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An Estimate of Hydrologic Characteristics of Major Khors in Lake Nasser

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ملخص البحث

تتوقع العديد من الدراسات العلمية حدوث تغير ملحوظ في الطبيعة الهيدرولوجية لبحيرة السد العالي نظرللأنشطة التنموية غير المخططه في منابع النيل او التأثيرات السلبية للتغيرات المناخية. ولهذا فمن المتوقع ان تواجه إدارة البحيرة تحديات مائية وبيئية كبيرة يلزم دراستها وتحويلها الي فرص للتنمية .ونظراً لاحتواء البحيرة علي عدد كبير من الخيران يصل إلى 85 خور منها ثلاثة خيران كبرى هي كلابشة والعلاقي وتوشكى والتي تعتبر من أفضل المواقع لتنفيذ مشروعات تنموية للاستفادة من الوضع المتوقع وبدون إخلال بالظروف الهيدرولوجية والبيئية للبحيرة. وتقدم هذة الورقة البحثية تحليلا دقيقا للوضع الطبوغرافي والهيدرولوجي للخيران الرئيسية، حيث تم أستخدام نظم المعلومات الجغرافية في تحليل البيانات المتوفرة من العديد من المصادر لاستنباط نموذج إرتفاع رقمي عالي الدقة للخيران الرئيسية للبحيرة بأستخدام افضل وسيلة استكمال البيانات رقميا. ومن ثم تم تحديد علاقات المنسوب والحجم والمساحة السطحية بالإضافة للبيانات الهيدرولوجية المعلنة لبحيرة السد العالي لاستخدامها في إعداد دراسة هيدرولوجية عن حجم المياه وكمية البخر السنوية بكل خور منذ بداية انشاء السد العالي بالإضافة إلى المساحة السطحية المقابلة لذلك. وهذه النتائج يمكن استخدامها لإعداد الدراسات المستقبلية لمشروعات التنمية في لبحيرة.

Abstract

Significant impact on Nasser Lake (NL) inflow is highly expected due to unilateral ongoing 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. 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. NL contains about 85 Khors, including the major three Khors (Klabsha, Alaky and Toshka), which are considered the best sites for the implementation of future development projects to benefit from the expected situation without influencing the current hydrological and environmental conditions of the lake. This paper presents a topographical and hydrological analysis for the major Khors. The ARC GIS has been used to analyze and standardize data from several sources to produce a high resolution (10m*10m) digital elevation model (DEM) using the best raster interpolation techniques, the calculated relation for (Level – Surface Area) and (Level- Volume) were used in addition to the available hydrological data of the High Dam Lake in order to conduct a hydrological study to estimate the annual water volume in each Khor as well as the amount of evaporation. Results of this research could be considered as a base for any future studies to develop NL.

Keywords: Nile Basin, Nasser Lake (NL), High Aswan Dam (HAD), Arc-GIS, Raster Interpolating

1. Introduction

Nasser Lake (NL) or High Aswan Dam Lake (HADL) is a manmade lake formed by impoundment of the High Aswan Dam. The total length of the lake is approximately 500 km; about 350 km in Egypt, and the remaining 150 km is in Sudan. The Lake lays between latitudes 21 and 24 north and longitudes 31 and 33 east covering an area of about 6,600 km2 out of which 5,600 km2 in Egypt at a storage level of 182 m AMSL. The lake was formed mainly to store water for irrigation and power generation but it is also used as a source of water for domestic use (Ahmed, 1999). Many development scenarios and multipurpose projects at the different Nile River sub-basins, which aim to provide storage and new river regulation. The expected development activities would provide opportunities and challenges to Egyptian water resources. For decades HADL considered as the Water Bank for Egypt, storing Nile water during flood to be used during the recession for Agriculture, Industrial and Municipal uses. The development plans for the Nile sub-basins will lead to change in HADL management plans, which will be reflected on the river system in Egypt. The impacts of that change on the Nile River flows and Egyptian water management plans should be investigated as an urgent response to possible scenarios that could affect HADL.

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). Therefore, this research offers an overview regarding the bathymetric NL major khors (Klabsha, Allaqui and Toshka) using ARC-GIS tools in addition to hydrological study using the most up-to-date available data, the outcome of this study considers as a base for farther studies regarding new development plans for NL to cope with possible threats, proposed projects such the hydropower plants would depend on water depth an available discharge (N.El-Bahrawy, 2002).

1.1. Study Area

The shoreline of the NL has numerous embayment which are called Khor as shown in figure 1, the total number of important khors are 85 of which 48 lie on the eastern side and 37 on the western one (Mola, 2014). For the purpose of this paper, only the major three khors (Klabsha, Alaky and Toshka) are investigated, Khor Klabsha is located on the northern part of the lake with largest surface area and highest evaporation volume compared to the other khors, 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). Khor Alaky is about 100 km upstream of the HAD and extends into the Eastern Desert. It has a large surface area of 500 km^2 (Emad Elba, 2014), the Khor is located on the middle part of HADL with the largest water storage compared to the other khors. Khor Toshka located on the Southern part of HADL with the lowest water storage (without Toshka spillway) compared to the other khors.

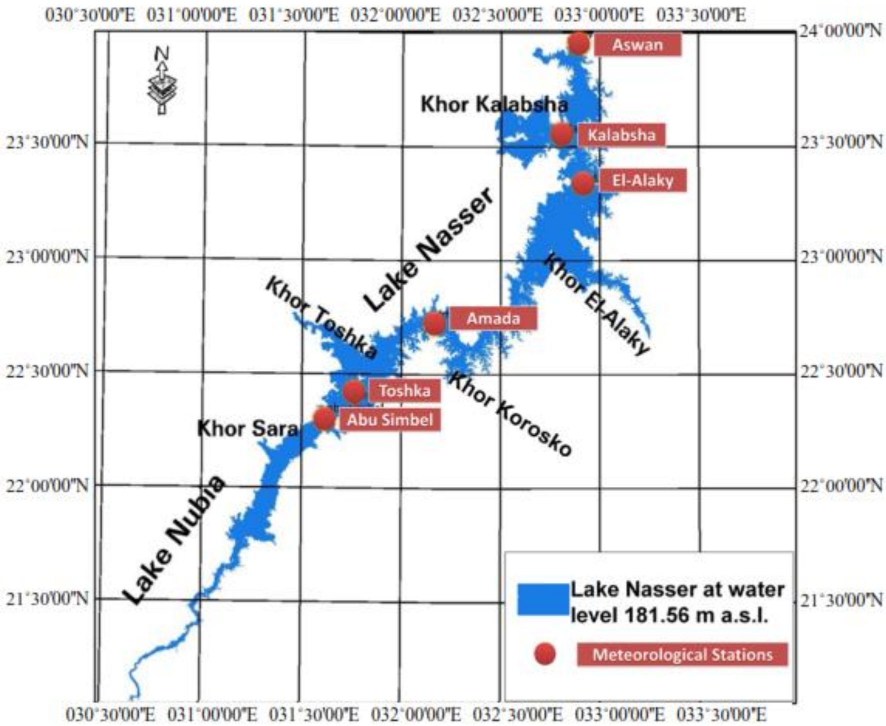


Figure 33:Lake Nasser or Hight Aswan Dam Lake (Emad Elba, 2014)

1.2. Available Data and Tools

This reserach contains the description of different tools and assumption used to identify the topography of each major Khor, Based on historical survey maps before HAD construction and new bathymetric survey missions, Arc-GIS was used to create Digital Elevation Model (DEM) for each Khor to identifies water level, surface area and storage relationships (Godone, 2013). Furthermore, hydrological analysis was conducted to give an overview regarding each Khor water content and evaporation.

2. Methodology

2.1. Interpolation Techniques

Interpolation tools available in geographical information systems are useful and allow to easily perform different kind of elaborations and to display them graphically in order to show the results in a way intelligible also to non-skilled subjects (Hartkamp, A.D., K. De Beurs, A., Stein, J.W., 1999). Interpolators are divided in two typologies deterministic and stochastic. Therefore, in order to deal with the differences in elevation covering a large area like HADL, interpolation techniques have been used to measure this elevation at every point within a geographic area, simply interpolation is the process of estimating unknown values that fall between known elevation values. However, obtain a sample of measurements from various locations within HADL including old maps and (x,y,z) points from HADL bathymetric surveys (available from deferent sources in MWRI), those samples (inputs) used to make inferences about the entire geographic area of HADL before HAD construction.

Spatial Interpolation process one among best techniques to enhance DEM, "the goal is to create a surface that models the sampled elevation in the best possible way. Analysis starts with a set of known measurements and, selectin a prober interpolation method, estimate the unknown values for the area, then make adjustments to the surface by limiting the size of the sample and controlling the influence the sample points have on the estimated values" (InterpolMethods, 2009). it calculates an unknown value from a set of sample points with known values that are distributed across an area, the distance from the cell with unknown value to the sample cells contributes to its final value estimation, more sample points and well-distributed are better for a detailed surface.

As an important advantage of interpolation approach, it is also possible to increase the accuracy of the DEM by reducing the dimensions of the cell size of HADL bed to the minimum possible size. Different software programs were used to reduce the relatively large cell size as a result for data availability and distribution, the result of this Process has been contributed to refining and verifying the calculation of surface area, contents and level relation. In this study, several interpolated raster DEM for HADL were created using the lowest available cell size (10m * 10m), a simple comparative for different types of interpolation was described in the next section.

2.1.1. Deterministic Interpolation Technique

Triangulated Irregular Networks TIN is used to display and analyze surfaces (Childs, 2014). They contain irregularly spaced points that have X, Y coordinates describing their location and a Z-value that describes the elevation surface at that point. A series of edges join the points to form triangles. The resulting triangular mosaic forms a continuous faceted surface, where each triangle face has a specific slope and aspect.

The interpolation at TIN depends on linear interpolation technique and it different from shape to another, which comprised of points, lines, or polygons may be used. Geometry is incorporated into the triangulation using a surface feature type.

Because of interpolation the input TIN surface occurs at regular intervals, some loss of information in the output raster should be expected. How well the raster represents the TIN is dependent on the resolution of the raster, and interval of the TIN surface variation. Generally, as the resolution is increased, the output raster more closely represents the TIN surface.

2.1.2. Stochastic or Statistical Interpolation Technique:

The type of interpolation method will depend on many factors, different interpolation methods has been investigated and compare the results to determine the best interpolation method, for the objective of this study only three main methods were used to calculate the basic characteristics of HADL as a main input for water management and planning models, following short description for each method:

a) **Inverse Distance Weighted (IDW):** the method presents the concept of spatial autocorrelation literally. It assumes that the nearer a sample point is to the cell whose value is to be estimated, the more closely the cell’s value will resemble the sample point’s value. IDW is a good interpolator for phenomena whose distribution is strongly correlated with distance, occasionally, IDW surface accuracy can be improved by using line layers as barriers. It is particularly suitable for narrow datasets, where other fitting techniques may be affected by errors (Tomeczak, 2013). The process is highly flexible and allows estimating dataset with trend or anisotropy.

b) Natural neighbours: the method determines the nearest subset of input points to an unknown point, and applies weights to them based on proportionate areas in order to interpolate a value (Sibson, 1981). Natural Neighbours is local, using only one subset of points that surround the unknown point. It infers no trends and will produce no peaks, pits, ridges or valleys not already represented by the input data. This method can competently handle large input point datasets; local coordinates define the amount of influence any scatter point will have on output cells.

c) Kriging: the method is one of the most complex and powerful interpolators (Childs, 2014), it applies sophisticated statistical methods that consider the unique characteristics of your dataset. a solid understanding of geo-statistical concepts and methods is required to use Kriging interpolation properly. It uses statistical models that allow a variety of map outputs including predictions, prediction standard errors, probability, etc. also, the distance and direction of every point pair is quantified to provide information on the spatial autocorrelation of the sample point set. finally, a best-fit model is automatically applied to the data and the unknown values are predicted.

2.2. Bathymetric Representation of Major Khors

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 the major Khors 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 each major Khor 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. 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.

2.3. Hydrological Analysis of Major Khors

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

3. Results

3.1. Bathymetric representation of Khor Klabsha

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, a detailed overview for Khor Klabsha topography, DEM demonstrate that water starts to enter Khor Klabsha 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.

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, Figure 2 shows a 4th degree equations simulate (Level & Volume and Level & Surface Area) for Khor Klabsha with an excellent correlation coefficient R^2=0.99. In order to have an overview for Khor Klabsha according to lower water levels, equations are used to conduct hydrological study for Khor Klabsha.

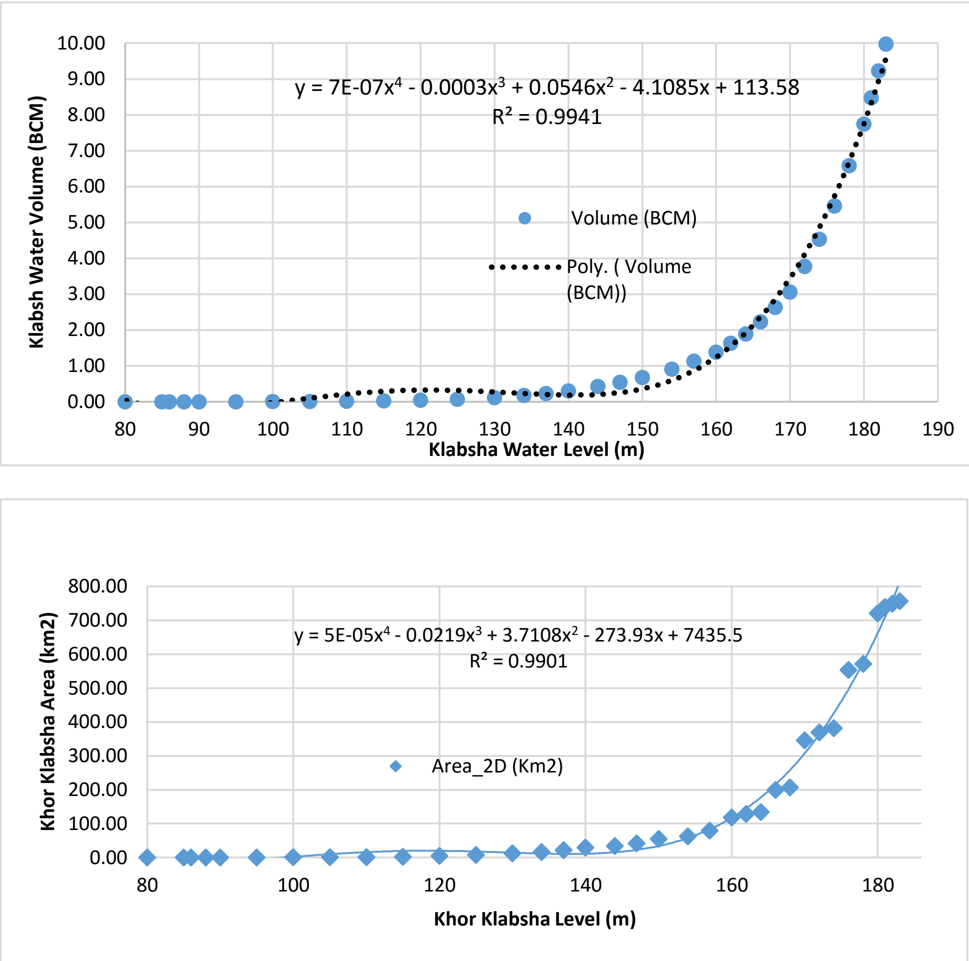


Figure 34:Klabsha (Level & Volume and Level &Area) relation chart and equations

As an outcome for this analysis, figure 3 shows an average annual water volume and total evaporation for the period (1976-2017), the graph is well representing for the hydrological cycle of HADL, the lowest average annual water volume was 0.83 BCM at 1987 and 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 Khor Klabsha using the Level & surface area as shown in Figure 3, Maximum total average annual evaporation was 1.832 BCM at 2015 while the minimum total average annual evaporation was 0.246 BCM a 1987.

In order to have an overview for Khor Klabsha according to lower water levels, figure 4 shows a visual presentation using Arc-Scene, the DEM shows that water starts to enter Khor Klabsha at 140 m AMSL equivalent to a water volume of around 0.3 BCM and surface area of around 35 km^2.

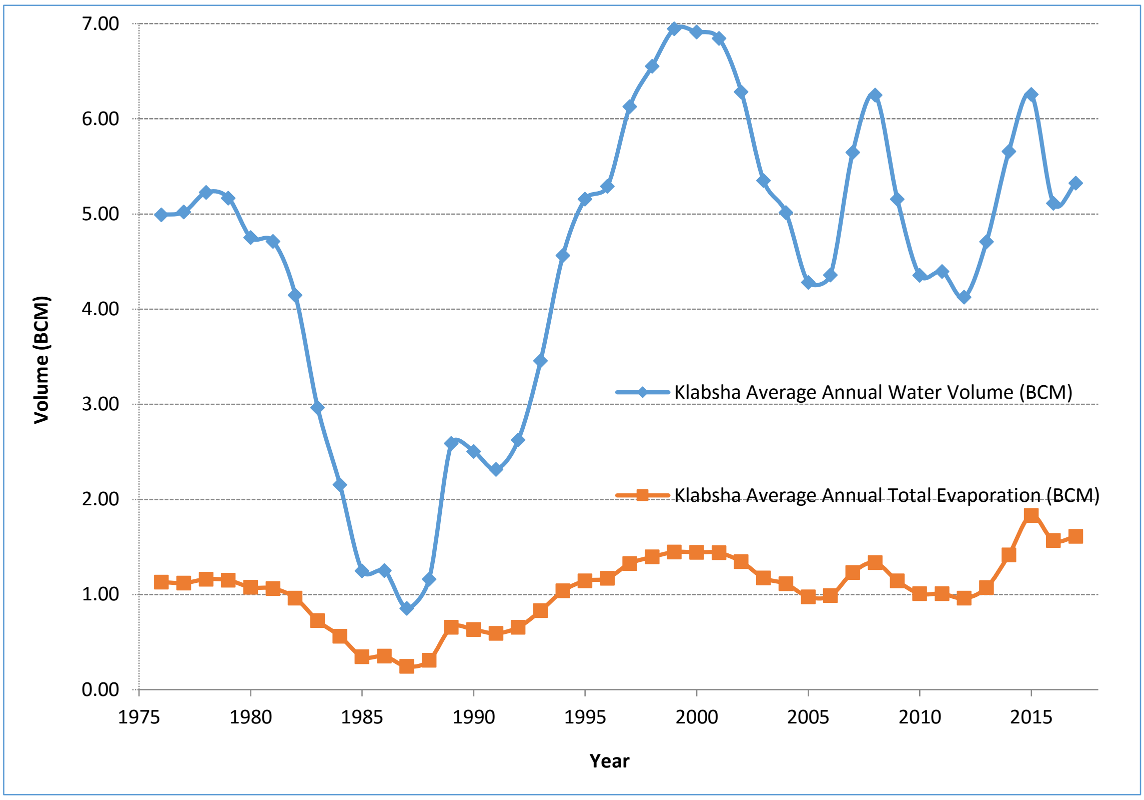


Figure 35:Klabsha Average Annual Water Volume and Annual Total Evaporation

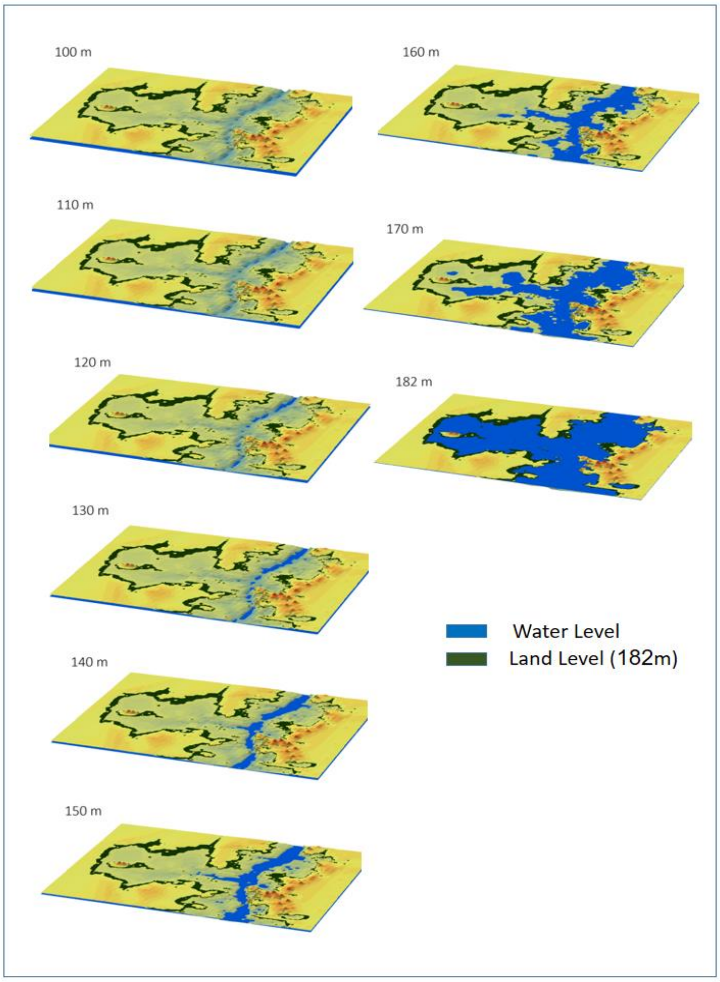


Figure 36:Visual presentation of different Water Level in Khor Klabsha

3.2. Bathymetric Representation of Khor Alaky

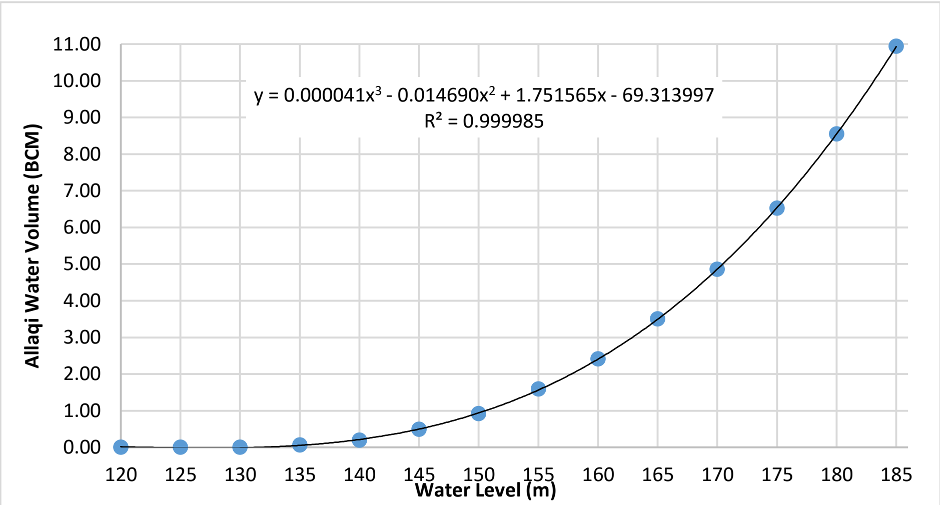
Khor Alaky is about 100 km upstream of the HAD and extends into the Eastern Desert. It has a large surface area of 500 km2 (Emad Elba, 2014), the Khor is located on the middle part of HADL with the largest water storage compared to the other khors. Likewise, similar approach is used to describe Khor Alaky topography. As the deepest Khor among the others, result of a detailed overview for Khor Alaky from bottom level to maximum water level, DEM demonstrate that water starts to enter Khor Klabsha at the lower level 125 m AMSL equivalent to a water volume of around 0.57 BCM and surface area of around 126 km^2. However, at the maximum level 182 m AMSL the storage volume is around 9.76 BCM and the equivalent surface area is around 457 km^2.

a simple regression model used to describe the relation, Figure 5 shows a 2nd and 3rd degree equations simulate (Level & Volume and Level & Surface Area) for Khor Alaky with an excellent correlation coefficient R2=0.99. In order to have an overview for Khor Klabsha according to lower water levels, equations are used to conduct hydrological study for Khor Alaky.

In comparison, Khor Allaqi has almost the same water volume of Khor Klabsha at the maximum water level but 38% less in term of surface area. Therefore, under the same climate conditions, Khor Alaky has less evaporation losses camper with the other khors, this result eliminates the opportunity to apply the proposed WEF nexus approach of the study in Khor Allaqi, it is recommended to keep the current function as a massive water storage body of NL with less evaporation, furthermore it offers good opportunity to implement development plans in other khors without a significant change in NL content.

Applying the same analysis procedures, figure 6 shows Alaky average annual water volume and total evaporation for the period (1976-2017), the lowest average annual water volume was 2.47 BCM at 1987 and the maximum was 8.67 BCM at 1999. Monthly average evaporation rate was selected to estimate the average total evaporation from Khor Alaky using the Level & surface area, Maximum total average annual evaporation was 1.427 BCM at 2015 while the minimum total average annual evaporation was 0.419 BCM a 1987.

Figure 7 shows a visual presentation using Arc-Scene, the DEM shows that water starts to enter Khor Alaky at 132 m AMSL equivalent to a water volume of around 0.2 BCM and surface area of around 18 km^2.



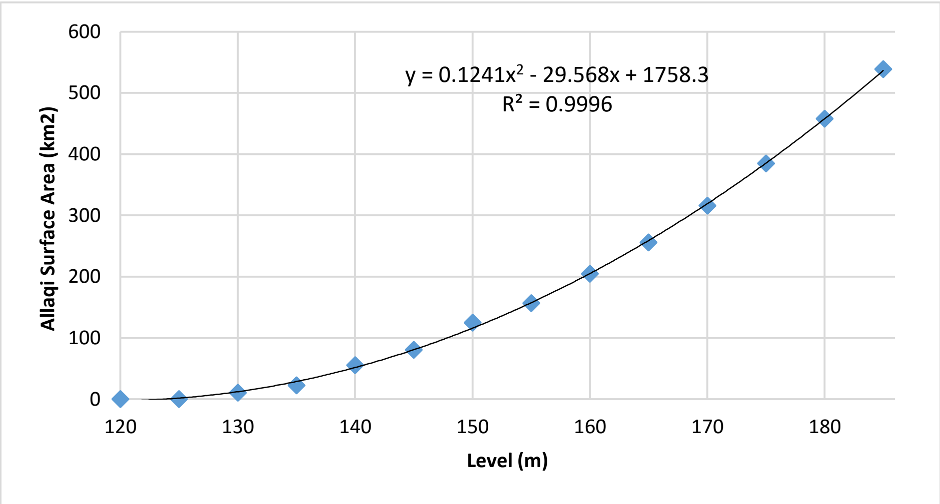


Figure 37:Khor Alaky Level & Volume and Level & Surface Area

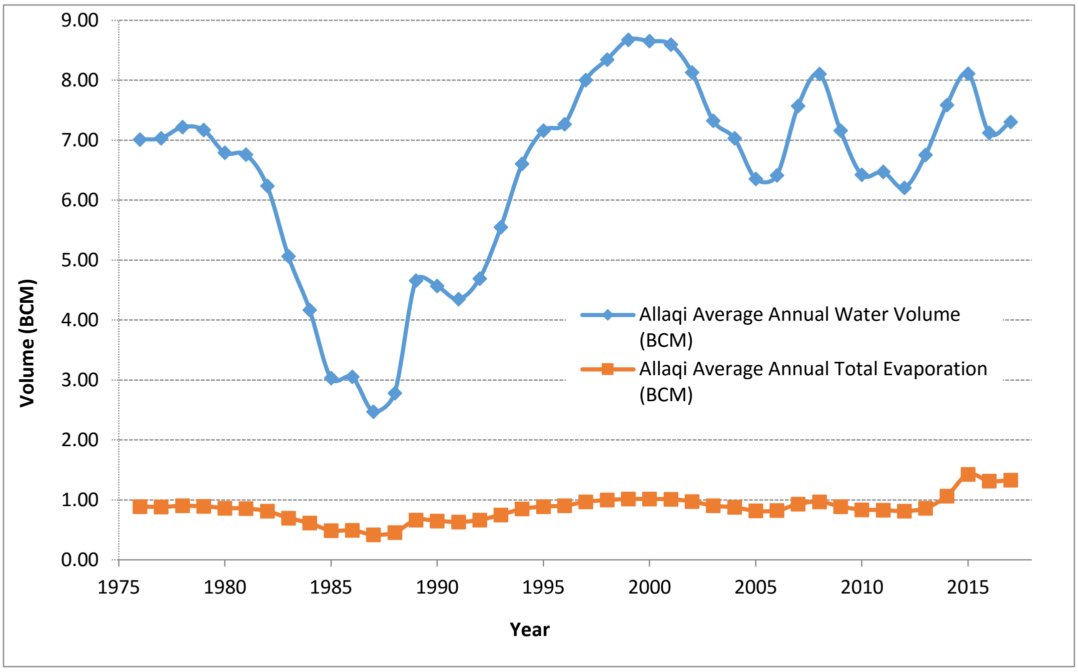


Figure 38:Alaky Average Annual Water Volume and Annual Total Evaporation

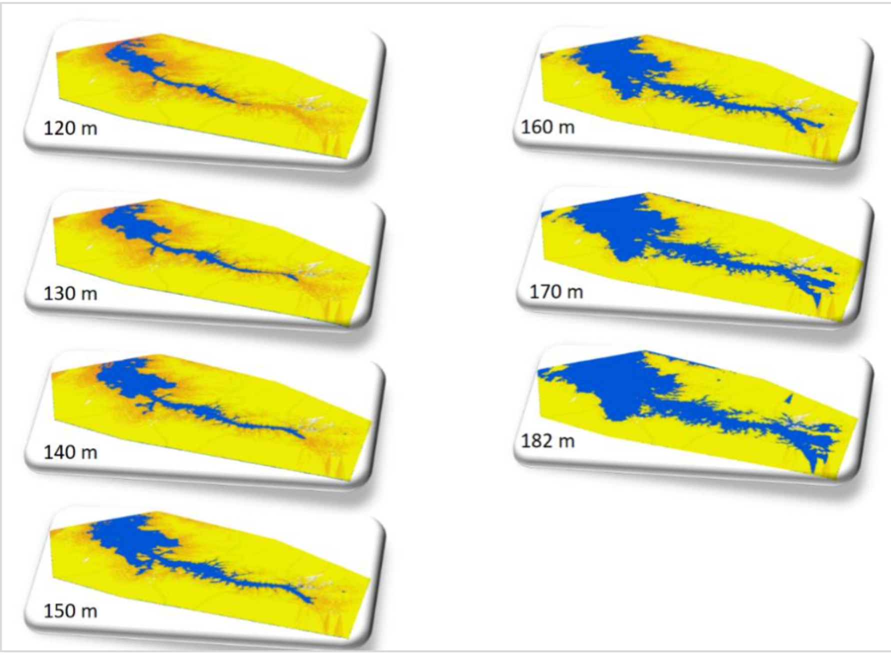


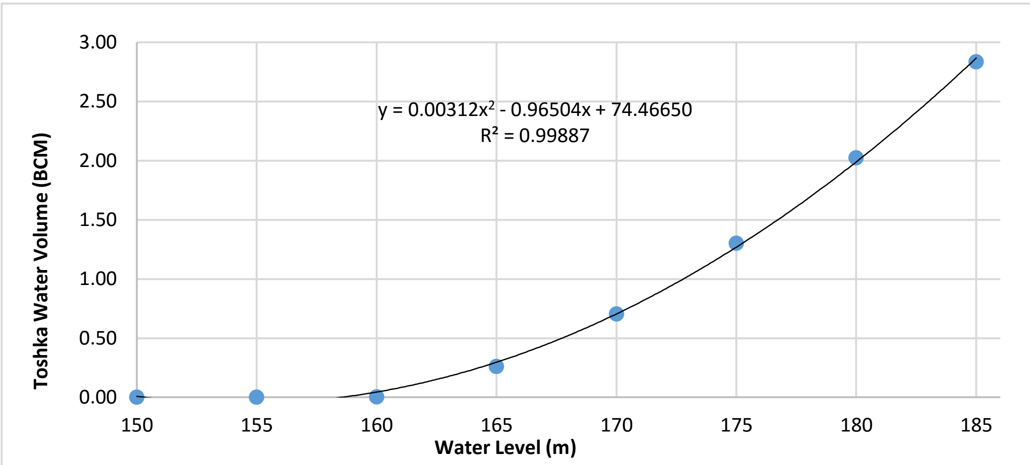
Figure 39:Visual presentation of different Water Level in Khor Alaky

3.3. Bathymetric Representation of Khor Toshka

Khor Toshka located on the Southern part of HADL with the lowest water storage (without Toshka spillway) compared to the other khors, as shown in figure 7 at HADL maximum level 182 m the storage volume is around 2.5 BCM and the equivalent surface area is around 170 km^2. 2nd degree equations would be sufficient to simulate (Level & Volume and Level &Area).

Applying the same analysis procedures, figure 8 shows Toshka average annual water volume and total evaporation for the period (1976-2017), the lowest average annual water volume was 0.02 BCM at 1987 and the maximum was 1.82 BCM at 1999. Monthly average evaporation rate was selected to estimate the average total evaporation from Khor Alaky using the Level & surface area, Maximum total average annual evaporation was 0.361 BCM at 2015 while the minimum total average annual evaporation was 0.001 BCM a 1987.

Finlay, Figure 9 shows a visual presentation using Arc-Scene; the DEM shows that water starts to enter Khor Toshka at 155 m AMSL equivalent to a water volume of around 0.02 BCM and surface area of around 0.37 km^2.



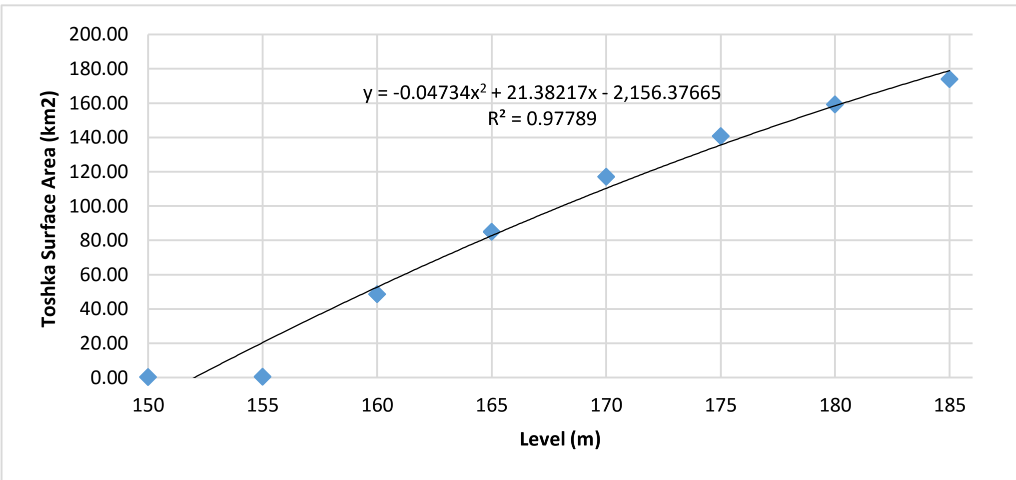


Figure 40:Toshka (Level & Volume and Level &Area

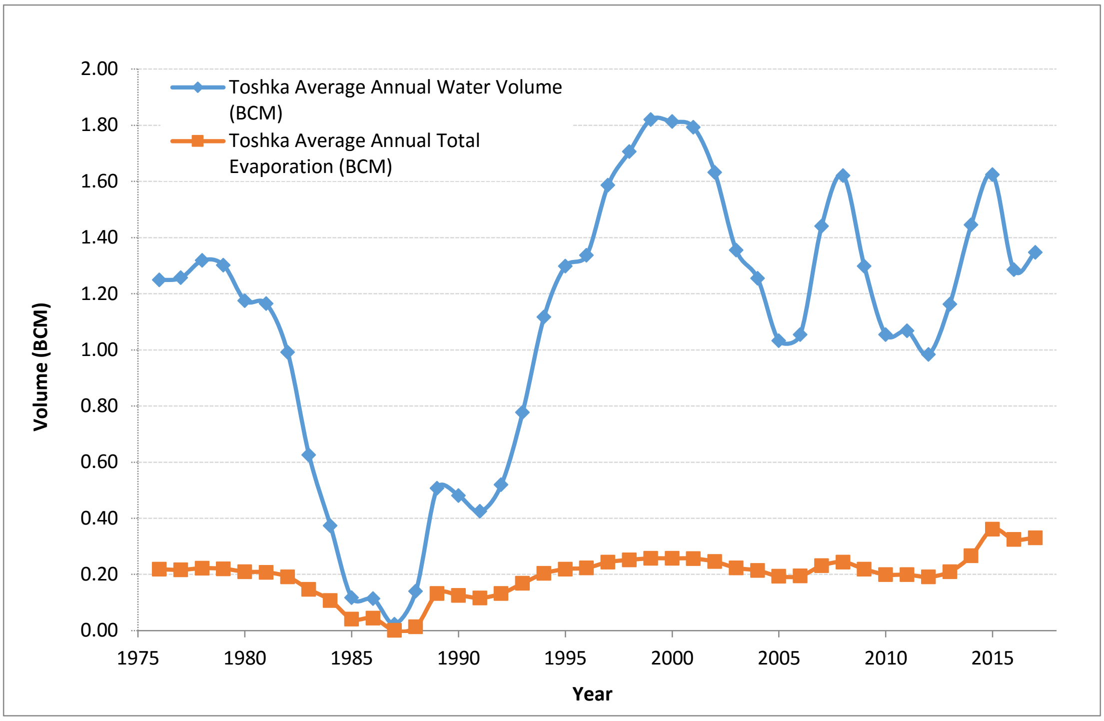


Figure 9:Toshka Average Annual Water Volume and Annual Total Evaporation

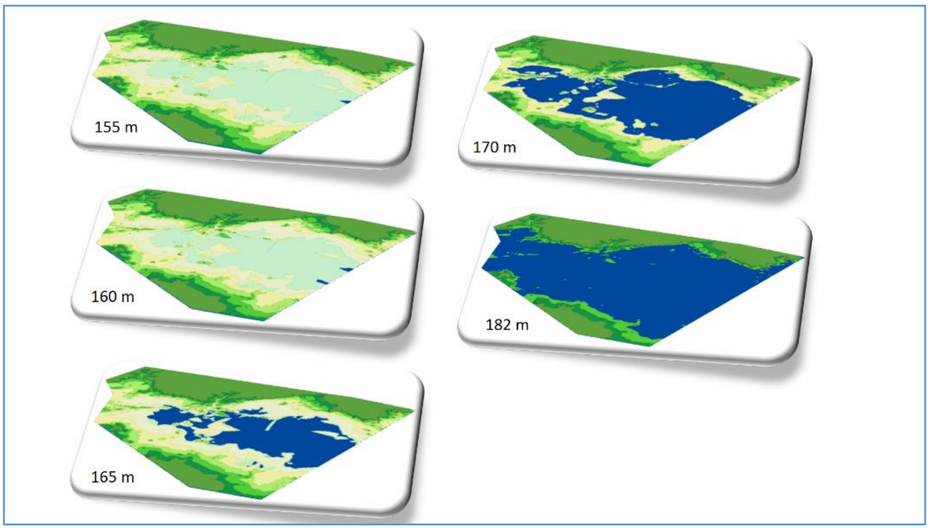


Figure 10: Visual presentation of different Water Level in Khor Toshka

4. Conclusion and Recommendation

This research presents a precise DEM to analyse HADL topography, as a significant result it is possible to study all parts of the lake, especially the main Khors, which can be a main input for the next steps of the study.

Studying the possible challenges and opportunities in NL needs a well define determination for all influencing parameters include (Water level, Evaporation rate, Surface Area and Topography), this research offers a detailed overview for situation in each Khor according to low water levels may occur on HADL inflow due to uncontrolled development Upstream NB or as a negative impact for climate change.

Analysing HADL daily available data during the period 1976-2017 on annual basis, show the following results, in terms of annual water volume for each Khor, the average annual water volume in Khor Alaky was about 6.43 BCM, Khor Klabsha was about 4.472 BCM and finally Khor Toshka was about 1.09 BCM. Regarding the average total annual evaporation for each Khor were resulted as the following, Khor Klabsha was estimated to 1.042 BCM, Khor Alaky was estimated to 0.85 BCM and finally Khor Toshka was estimated to 0.20 BCM.

As a main conclusion Khor Klabsha has a highest potential to apply WEF nexus, during the drought period or water shortage might occur in the future, the water surface area would significantly decrease from 118 km^2 at water level 160 m to an area of 749 km^2 at 182 m, which offer about 631 km^2 of fertile land ready for gradual cultivation with available groundwater as a main source for irrigation and supplementary surface water from HADL if needed. In addition, an annual evaporation reduction occurs from 1.83 BCM at highest water levels around 182 m to 0.35 BCM at the lowest water levels around 160 m,

As a recommendation, farther studies are needed to focus on present alternative based on integrated management and Water, Energy and Food nexus to convert expected risks of HADL inflow possible reduction to opportunities for achieving the greatest possible economic return based on proposing some infrastructure to provide a new perspective for water management in HADL, especially in Khor Klabsha as a potential prototype model would be used to reduce evaporation losses and create new cultivated land within the use of renewable energy .

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