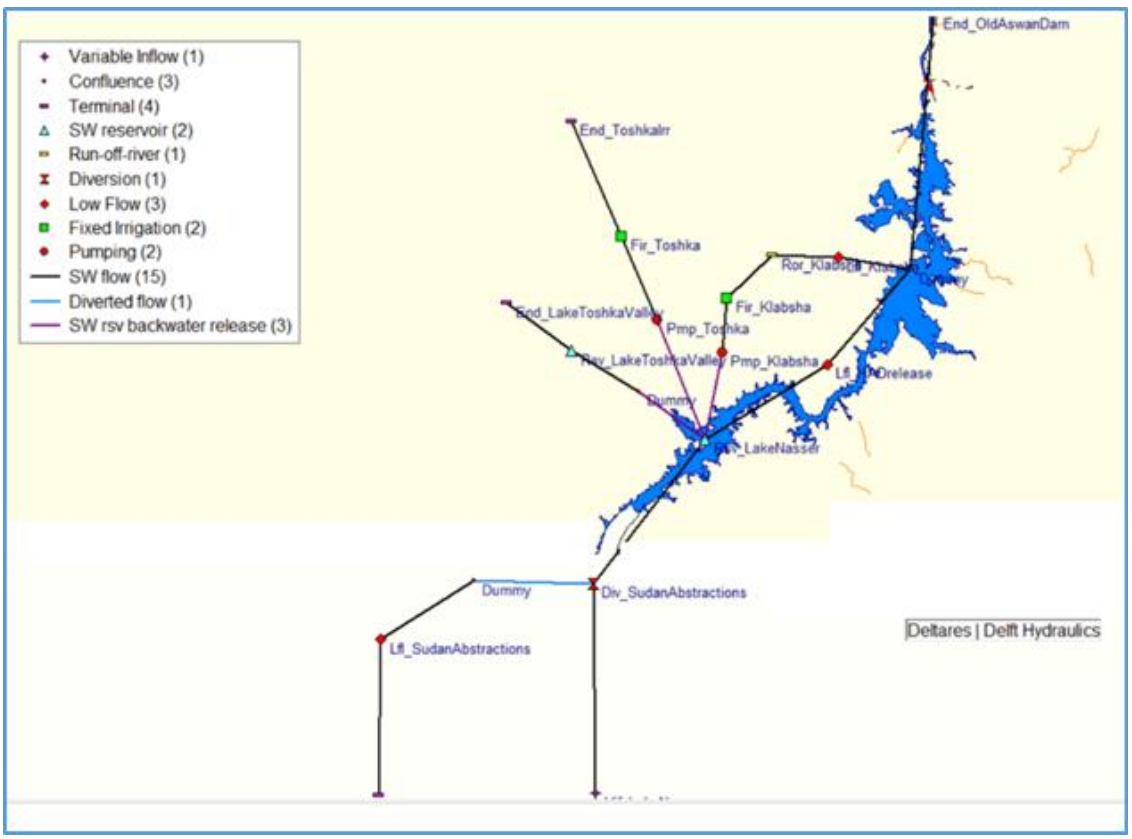

Figure 2: Nasser Lake Model Schematization

2.3.2. Model Assumption

Available data and model development were based on earlier work of Deltares on behalf of MWRI; Lower Nile scheme was presented including the required data as a package with the educational version of RIBASIM 7 during the training course held in Cairo in August 2015 (Krogt, 2015). This data includes time series and spatial datasets, models, and reports. Subsequently, a gap analysis has been performed to identify the additional data needed to complete this study.

For the purpose of running RIBASIM simulation, "Natural flow at Aswan" time series has been used as inflow to simulate the water balance of NL; 10 days' time series represents different hydrological condition including flood/drought periods starting from 1 January 1871 till 31 December 2002 (Krogt, 2015).

Since HAD construction, a new hydrological system for the lower Nile River was familiarized in Egypt. Hydropower generation was the main factor affecting the management decisions but recently demand management approach is applied. Nasser Lake schematization contains the most common assumption regarding all elements affecting the water balance of the lake, which includes only the inflow and outflow of NL, average evaporation rate, HAD operation rules, Toshka Pump station characteristics and Egypt-Sudan abstraction according to 1959 agreement.

2.3.3. Model Calibration

For the purpose of calibrating and validating RIBASIM simulation model only, the data for the period (August 1975-December 1995) were used to represent the same boundary conditions (after NL filling and before starting the construction of MeroweDam in Sudan). In spite of the quality of the well-known model used in this study, and prior calibration and validation steps conducted during previous national studies in Egypt, the next part contains an accurate description of the results of calibration process for model schematization used in this study, where about 100 simulation runs were conducted to test model parameters affecting model results.

2.3.4. Scenarios

For the purpose of this study five scenarios have been used to exam the effect of the proposed development plan according to WEF nexus, Table 1 shows a summary for proposed scenario starting from the most optimal assumption in Scenario one to give an overview for the decision maker to find the best alternative. Consequently, four other scenarios were adapted to give an overview for the effect of changing cultivated area, pump station intake level, pumping head and return outflow to lower Nile system. A detailed and more specific scenarios analysis is recommended in the design stage including multi criteria analysis to cover all the involved factors (Environmental Impacts, feasibility, etc.). For instance, NL upstream water level is the main criteria for future plans; prediction shows possible reduction in the Nile flow particularly during drought periods similar to 1980s, the proposed development plan considers future changes in NL operation rules to make use of water in the dead storage zone.

Table 1: Summary of proposed WEF nexus scenarios for KhorKlabsha

ID	Name	Description	Klabsha proposed plan			
			Cultivated Area (ha)	Intake Level (AMSL)	Average Pumping Head (m)	Outflow (MCM/yr.)
1	Proposed Plan	Current + Klabsha Nexus Proposed plan	200,000	140	35	5,276
2	Irrigation Area Reduction	Decrease Klabsha cultivated Area from 200,000 to 50,000 ha	50,000	140	35	5,276
3	Pump Station Intake Level Reduction	Decrease proposed Klabsha pump station intake level from 140 m to 120 m AMSL	50,000	120	35	5,276
4	Increase Average Pumping Head	Increase average Pumping head from 35 m to 55 m.	50,000	120	55	5,276
5	Outflow Reduction	Decrease Klabsha Run-of River station outflow from 5276 to 2638 MCM/yr.	50,000	120	55	2,638

3. RESULTE

3.1. Bathymetric Representation Of KhorKlabsha

The results of the different interpolation methods are closed in the low levels (120-147m) and moderate in the high levels of the lake. Inverse Distance Weighted (IDW) gives best results as an interpolator for phenomena whose distribution is strongly correlated with distance, which is presented in our case, for this study IDW after improvement using (Power = 0.5) can be used as a final DEM. As a result, Figure shows a detailed overview for KhorKlabsha topography, DEM demonstrate that water starts to enter KhorKlabsha at the lower level 140 m AMSL equivalent to a water volume of around 0.3 BCM and surface area of around 35 km^2. However, at the maximum level 182 m AMSL the storage volume is around 9.32 BCM and the equivalent surface area is around 730 km^2.

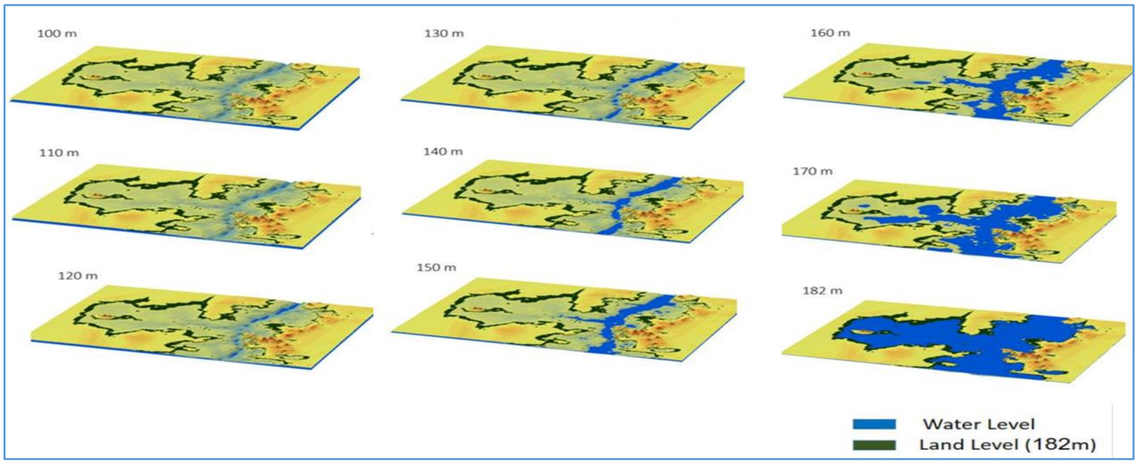

Figure 3: Detailed topography of KhorKlabsha

Furthermore, Arc-GIS 3D Analyst function surface used to calculate the volume and surface area related to each level, consequently a simple regression model used to describe the relation, equations 1and 2shows a 4^{th} degree equations simulate (Level & Volume and Level & Surface Area) for KhorKlabsha with an excellent correlation coefficient R^2=0.99. In order to have an overview for KhorKlabsha according to lower water levels, following equations are used to conduct hydrological study for KhorKlabsha.

$$\text{Volume} = 6.8E\text{-}07x^4 - 3.2E\text{-}04x^3 + 5.5E\text{-}02x^2 - 4.1E{+}00x + 1.1E{+}02$$

$$\text{Area} = 4.78E\text{-}05x^4 - 2.19E\text{-}02x^3 + 3.71E{+}00x^2 - 2.74E{+}02x + 7.44E{+}03$$

Where: X = KhorKlabsha Water Level (m), Volume= KhorKlabsha Water Volume (BCM) and Area= KhorKlabsha Surface Area (km^2)

3.2. Hydrological Analysis Of KhorKlabsha

Figure shows an average annual water volume and total evaporation for the period (1976-2017), the graph is simulating the hydrological cycle of NL, KhorKlabsha lowest average annual water volume was 0.83 BCM at 1987 where the maximum was 6.95 BCM at 1999. Due to the scope of this study a monthly average evaporation rate was selected to estimate the average total evaporation from KhorKlabsha using the Level & surface area as shown in Figure 4, Maximum total average annual evaporation was 1.832 BCM at 2015 while the minimum total average annual evaporation was 0.246 BCM a 1987. On a monthly basis, November contains the maximum volume of water with amount of 8.375 BCM however July contains the minimum volume of water with amount of 0.272 BCM.

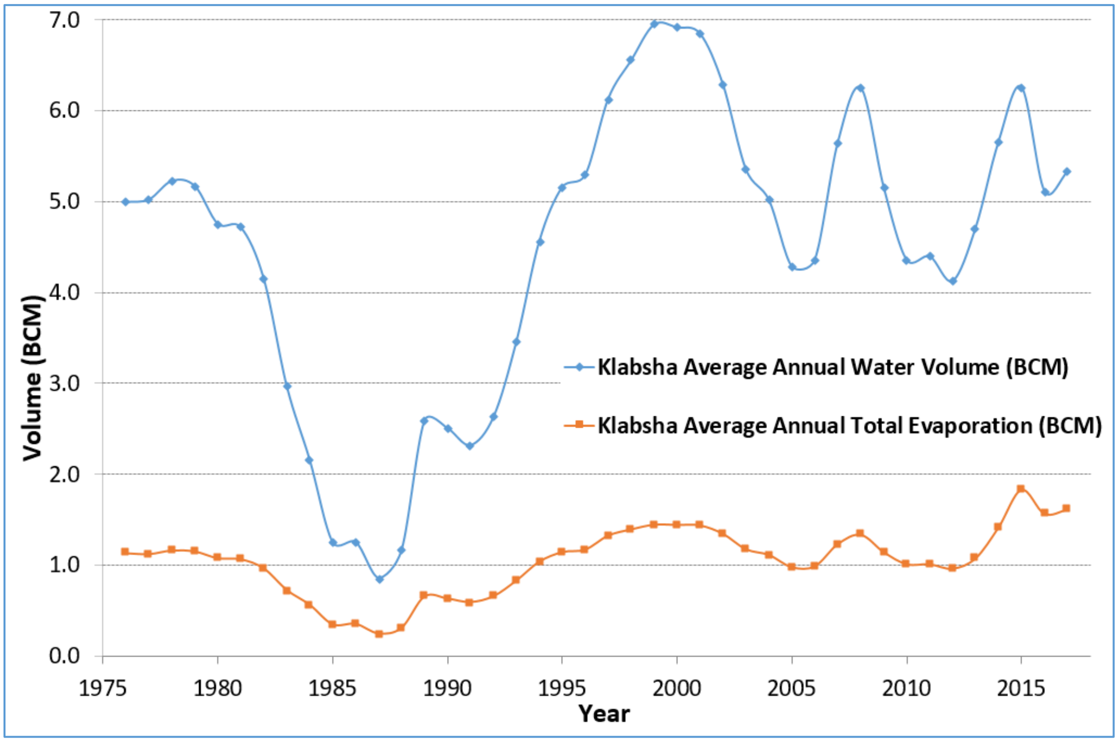

Figure 4: KhorKlabsha annual water volume and total evaporation for the period (1976-2017)

3.3. WEF Nexus Model Outputs

The variables and parameters of the model showed the best simulation results compared to observed data. NL upstream water level was the main criteria to check the model performance, since proposed and existing pump station depend on water level, Figure 5 shows a 10 days' time series plot of simulated average upstream water level from RIBASIM model against the observed record at NL. Overall there is a good agreement of observed and simulated water level according to the standard evaluation criteria. The 10 days' time series plot is useful for detecting outliers (very large differences between observed and simulated water level) particularly in rivers with a strong base flow like the River Nile, during the wet seasons although the model gives higher values during the period (1975-1977) it gives also lower values during the period (1991-1995), the reason could be change in the operation rules according to national policy to insure HAD safety. In comparison, during dry season the well-known NB drought during (1983-1988) recession was successfully simulated, the average water level during July 1988 was close to 151.5 m the lowest ever record for HAD upstream water level.

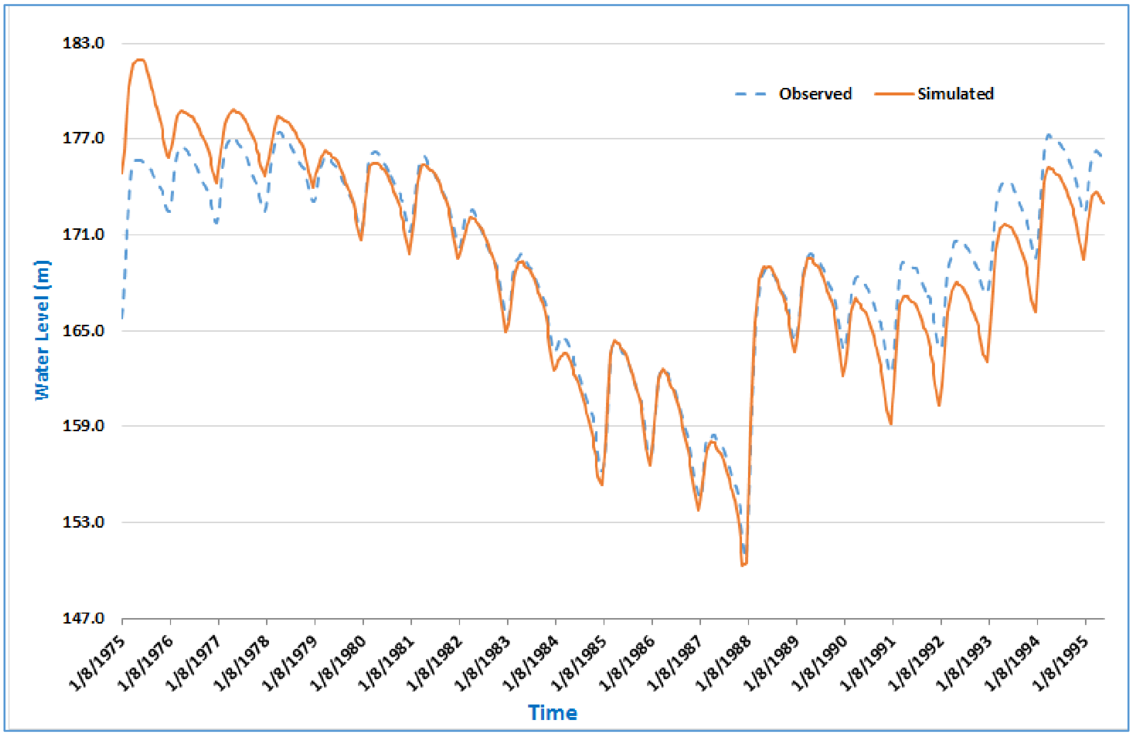

Figure 5: Average 10 Days Lake Nasser Upstream Water Level (Aug. 1975-Dec.1995)

In simpler terms, a well-known calibration parameters were used to describe model schematization quality and assumptions, the values were (Correlation Coefficient = 0.94, Determination Coefficient = 0.88, RMSE = 1.6278), for the purpose and limitation of this research, the model is considered as valid tool to be used for proposed plan alternatives investigation to apply WEF nexus approach in KhorKlabsha.

Based on NL schematization, RIBASIM model used to study the effect of each scenario using 10 days' natural flow time series for 115 years similar to the real Nile Basin hydrological cycle and with same operation rules for HAD according to 1959 agreement between Egypt and Sudan to fully utilize Nile Waters.The main two concerns of the proposed plan were the energy losses (energy for pumping- generated energy) and the limited capacity of Old Aswan Dam (OAD) reservoir (between OAD and HAD).

Regarding the energy, figure 6 shows a comparison between the consumed energy in Klabsha proposed pump station and the regenerated energy from the proposed single run-of-River station before diverting back the water to the lower Nile System upstream OAD.

As shown in figure 6 the comparative energy chart, scenarios 2 and 3 present the minimum energy losses with 26% from the consumed energy, scenarios 1 and 5 show the moderate energy losses with 35% and 42% respectively, scenarios 4 shows maximum energy losses with 52% from the consumed energy. Although, all parameters have moderate influence in energy losses, increase Klabsha average pumping head with 20 m will raise the consumed annual energy from 891,479 Mwh/yr. to 1,391,118 Mwh/yr. Likewise, generated energy from the single proposed run-of-River station decreased from 663,000 Mwh/yr. to 334,440 Mwh/yr. according to scenario 5 where the average outflow reduced to 2,638 MCM/yr. due the limited capacity of OAD reservoir. In term of water inflow/outflow overview including proposed Irrigation water demand, figure 6 indicates that scenarios 2, 3 and 4 present a minimal water reduction with 13% from the (including supplementary irrigation to Klabsha), however Scenarios 1 and 5 present maximum reduction with 23% from the inflow.

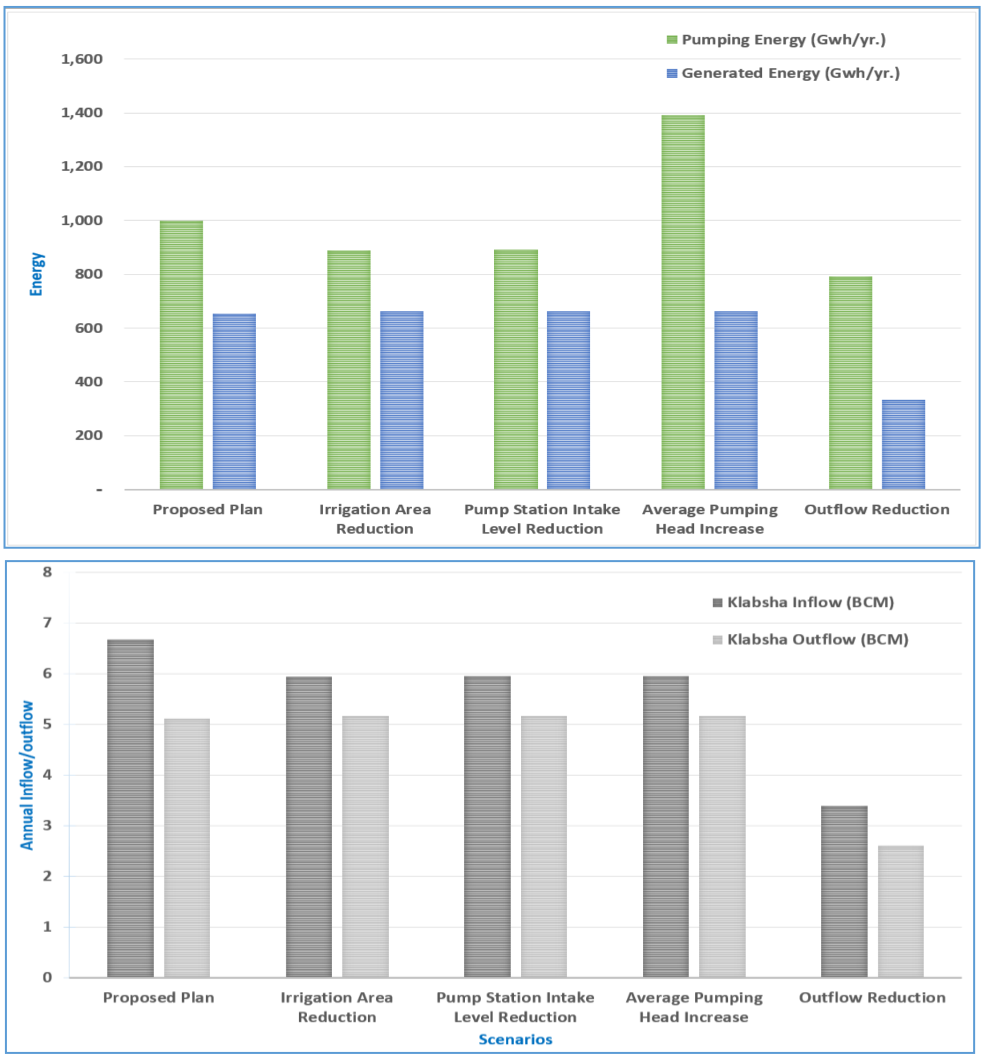

Figure 6: Comparative Chart for Energy and Water

An overall relative comparative for different parameters influencing the simulation model is shown in figure 7, scenario 1 is used as a reference case (the 100% line in the chart) to measure the change of each parameter, interpreting the radar chart will help to select the best scenario according to WEF nexus.

For example, the effect of scenario 5 on all energy parameterswasvariant, however positive impacts achieved compare to Scenario 1, like increase HAD average annual generated energy and reduce consumed energy in proposed Klabsha pump station, another negative impacts observed as an effective reduction on the generated energy from Klabsha Run-of-River occurs in addition to slightly increase for Toshka pump station consumed energy.

For water parameters, according to scenario 5 there is only one negative impact which is NL average 10 days' evaporation increase, otherwise positive impacts occur for all other parameters, both NL upstream water level and HAD downstream discharge remain without change, furthermore flow reduction in Toshka canal and proposed Klabsha canal is vital to reduce infrastructure/maintenance cost.

In term of food production, assuming the same crops planning in Toshka irrigation scheme, cultivated area determines the annual water demand, figure 8 shows a fixed Toshka irrigation water demand according to all scenarios as a positive impact, however Klabsha irrigation annual demand is decreased by 50% for all other scenarios apart from scenario 1, which negatively impact the food production in the proposed scheme.

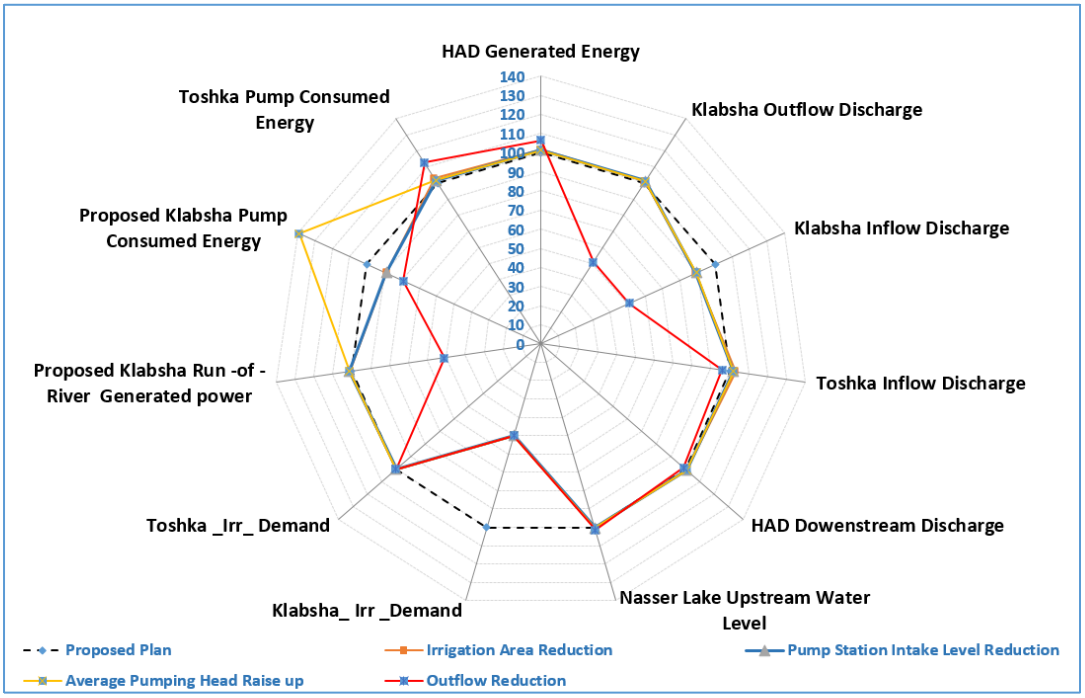

Figure 7: Overall Relative Comparison for the Proposed Scenarios (Annual Values)

4. Conclusion And Recommendation

In summary, the following is the conclusion based on conducted results, large scale WEF nexus approach is applied in KhorKlabsha in order to obtain additional economic gain simultaneously with investigating new management plans for NL could help to overcome possible water shortage.

Reliable data, tools and assumptions were used to simulate the proposed plans, NL upstream water level simulated results show high correlation with observed date, for the purpose and limitation of this research, the model is considered as valid tool to be used for proposed plan alternatives investigation to apply WEF nexus approach in KhorKlabsha.

Apply WEF nexus approach in KhorKlabsha offers a new opportunity to meet future challenges and would help to bring more investment returns for the region in spite of the economic feasibility of construction of renewable energy plants and the proposed infrastructure.

The proposed development plan for KhorKlabsha will keep the maximum water level at 174 m, offers an area of 350 km^2 (86,500 Feddan) to be immediately cultivated using groundwater, in addition to approximately 0.8 BCM/year of water saving from evaporation.

The average energy losses lie between 35%-45% for the proposed development plan, other techniques using more than Run-of–River stations or construct hydrokinetic stations along the water carrier would increase the generated energy to cover the significant amount of energy losses.

New cultivated land with an average area of at least 100,000 Feddan would be added to national plan; initially groundwater is the main source of water for irrigation in addition to supplementary irrigation equivalent to 1.3 BCM/yr.

The proposed WEF nexus plan in KhorKlabsha offers an innovative opportunity to adapt a new operation rules for NL, hence use efficiently the water in the dead storage zone (below 147 m AMSL) after evaluate and improve its quality. However, the storage limitation between OAD and HAD remains as an obstacle for increasing the pumping capacity.

The following is recommended, more investigation regarding the renewable energy potential, evaporation, water quality and land reclamation is recommended to improve the study. Furthermore, a detailed calibration study for the DEM is recommended through the annual bathymetric survey missions to determine the best method to update the level- volume – surface area relationship.

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