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Closure of Lake Nasser Khores by Different Types of Dams, using Satellite Images

Marwa M. Aly, H. A. Haggag, A. M. Abdel Fadil

Abstract: ***According to the agreement between Egypt and Sudan in 1959 for the full utilization of Nile water arriving Aswan, both countries agreed to build the High Aswan Dam (HAD) in 1964 to get benefits from the water which was flowing to the Mediterranean Sea. Therefore, Lake Nasser, the greatest artificial lake in the world, was created with large areas of shallow depths adjacent to the edges of the lake on both sides according to the topography of the surrounding area namely (khores). These khores increased the surface area; consequently, the estimated evaporation losses reach about 10 BCM/year in average.***

Reducing evaporation losses from HAD Lake is an option to increase the Egyptian available water resources. Many studies were done in order to partially or completely closure of the Khores, where the surface area of the khores of Lake Nasser is about one third of the total area of the lake, which indicates the effectiveness of its closure in decreasing the evaporation. The objectives of the research are studying the Lake Nasser's large area khores, evaluating the idea of closing these khores using different types of dams such as earthfill, rockfill and rubber dams, and the consequent saved water. Meanwhile, a preliminary cost study for the different types of dams was done to determine the most suitable dam type.

This research used the land sat 4 & 5 at years 1988 and 1999 in order to identify the surface area of the lake for the lowest and highest levels respectively. Also it gets benefit from the data available at Ministry of water Resources and Irrigation (MWRI), such as the Khores bathymetric maps and the evaporation rates of Lake Nasser. The results of the study show that Kalabsha khore is the most optimum for dam closure as its entrance is suitable for dam construction, and at high water levels it has the greatest area thus, reducing the evaporation. It is highly appreciated to use rubber dam either economically or environmentally. The amount of saved water reach about 1.0 Milliard m^3 representing 11.11% of the annual total evaporation losses from Lake Nasser, the water saved may reach 1.53 Milliard m^3 if the water level reaches 181.52 m for considerable time span.

Keywords: ***Evaporation Losses, Closure Dams, Khores, Lake Nasser, Satellite Images.***

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I. INTRODUCTION

The water losses of the HAD lake due to evaporation are one of the major problems facing the management of Egyptian water resources, where increasing the surface area of the lake at high levels and high temperature is the main raison for increasing the rate of evaporation.

The designed value for annual average water losses from Lake Nasser was assumed to be 10 km^3, 90% of it covering evaporation from its water surface and 10% for percolation and seepage along its soil surface. During the 70's decade of the last century, some ideas were initially discussed aiming at decreasing these losses as; Changing the operation rules of HAD by decreasing Upstream Water Levels, Cultivating Special Crops on the Lake Surface, Covering the water surface of the lake by a thin membrane and closure of the khores inlets by different dams [1].

Many studies were done in order to partially or completely closure of the Khores, where the surface area of the khores of Lake Nasser is about one third of the total area of the lake, which indicates the effectiveness of its closure in decreasing the evaporation. The latest study was by [2] for complete khore closure through integration of remote sensing, (GIS), aerodynamic principles, and Landsat images to determine the best khore that should be disconnected to reduce evaporation losses. It was based on many approximations as it assumed average depth for all water body through the khore deduced from the satellite images, which isn't suitable to rely on it in the design of suggested dams. In the present work the water depths get from bathymetric maps.

Dam-design-construction process has different phases of study (preliminary, prefeasibility, feasibility and detailed design and construction), for each phase there are international specifications. The specifications for the preliminary phase will be discussed in this research.

The objectives of the research are studying the Evaporation from Lake Nasser's large area khores, evaluating the idea of closing these khores using different types of dams, such as earth fill, rock fill to get benefit from the available material in the surrounding areas of the selected dam sites, in addition to rubber dam for its construction low cost and other advantages, and the consequent saved water. Meanwhile, in order to identify the most suitable dam type a preliminary cost study for the different types of dams was took place.

II. STUDY AREA DESCRIPTION

HAD lake attains about 350 km length inside Egypt namely (Lake Nasser) and 150 km inside Sudan namely (Lake Nubian) , and variable width from 3km in the south to 12 km toward north.

The maximum surface area reaches 6540 km^2 at water level of 182 m with total storage capacity of 164 billion cubic meters. Considering Lake Nasser,

It is located in the southern part of Egypt between longitudes 31˚ 00´ and 33˚ 00´ E and latitudes 22˚ 00´ and 24˚ 00´ N. It is bounded by Wadi Allaqei from east, Nubia desert from west, Aswan High Dam from north and Sudanese borders from south as shown in “Fig. 1”. The average temperature in this region ranges between 15.9 ° C in January and 32.2 ° C in August [3]. The average annual evaporation rate from the lake attains 2.7 m [4]; its distribution along the different months is shown in “Fig. 2”. Regarding the shape of the lake, it is irregular compared to some other large lakes. It is highly dendritic, owing to the khores lining its shores. Khores are finger like water intrusions filling the lower parts of the dry basins. Lake Nasser has about 85 side khores, from which 48 khores located on the eastern side of the lake and about 37 are on western side [5, 6].

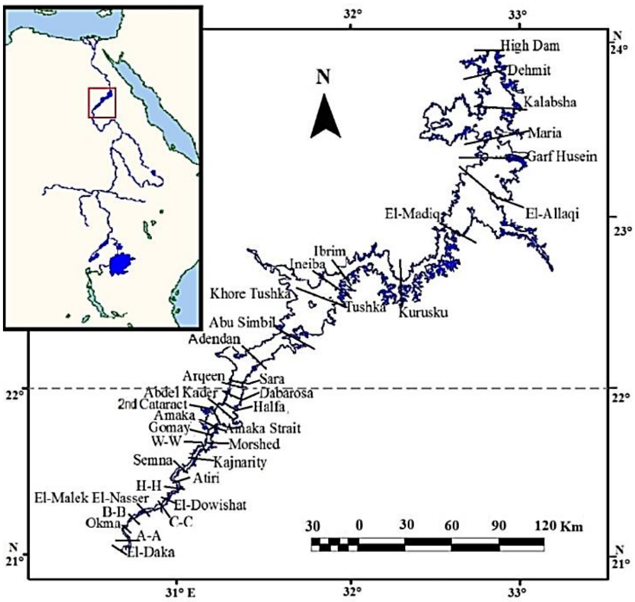

Fig. 1. Location of the study area

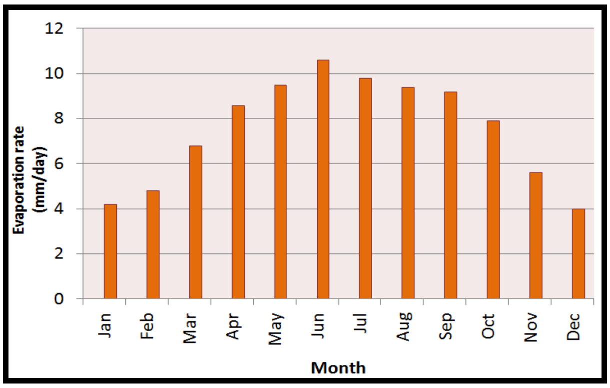

Fig. 2. Annual evaporation rates at Lake Nasser. [7]

The soil at the areas surrounding the lake is characterized by sandy and rocky deserts of high hills and mountains; the eastern lakeside comprises Nubia sandstone high hills in addition to narrow elongated belt of granite rocks extending northwards to Aswan. These hills possess peaks that exceed in elevation 600m A.M.S.L. The drainage lines of Wadi Allaqei transverse the area and is generally of dendritic shape. The limestone plateau in the western lake side is 400m AMSL. Toshka depression represents the low lands in the western side. The area of Toshka depression approaches 6000 km2 and acts as a spillway to HAD [5, 6].

III. MATERIALS AND METHODS

The study depends on many sources of data regarding Lake Nasser and HAD such as:-

- The available Land-sat 4 & 5 satellite images for the complete lake surface area with cell size (30*30) and 7 Bands at (March1988, November 1999), representing the high and low levels of the lake, respectively.
- The data of khores surface area, after NRI [4].
- The historical water levels of Lake Nasser [8].
- The evaporation rate at Lake Nasser [4].
- Bathymetric contour maps for different khores [8].

After supervised classification of the satellite images, it was analyzed to calculate the surface area of the large Khores, at the highest and lowest water levels occurred in the lake, which expected to affect the amount of evaporation losses from the Lake and the shape of connection. The satellite images were analysed using Erdas Imagine, the Arc Map and Arc Catalog softwares.The approximate volume of water lost by evaporation (E_O) from the lake was calculated using the following equation, in addition to the relation between the surface area (km^2), the storage volume (Milliard m^3) of the lake and water levels (m) in the lake as shown in “Fig. 3”.

- E_O (m^3/year) = Annual mean area (m^2) x Evaporation rate (m / year) Eq.1

The second step is the selection of the suitable site for dam construction and its preliminary hydraulic design by using topographic maps with scale (1:50000), the Digital Elevation Model (DEM 90), land-sat images and bathymetric contour maps of the selected khore.

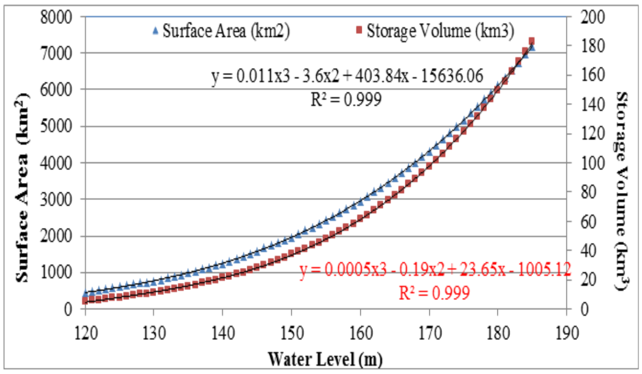

Fig. 3. Relation between Water levels, Surface Area and Storage volume for HAD Lake.

According to the Physical data of HAD, presented in Table I [10], its operation rules and the historical records of Lake Nasser, the maximum allowable water level attains to be 182 m AMSL. In November 1999 the level reaches the maximum water level along the HAD history where it records 181.53 m AMSL. The maximum allowable water level at the beginning of Water year (1st August) is 175m to provide storage capacity for the new flood and to protect HAD against overtopping. Nowadays Ethiopia is constructing Grand Ethiopian Renaissance Dam (GERD) on the Blue Nile.

In order to take into account any expected theoretical impact of GERD on the normal operating levels of Lake Nasser, Kevin G. Wheeler et. al, 2016, [11] concluded that, the maximum water levels in Lake Nasser will be affected by operating GERD, if non-cooperative filling rules of GERD were adopted. Consequently, this study will assume the maximum water levels in Lake Nasser to be 175 m AMSL, at any time of the year, as an input to the hydraulic design process of the closure dams.

Table -I: HAD physical data

Dam type	RCC
Bottom elevation	85 m
Toshka Spillway Elevation	178 m
Crest Elevation	196 m
Maximum Elevation Allowed	182 m
Elevation of dead Zone	147 m
Elevation of Live Zone	175 m
Elevation of Flood Zone	182 m
Maximum Release allowed	270 Million m^3/day
Minimum Release allowed as future plan	60 Million m^3/day
Maximum Release required	270 Million m^3/day
Minimum Release required	60 Million m^3/day

IV. DATA ANALYSIS AND RESULTS

Comparing the surface area of the lake with satellite images at the lowest and highest water levels, it can be concluded that there are three Khores characterized by large surface area which are (Toshka - Allaqei - Kalabsha) khores, as summarized in Table II and "Fig. 4". There are other small khores that will not be considered in the study due to its individual insignificant effect on the evaporation. The following section gives more details about the above three mentioned large khores, the evaporation losses saving from the selected khore(s), and the design of the proposed selected closure dam(s). From the above table and by studying the relation of levels and surface areas, it can be noticed that the largest surface area is Kalabsha khore at high water levels and Allaqei khore at low water level. It was found that the turning point of this relation is at level 170m AMSL.

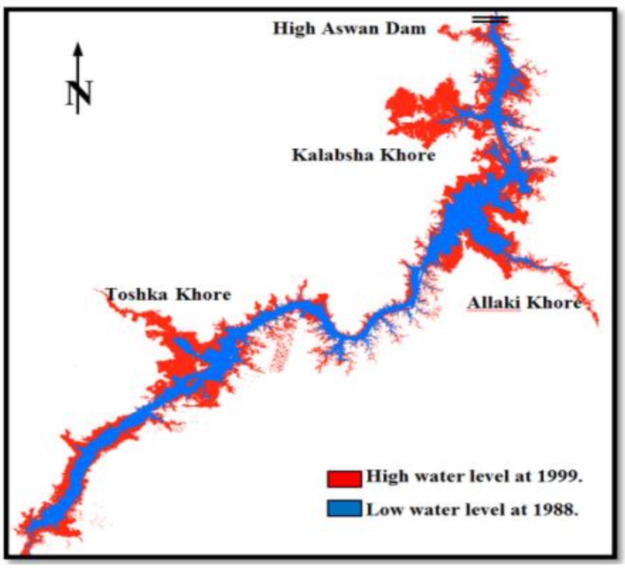

Fig. 4. Lake Nasser khores at different water levels

Table- II: The area and annual evaporation loss at high and low water levels (1988-1999) for described Khores.

	At Year 1999 W.L.=181.52 m		At Year1988 W.L.=156.90 m	
Khore Name	Surface Area Km^2	Average Evaporation Losses Milliard m^3	Surface Area Km^2	Average Evaporation Losses Milliard m^3
Toshka	246,87	0,67	26,17	0,07
Allaqei	353,66	0,95	101,09	0,27
Kalabsha	565,56	1,53	28,41	0,08

A. Khores Details

Toshka Khore

Toshka Khore extends 50 kilometers west the lake. The (MWRI) established a spillway at level 178m AMSL to divert excess water from the lake represented in Toshka khore to Toshka depression through Toshka canal in 1978, as shown in "Fig. 5", as a mitigation measure to protect HAD against overtopping. Consequently Toshka khore has been excluded from the study due to its strategic importance.

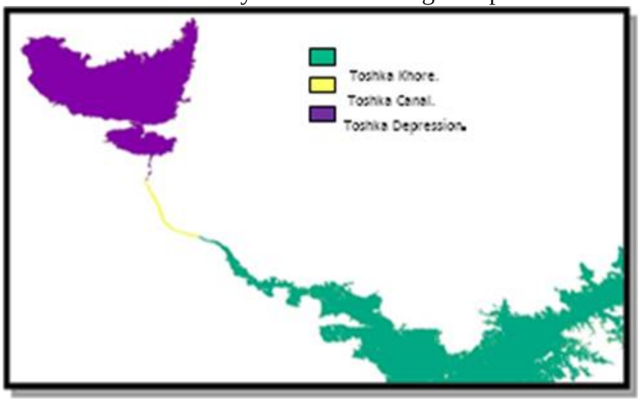

Fig. 5.Toshka Khore, canal and depression boundary.

Allaqei Khore

Allaqei Khore is one of the largest khores. It is ranged from 67 to 170 km long according to the water level as can be indicated from the bathymetric contour map of the khore shown in "Fig. 6". It is located on the right side of the lake, characterized by deep water depth.

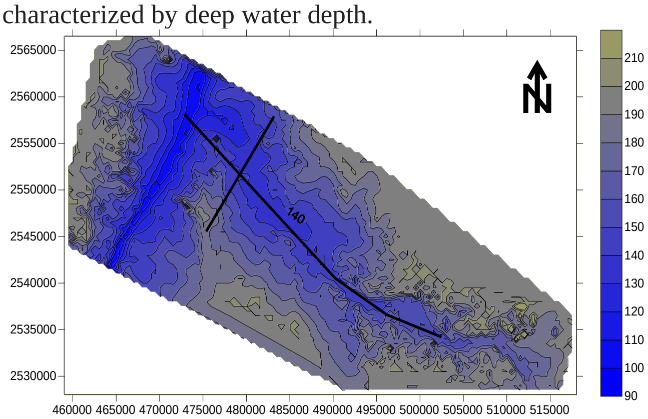

Fig. 6.Allaqei khore bathymetric contour map

The khore is considered as a natural protected area according to the Egyptian Ministry of Environment. It was excluded from the closure assessment due to its importance to the ecosystem and wildlife, in addition to the wide connection with the lake (about 15 km) as shown in “Fig. 7” that may affect the cost of the dam construction significantly.

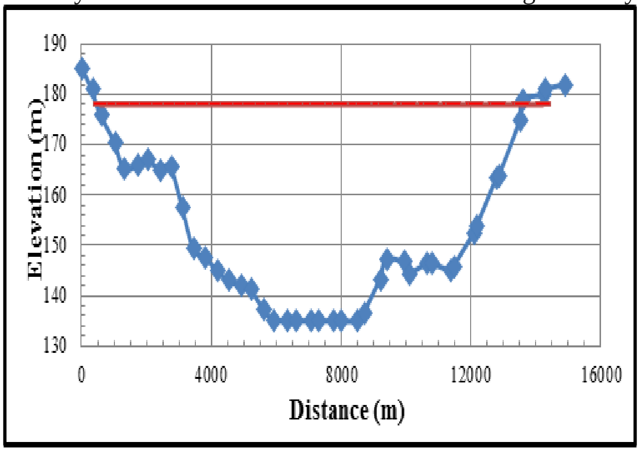

Fig. 7. Allaqei khore entrance cross section

Kalabsha Khore

Regarding Kalabsha Khore, it was found that its surface area is the largest between the studied Khores, reached about 600 km^2. The maximum width and length of the khore were founded be 30 and 40 km respectively. The khore is characterized with relatively narrow connection with the lake, with intermediate islands which may be used as midway supporter to the proposed closure dam. From the above it can be identified that this khore is the most suitable one to execute the idea of khores closure study.

The satellite Images of the khore for years (1988-1996-1999-2008-2010) were analyzed by integration with available bathymetric survey, using GIS and remote sensing techniques, to drive a relationship between the water level and the surface area of Kalabsha Khor as shown in “Fig. 8”. The longitudinal profiles of the khore and its entrance cross section shown in “Fig. 9” were calculated and drawn along the center line of the khore shown in “Fig. 10”, with the support of the bathymetric map of the khore shown in “Fig. 11”.

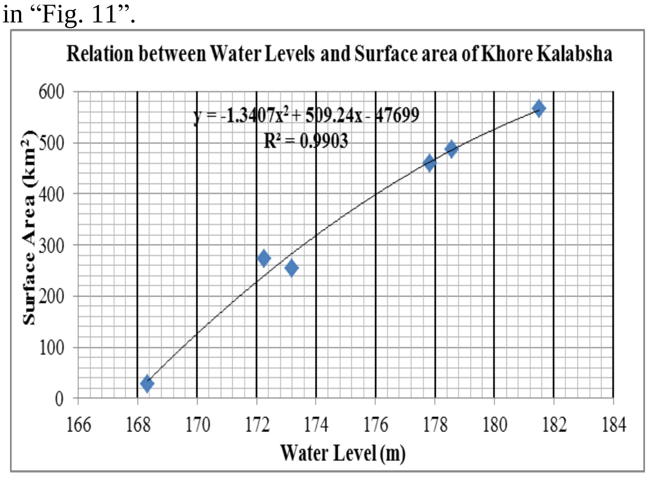

Fig. 8.Water level and surface area relationship of Kalabsha Khore (1988-1996-1999-2008-2010).

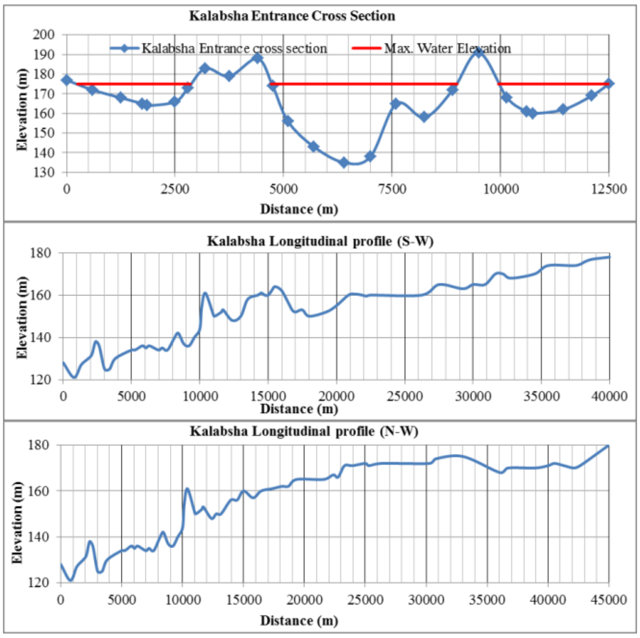

Fig. 9. Longitudinal profiles N-W & S-W & Cross section at the entrance of Kalabsha Khore.

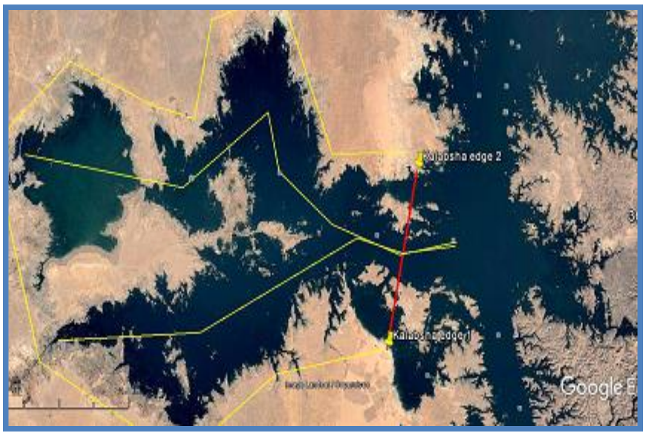

Fig. 10. Kalabsha Khore and proposed dam site (Google Earth).

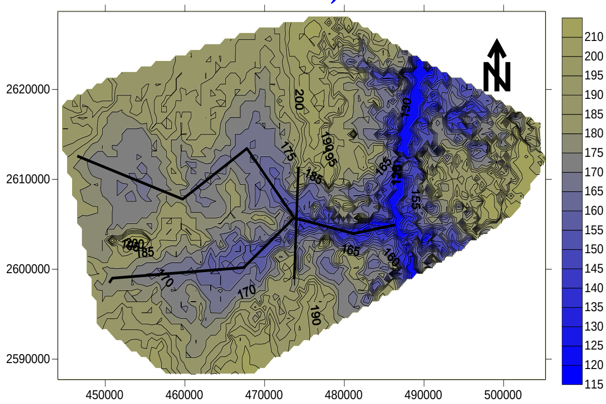

Fig. 11. The bathymetric contour map of Kalabsha khore.

B. Water Saving Details

As Toshka khore and Allaqei khore were excluded due to the reason mentioned above, the evaporation was calculated only for khore Kalabsha. The study will analyze the impact of khore closure, at level 175m AMSL. From the relation shown in “Fig. 8”, it can be identified that the surface area of the khore corresponding to level 175m is about 360 km^2. Comparing with (bulletin 145, NRI, 1999), which was based on land surveying, it was found that for the same level (175 m) the area is 371 Km^2. the difference may be due to the variance in deducing the relationship between the two methods. In order to calculate the evaporation losses from the khore, “Equation 1” mentioned above was used, and the evaporation was found about 1 Milliard m^3 represents 11.11% from the lake total evaporation losses, which may reach 1.53 Milliard m^3 if the level reaches 181.52 m for considerable time span.

In case of complete closure of Kalabsha khore, the amount of water downstream the closure dam varies according to the lake level when the dam is constructed. Assuming that the closure will take place at lake level 175m, so the water amounts that will be stored in the khore, can be approximately calculated knowing that the average depth (D) is 23.25m, calculated from the longitudinal profiles, and the surface area (S.A) is 360 km^2;

Water Content (W.C) = (S.A) (D) =* $360*10^6 * 23.25 = 8.37x\,10^9\ m^3 = 8.37\ km^3$

C. Closure Dam Design

The closure dam design will be only for khore Kalabsha as it is the optimal solution for the study of khore closure. It is noticed that the khore has steep bed slope for the first 3.0 km from the inlet and gentle bed slope after that to its end. So, it is better to select the dam closure site within the gentle slope reach to reduce the acting forces on the assumed dam section. Meanwhile, it is necessary to maximize the area which will be closed a way from the lake to reduce its surface area, so the most suitable location for the closure dam should be at certain distance far from end of the steep slope and near the entrance of the khore. Consequently the optimum location achieve these two constrain is at about 2 km from the entrance with bed levels of 134 m AMSL, which is considered suitable for small dam profile.

Closure Dams for Kalabsha khore

From the cross section of the dam location “Fig. 9”, which is far about 40 km from the western desert road Aswan-Abu-Simble, it is clear that the entrance of the khore is characterized by the existence of two intermediate islands which may act as abutment to of closure dam and reduce the total dam length, they also divide the dam into three individual parts. Table III presents the coordinated of the dam axis of the dam. Then the field data of quarries and the surface geologic features description of the surrounding areas around the khores show that the surrounded material is from fluvial deposits with cross bedded sandstone and some kinds of basement rock. The two edges of the selected site have a suitable topographic level higher than the maximum predicted water level (175m) and from hard rock.

Table -III :Details of the closure dam axis for Kalabsha khore

Dam parts	Dam Edges	E (m)	N (m)	Crest level	Max. water level	Max. water depth (m)	Length (m)
Right	1st	481528	2609774	(177) m AMSL	(175) m AMSL	15	2420
	2nd	480974	2607183				
Middle	1st	480793	2606340			39.5	4260
	2nd	479903	2602174				
Left	1st	479579	2600661			9.5	2590
	2nd	478938	2597657				

Three types of dams were proposed namely Earthfill, Rockfill, and Rubber dams’ type. A bill of quantities of major items prepared for Kalabsha khore closure dam assuming suitable costs for each item as the market price, and then a comparison has been done aiming to get the most suitable type from the cost point of view.

The approximate relation used to calculate the volume of each item in earthfill and rockfill through dam body.

$$V = \frac{3}{8} * L_c * \frac{(b+B)}{2} = \frac{3}{8} * L_c * H * (b + 2H) = \frac{3}{8} * L_c * A \qquad \text{Eq.2}$$

Where b is the dam crest width, L_c is the length at the crest level; H is the max height; B is the width at foundation level; A is cross sectional area, V the volume of any dam item, (which it is close to be parabola of length L_c and height H)

An economic study for different dam types of the mentioned items in the Tables (IV, V, and VI) with reasonable itemized price list based on similar projects in similar areas is assumed [11]. Using items quantities and the assumed price list, the bill of quantities prepared to choose the most suitable dam.

Earthfill type

The three cross sections located at the max water depth were preliminary designed as earthfill dam, in order to get benefit from the surrounding available material, with crest width of 8 m and trench core of clay at its foundation levels. The main core is impermeable vertical symmetrical section from clay with side slope of 0.3 H: 1 V, surrounded by filter layer and drain layer from two sides then shoulder layer U/S and D/S the core body from fill material with U/S side slope of 2.25 H: 1 V and 1.75 H: 1 V at D/S slope. For the deepest section, the U/S coffer dam is considered as part of the main dam as shown in detail drawings “Figs. 12&13”.

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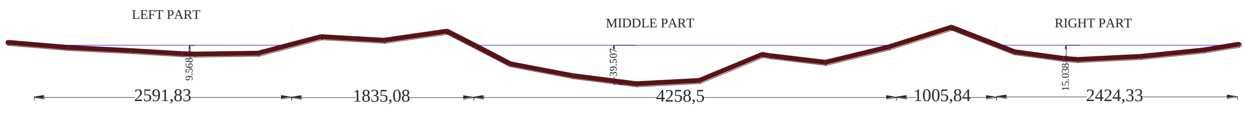


Fig. 12. Cross section of earth and rockfill dam for Kalabsha Khore

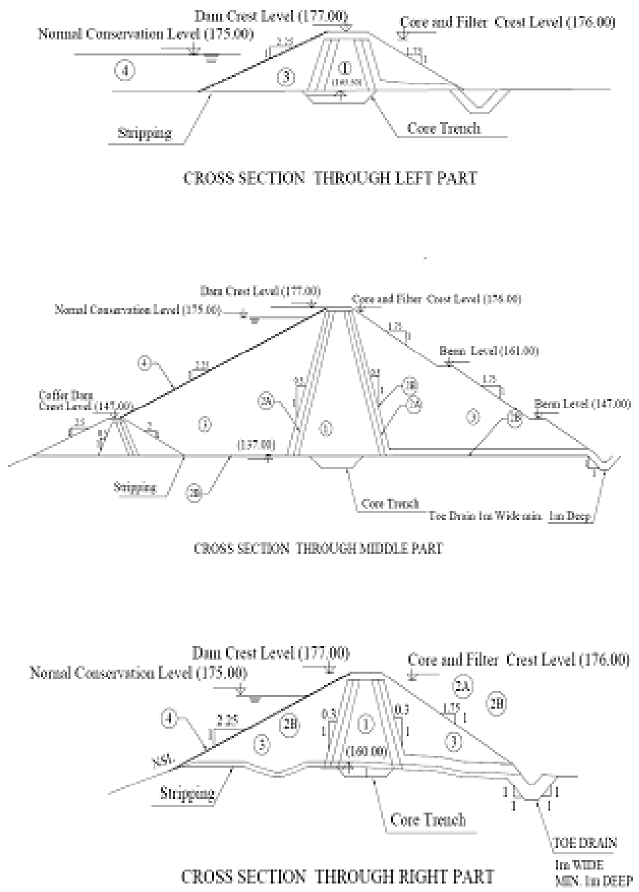


Fig. 13. Detailed drawings for Rockfill dam for Kalabsha Khore.

Embankment Dam Zones Description and Function

ZONE	DESCRIPTION	FUNCTION
1	EARTH FILL (IMPERVIOUS CORE)	CONTROL SEEPAGE THROUGH THE DAM
2A	\\FINE FILTER	CONTROL EROSION OF ZONE 1 BY SEEPAGE WATER
2B	COARSE FILTER	(a) CONTROL EROSION OF ZONE 2A INTO ROCK FILL, (b) DISCHARGE SEEPAGE WATER COLLECTED IN CHIMNEY OR HORIZONTAL DRAIN (c) CONTROL EROSION OF THE DAM FOUNDATION (WHERE USED AS HORIZONTAL DRAIN).
3	ROCK FILL	PROVIDE STABILITY
4	RIP RAP	CONTROL EROSION OF THE UPSTREAM FACE BY WAVE ACTION

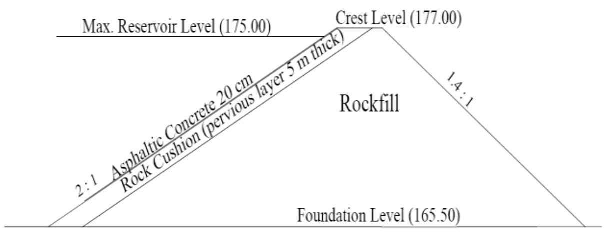
\\

Table IV: Major items quantities and total cost For Kalabsha Closure Earthfill Dam

Item	Dam parts	Core (m^2)	Fine Filter (m^2)	Course Filter (m^2)	Rockfill (m^2)	Riprap (m)
Measured Values	left	60	30	55	200	25
	Middle	570	70	140	2850	95
	Right	145	32	50	570	45
Quantity (m3)	left	58275	29138	53419	194250	24281
	Middle	908438	100000	223125	4542188	200000
	Right	131588	29040	45375	517275	40838
Length m	left	2590				
	Middle	4250				
	Right	2420				
Total cost		$34,183,182.50				

Rockfill Dam

The dam cross sections were preliminary designed as rockfill dam, with crest width of 14 m to permit using it as a roadway between two sides of khore banks. U/S side slope is chosen to be 2 H: 1 V to allow for right positioning of the U/S impermeable asphaltic concrete layer of 20 cm thickness over pervious cushion layer of 5 m thickness then the rockfill material to the D/S side slope of 1.4 H: 1 V for the deepest section. Assume U/S concrete cut off and gallery for grouting along the U/S side, as shown in detail drawings “Figs. 12&14”



CROSS SECTION THROUGH LEFT PART

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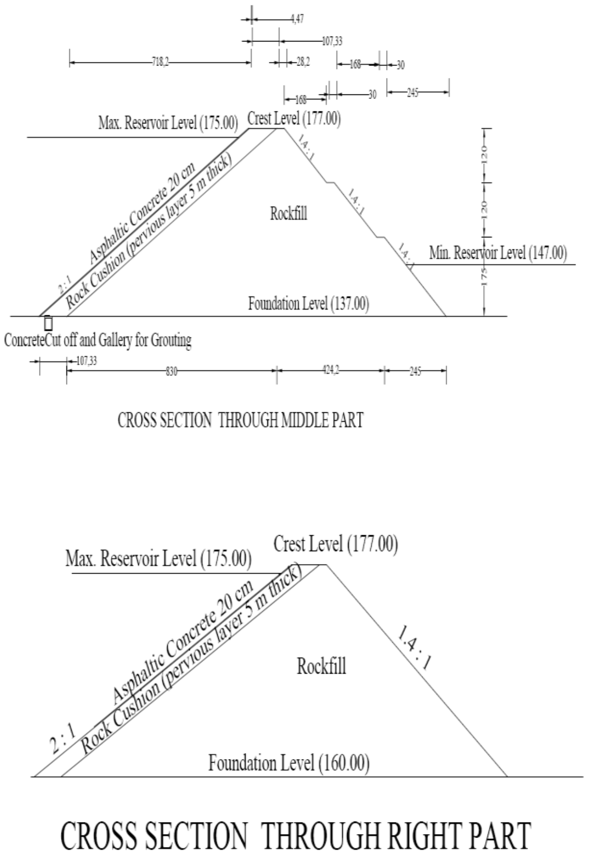

Fig. 14. Detailed drawings for Rockfill dam for Kalabsha Khore.

Rubber Dam

Rubber dam is the last alternative for Kalabsha Khore, the cross sections were designed with crest level of (167) m and the rubber dam tube is of diameter of 8.6 m, length 200 m and thickness 25 mm consisting of 3 layers. Assuming reinforced concrete piers of 3 m width to ensure fixation of the rubber tube from its two ends and support the concrete raft foundations and 14 m length (to cover the deflated position of rubber tube, this length should be greater than πD/2. The top level is (178 m) rising about 11 m above the crest level, 200 m spacing. The rubber dam is supported on concrete raft of 100 cm thickness (to fix the anchorage bolts of the rubber) and assuming two rows of concrete cutoff with depth of 6 m and thickness of 30 cm along the total length of the dam to ensure fixation of the raft with its foundation from rockfill dam components and control seepage through the lowered portions of rockfill bodies. The rubber foundation is assumed to be a rigid concrete layer with 2 concrete cut-off walls (6 m depth) inserted into compacted rock fill to the lower level of the khore as shown in "Figs. 15&16". It is worthy to mention that top level of concrete pier at 178 m AMSL, which is higher than maximum water level by 2.4 m to allow overtopping flow during high flood times (if any). The major Items necessary for dam construction using different type of dam are calculated. [12, 13]

Table -V: Major items quantities and total cost for Kalabsha Closure Rockfill Dam.

Item	Dam parts	Asphaltic concrete (m)	Rock Cushion (m2)	Rockfill (m2)	Stripping (m2)
Measured Values	left	23	33	240	60
	Middle	82	440	3150	240
	Right	38	60	500	60
Quantity (m3)	left	22339	32051	233100	58275
	Middle	130688	700000	5000000	382500
	Right	34485	54450	453750	54450
Length m	left	2590			

		Middle	4250
		Right	2420
Total cost			$39,600,538.75

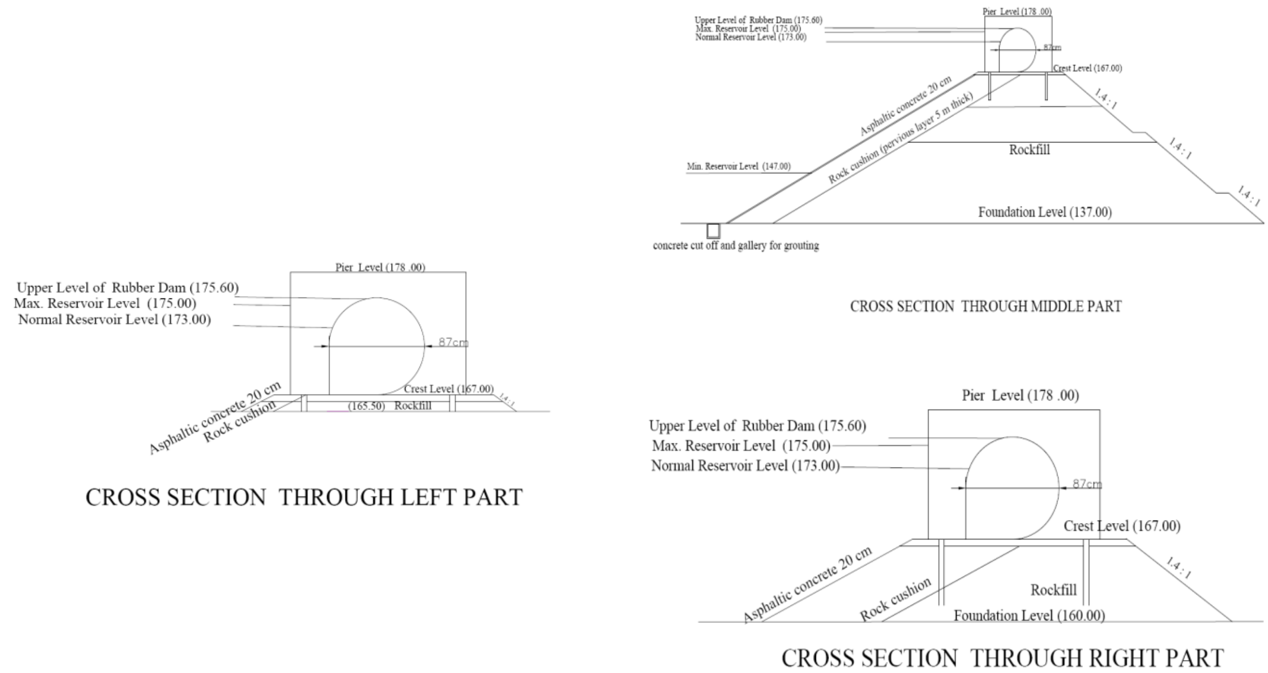

Fig. 15. Detailed drawings for Rockfill dam for Kalabsha Khore.

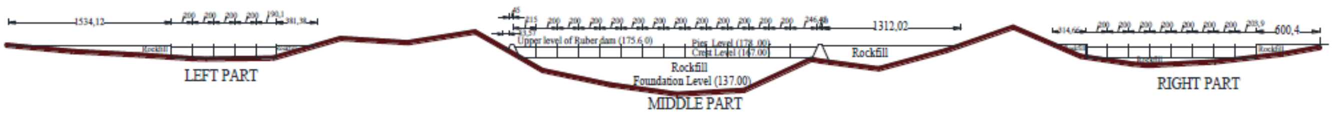

Fig.16. Cross section of rubber dam for Kalabsha Khore

Table-VI: Major items quantities and total cost for Kalabsha Closure Rubber Dam.

Item	Dam parts	Cutoff curtain (m^2)	Raft concrete (m^2)	Pier concrete (m^3/unit)	Rubber tube 8.6 m Dia. (m)	Rockfill parts
Measured Values	left	3.6	8.4	300	970	0.4 of rockfill
	Middle	3.6	8.4	300	2800	0.33 of rockfill
	Right	3.6	8.4	300	1600	0.18 of rockfill
Quantity (m3)	left	2500	8300	1800	970	9712.4
	Middle	5040	23520	4500	2800	66000
	Right	2800	13400	2700	1600	7350.84
Length (m)	left	990 m rubber and 6 piers & 1600 m rockfill				
	Middle	2800 rubber and 15 piers & 1450 m rockfill				
	Right	1600 rubber and 9 piers & 820 m rockfill				
Total cost		$33,521,767				

V. CONCLUSION AND RECOMMENDATIONS

The water saved from evaporation losses in case of the closure of the Kalabsha khore is 1 Milliard m^3 at level 175m and it may reaches about 1.53 Milliards m^3 if the level in the lake reaches 181.52m for considerable time span.

The water stored downstream the proposed dam in Kalabsha khore reached a considerable amount (8.37 Milliard m^3).

Different dam closure types; earthfill, rockfill and rubber, were suggested and designed according to the international specification of the preliminary phase then evaluated based on costs of main construction items. The cost comparison results showed that the rubber type has the least value among others for the Kalabsha khore.

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These rubber dams are made of high strength fabricated with rubber, forming a ballooned rubber bag when filled with water/air with suitable internal pressure ratio and anchored to the concrete foundation can retain/release the surplus water over its top by emptying filled water/air from it hasn't a beneficial negative impact on environment and ecology. It has many advantages compared with the other suggested dam types [14] as;

1. The large amount of clay needed for earthfill core as shown in bill of quantities will be saved and may be used for other purposes such as desert reclamation.
2. The induced seismicity due to large weight of the rockfill or earthfill will be decreased when using rubber type.
3. In case of any high risk flood and emergency, it can easily decrease the rubber dam height, for one or more span, allowing water to flow downstream of the dam into the khore.
4. Adjustable height of rubber dam can control the water flow to the khore, as a mitigation measure for social and environment aspects.

From the previous discussions and conclusions it is recommended that:

- The closure of Kalabsha Khore is considered a top priority due to its large surface area and high evaporation.
- The idea of closing Allaqei khore and Toshka Khore should be excluded from the decision maker agenda due to their environmental and strategic importance.
- It is important to look for other alternatives to reduce evaporation losses such as examining the feasibility of operating HAD under low levels and its impact on the energy generated from the high dam and the strategic capacity of the lake.
- It is important to study the feasibility of getting benefit from the water stored downstream the proposed dam in Kalabsha khore instead of its evaporation which may take around 8.6 years. Taking into account that this water can be used for seasonal crops or pastoral projects, or in recharging the ground water aquifers in the region, either naturally or artificially according to the type of soil and the infiltration rate.

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