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Impacts of the Aswan High Dam After 50 Years

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Abstract
Objectives Perform an assessment of the environmental and health impacts of the Aswan High Dam (AHD) after nearly 50 years of operation. This paper describes the effect the AHD had on (1) the prevalence and incidence of schistosomiasis in Egypt, (2) sedimentation in the reservoir formed by the AHD (Lake Nasser in Egypt and Lake Nubia in North Sudan), (3) soil water logging and subsequent soil salinization in the Nile Delta (4) coastal retreat along the Egyptian Mediterranean Sea.
Results • Schistosomiasis has decreased in Egypt since the AHD.

• Agricultural fields in the Nile Valley and Delta tend to waterlogged and since the water is not flushed out annually, the soils are saltier and so less fertile. However, the AHD affords multi-cropping during the year and Egyptian farmers have adopted better seeds and harvesting methods. Overall, agricultural production in Egypt has increased.

• Coastal erosion is severe in some areas, especially at the Rosetta and Damietta promontories. Efforts to stop the overall coastline retreat have been largely unsuccessful. Other areas of the Egyptian Mediterranean coastline are stable or have accreted.

• Reservoir-induced seismicity is not an issue.

• Deterioration of low-lying ancient Egyptian monuments due to seepage water from irrigation is a problem.

Keywords Aswan High Dam · Egypt · Nile · Environmental impact

1 Introduction

Negative public opinion on the Aswan High Dam (AHD) formulated soon after it began operation in 1968 and it became a famous example of poorly conceived civil engineering projects. A journalist and major critic of the project, Claire Sterling, wrote a series of articles critical of the project in the early 1970's. Her writings were widely read in magazines such as Life (Sterling 1971a). Construction on the AHD was just completed when Sterling made

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alarming predictions about the potential environment and health impacts of the dam. In one, article she said it would be "the greatest environmental catastrophe of mankind" (Sterling 1971b). In another article, Sterling said it was "More Damn than Dam" (Sterling 1971c, 1972).

Some of Sterling's prognostications were:

1. There would be coastal erosion along the entire coastline of the Egyptian Mediterranean Sea.
2. Evaporation and seepage would cause huge losses from the reservoir formed by the AHD.
3. The reservoir would fill with sediments within 20 years.
4. Marine life in the Mediterranean Sea would be "decimated"
5. The disease schistosomiasis would "explode" in Egypt.
6. Perennial irrigation afforded by the AHD would cause farmers to overwater their fields resulting in water logging and subsequent soil salinization. Also, since silt would be trapped behind the AHD, nutrients that formally replenished the Nile Delta's soil would be lost and so artificial fertilizers would be needed.

This paper will examine these potential impacts. It categorizes them into three groups (1) those that never came to pass (2) those that happened, but are minor and (3) those that were accurate and present a threat to Egypt.

2 Geography of the River Nile

The Nile is the longest river in the world, traversing nearly 7000 km through 11 riparian countries (Egypt, North Sudan, South Sudan, Burundi, Ethiopia, Uganda, Eretria, Kenya, Tanzania, Rwanda, and the Democratic Republic of Congo), before emptying into the Mediterranean Sea. Its basin covers approximately one- tenth of the African continent, with a catchment area of over 3,000,000 km^2. The Nile consists of two major rivers: the White Nile and the Blue Nile. The 3700 km long White Nile originates at Lake Victoria and has a relatively constant discharge from month to month and also annually. The 1450 km long Blue Nile originates at Lake Tana in Ethiopia and has a highly stochastic discharge both monthly and annually. Over 80 % of the discharge of the Blue Nile occurs between July and August during the rainy season in the highlands of Ethiopia. Year-to-year variation fluctuates highly and has done so since records were first kept during ancient times. Ethiopia and all countries downstream have, for centuries, tried to dampen the flow with dams and other flow augmentation structures.

From its most remote source in Central Africa to the Mediterranean Sea, over 300,000,000 people along its course are affected by the river. Sparse human development exists in the catchment areas of the headwaters for the Blue and the White Nile. Most large population centers in the Nile's watershed are in the arid and semi-arid regions of Egypt and the city of Khartoum in North Sudan (Smith 1990).

The hydroelectric power production potential of the Nile is large. The Victoria Nile, for example, could generate over two gigawatts. Currently hydroelectric plants are located at Owen and Kabalega falls.

The Merowe Dam in North Sudan was completed in 2009 and produces electricity as does a new dam at Jinja, Uganda . A dam at Bujagali Falls in Uganda was completed in 2012. Other hydroelectric dams are planned by riparian nations of the Nile. The largest is the "Grand Ethiopian Renaissance Dam" which will be the largest hydroelectric generating dam in Africa when completed in 2017.

3 The Aswan High Dam

In the mid-20th Century when plans were being made for the Nile, the concept of a large dam at Aswan had one major advantage over the idea of a series of coordinated smaller dams along the entire course of the Nile. It would give Egypt long-term protection against drought and flood. For example, the droughts that occurred between 1979 and 1987 had no effect on water supply downstream from Aswan thanks to the AHD. The AHD also provided flood protection against high water periods such as between 1998 and 2002. These floods would have been a major catastrophe had it not been for the AHD. The other noteworthy advantage over smaller dams was the AHD's production of electricity. At the time it was built, the hydroelectric power production from the AHD would have met most of Egypt's electrical needs.

Other benefits of the AHD were: (1) providing water for agricultural land reclamation (2) converting basin irrigation with perennial irrigation (3) expanding rice production (4) development of a fishery in the reservoir formed by the AHD (5) improvement of river navigation due to steady water level downstream from the AHD.

In 1955, the World Bank issued a favorable report on the technological and economic feasibility of the concept in 1956 and Egypt hired a British civil engineering firm to design the AHD. Egypt then negotiated an Anglo-American financing plan. However, later in 1956, Egyptian President Nasser formally recognized Communist China and the United States reacted by canceling its portion of the agreement, as did Britain.

The Soviet Union offered to build the dam in 1958 and construction began in 1964. The project was completed in 1970 and the reservoir reached its operating level in 1976.

The reservoir formed by the AHD, shown in Fig. 1, is named Lake Nasser in Egypt and Lake Nubia in Northern Sudan. It has a total volume of 130 billion cubic meters of stored water. Of this, 32 billion cubic meters is dead storage, leaving enough live storage to satisfy Egypt's agricultural and domestic water needs. The AHD is situated on the First Cataract of the Nile River. The dam is four kilometers along its crest and has height of 111 m. Lake Nasser/Nubia is one of the world's longest (500 km) and largest (over 6000 km^2) reservoirs. The AHD

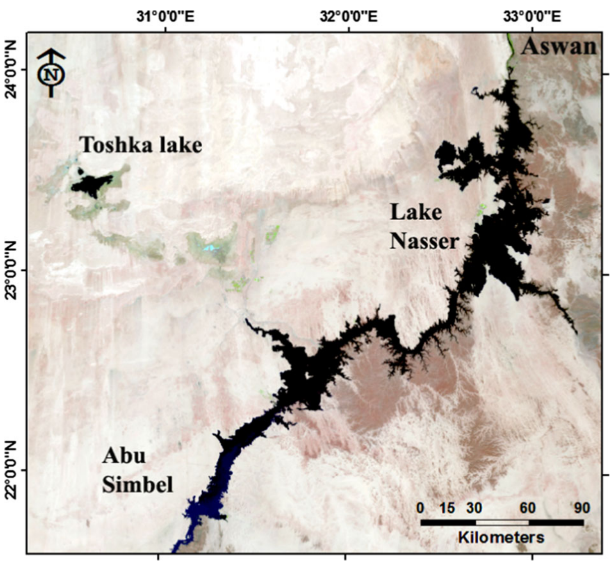

Fig. 1 Lake Nasser/Nubia. Source: Landsat 8 taken 19 June 2014

has produced hydroelectric power, held back floods and provided steady water during prolonged droughts in its nearly 50 years of continuous operation (Abu-Zeid 1987).

4 The New Valley Project

Between 1998 and 2002, a series of unusually high-volume floods of the Nile increased the water level of Lake Nasser/Nubia to beyond the capacity of the AHD. This problem prompted construction of a draw-down channel linking Lake Nasser with the Tushka Depression adjacent to Lake Nasser. The Tushka Canal, completed in 2008, is a release canal for Lake Nasser. It seemed logical to reclaim land for agricultural use in the Tushka Depression and so "The New Valley" project was initiated.

The New Valley project, which started in 2008 and ended in 2013, failed to reach its objectives due to poor soils, sand dune encroachment and excessive evaporative losses. Figure 2 shows the project area as it was in June 2014. There are evident in the image a few pivot irrigation schemes, but according to the original plan, the entire area was to have been covered by agricultural plots. Instead, much of the area is covered by migrating sand dunes that have encroached into the region. In several areas on the western shore of Lake Nasser, sand dunes have encroached onto the lake and so have reduced the capacity of the reservoir.

5 Purpose of Aswan High Dam

The annual discharge of the Nile varies dramatically. It is characterized by long periods of drought followed by extreme floods. Discharge volume has been measured at the Nilometer in Cairo since AD 861 and it ranges from 32 billion cubic meters to over 100 billion cubic meters annually.

Most of Egypt's 100 million people live in close proximity to the Nile. Consequently, the river's flow has historically meant the difference between famine and prosperity. Extraordinary floods and prolonged droughts have caused loss of life and property for thousands of years. In addition to water, the Nile provided an average of 125 t of silt to the Nile Valley and Delta

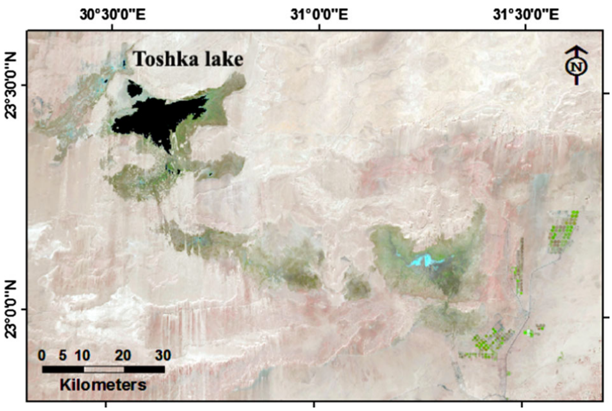

Fig. 2 Toshka Project. Source: Landsat 8 taken 19 June 2014

annually. This replenished the soil with nutrients and the flood waters flushed out excessive salts.

Similarly, North Sudan is dominated by vast barren desert and the populated land is limited to a narrow strip along the Nile. Egypt and Sudan occupy over 85 % of the Nile Basin and variations in the Nile's discharge made it difficult to maintain sustainable agricultural production and support land reclamation from the desert.

Before the AHD, most of the Nile's water was released unused to the sea. Water release from the AHD is now dictated by downstream water demand requirements and not the vagrancies of nature. Before the AHD, fields adjacent to the Nile Valley and in the Delta were supplied with water through the age-old practice of basin irrigation. Water was captured through a network of levees and dikes that percolated into the ground. Since the Nile floods only once annually, only one crop could be harvested each year. On the other hand, the AHD has an over-year water supply capacity and so provides year-round irrigation water. This capacity has, effectively, transformed the entire irrigation system to a perennial one. Three crop seasons are used and Egypt's total food production has increased as a result.

Another benefit of the AHD was that it afforded year-round unrestricted shipping along the Egyptian Nile. Prior to the AHD, ships would frequently get grounded during low-flow periods in summer. This problem was eliminated by the AHD.

The AHD produced most of Egypt's electric for decades until demand for electricity surpassed the capacity of the AHD to produce it. This was the result of high population growth and an ever-improving economy. Egypt would have not been able to develop as quickly as it did had it not been for the AHD.

6 Impacts of the Aswan High Dam

6.1 Incidence and Prevalence of Schistosomiasis in Egypt

Epidemiologists and journalists predicted that the disease schistosomiasis would increase in incidence and prevalence in Egypt as a result of the AHD (El Alamy and Cline 1977). Their reasoning was that (1) the impoundment of the Nile would create environmental conditions conducive to increasing the snail population and snails are the intermediate host of the schistosomiasis parasite and (2) steady water flow and levels downstream from the AHD would make the Nile more accessible to people and increased accessibility would lead to more contamination.

The disease schistosomiasis is endemic to Egypt. Mummies over 4000 years old have been found with the parasite. Schistosomiasis is a debilitating parasitic disease that does not kill the host outright, but saps the infected person of energy and makes them more susceptible to other diseases, especially liver cancer. It is contracted through contact with a parasite that uses snails as an intermediate host. Because the parasite can penetrate skin, it is nearly impossible for anyone in contact with contaminated water to avoid becoming infected. It is especially a problem for the 6000 fishermen who work on Lake Nasser/Nubia and for the hundreds of thousands of farmers who stand barefoot in irrigation and drainage canals.

It was feared that formation of a large lake behind the AHD would provide ideal habitat for the snail that serves as an intermediate host for the parasite. The snails only survive in slow-moving water such as a reservoir or lake and so it was thought that the snail population

An increase in schtosomiasis was predicted by epidemiologist Van Der Schalie who stated, "there is evidence that the high incidence of the human blood fluke schistosomiasis in the area may well cancel out the benefits the construction of the Aswan High Dam may yield (Farvar and Milton 1972)". Van Der Schalie thought that schistosomiasis would increase as farmers converted from basin irrigation system to perennial irrigation and so had more water to irrigate with.

In 1977, Malek stated other reasons for a potential increase in schistosomiasis transmission. His study indicated that in some sections of the lower Nile, ecological changes as a consequence of the AHD would enhance spread of the disease because the absence of silt and decrease in water current velocity in the lower Nile would have given higher chance for the miracidia to come in contact with the snails and for the cercaria to infect humans (Malek 1975).

Malek reported that human activities in and near the Nile water had increased considerably throughout the year because of the low, and slow water. There was more fishing, swimming and washing of domestic utensils and clothes since the AHD. These activities used to be confined to irrigation canals.

Another significant factor in the ecology of the snail host living in the irrigation canals in the Nile Delta is the elimination of the winter closure because clearance of the canals. During this period-from the flood silt deposited in their beds was no longer needed. Therefore, conditions that used to control the snail population will be absent after the AHD, thus leading to more snails in the Nile Delta canals.

However, the fears of Van Der Schalie or Malek were not borne out. Many epidemiological studies conducted prior to and after the AHD have reported that prevalence and incidence of schistosomiasis in Egypt has actually decreased. In 1978, soon after the AHD was commissioned, De Wolfe-Miller et al. (1978) conducted an baseline epidemiological survey on over 15,000 rural Egyptians from three geographical regions of Egypt (Nile Delta, Middle Egypt and Upper Egypt), in addition to the resettled Nubian population. The prevalence of schistosomiasis was 42 % in the North Central Delta region, 27 % in middle Egypt and 25 % in Upper Egypt.

In 1996, the Schistosomal Research Project reported that for the same area as studied by Miller, 168 villages had an infection rate of greater than 30 %, 324 villages had rates of 20 to 30 % and 654 villages had rates of 10 to 20 % (Baralat 2013).

In 1997, the National Schistosomal Control program adopted a plan to decrease the prevalence of the disease. The program consisted of installation of clean fresh water pumps in every village, treatment of canals and drainage ditches of copper sulfate and wide distribution of a new drug, metrifonate. By the end of 2010, there were only 29 villages with prevalence greater than 3 % and none had more than 10 % (Baralat 2013).

As regard to the schistosomiasis in Lake Nasser, the infection rate was high for fishermen working there. However, the infection declined from 67 % in 1974 to 20 % in 1981. This was attributed to the widespread use of metrifonate in Upper Egypt beginning in 1975 (Baralat 2013).

7 Lake Nasser/Lake Nubia Infilling with Sediment

During the annual flood, the Nile carries between 80 million and 130 million tons of sediment to Egypt and North and South Sudan from the Ethiopian Highlands. Some of is deposited along the flood plain of the Nile in North and South Sudan, but most settles in Lake Nubia (the Sudanese portion of the Aswan High Dam reservoir). The reservoir has a trapping efficiency of 99 %, which effectively means that only clay-sized particles in suspension are discharged through the dam. All sand and silt-sized particles remain in the reservoir.

However, as the reservoir was filling between 1971 and 1978, sediment-laden water traversed the entire length of the reservoir. As the reservoir filled, the velocity of the flow declined and so sediment was deposited progressively upstream from the AHD.

Annual surveys of sediment deposition in Lake Nasser/Nubia have been conducted since 1964 by the Aswan High Dam Authority. The surveys conduct a cross-section using echo-sounding at 45 points along the length of the reservoir from the AHD to 500 km upstream at Daka. The cross-sections indicate that nearly all sediment build-up is confined to between 350 and 500 km upstream of the AHD as shown in Figs. 3 and 4. Sediment depth ranges from virtually nothing near the AHD to over 75 m at the Second Cataract of the Nile in North Sudan.

Therefore, concerns that the live storage capacity of Lake Nasser/Nubia would be compromised (e.g. Lake Nasser/Nubia would rapidly fill with sediments) were unfounded. Sedimentation is restricted to a narrow 150 km stretch of the riverine portion of the reservoir. While light suspended material is transported through the reservoir, it does not settle and so does not impact the long-term life of the AHD. Recent long-term forecasts of the useful life-time of the reservoir are in the range of 300–400 years (Smith 1990).

8 Reservoir-Induced Seismicity

The HD is situated on a natural fault zone. The HD was built on the first cataract of the Nile's five cataracts because the abrupt change in topography at fault or cataract makes it a natural waterfall. Early in the planning stages, concern for the stability of the fault was voiced by Egyptian geologists. It was hypothesized that the weight of Lake Nasser/Nubia might trigger an earthquake along the fault line.

Seismic activity is closely monitored at Aswan and, to date, no earthquakes have occurred. A small earthquake took place near Cairo in Lower Egypt in 1982, but it was unrelated to the structural lineage of Aswan.

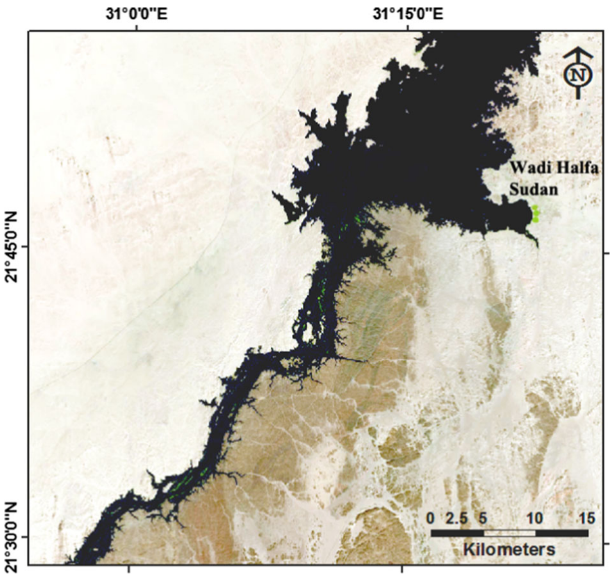

Fig. 3 Active sediment deposition zone. Source: Landsat 8 taken 19 June 2014

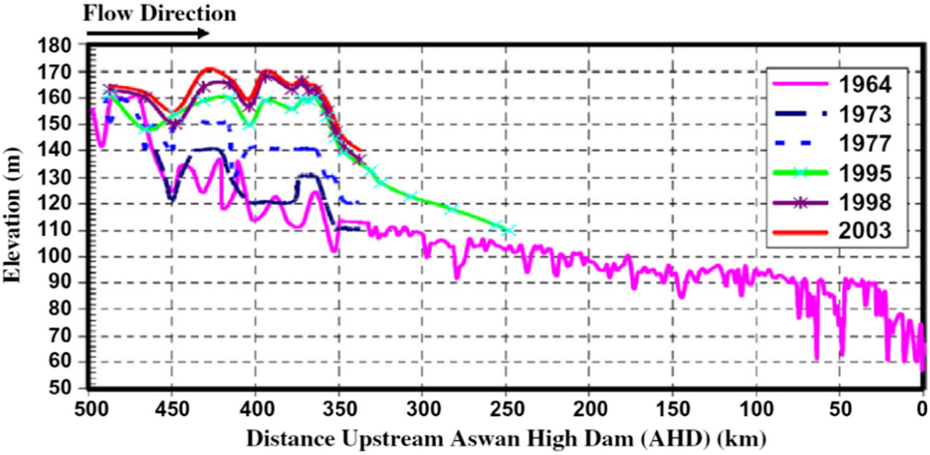

Fig. 4 Longitudinal section of the lowest bed elevation of Lake Nasser/Nubia between 1964 and 2003. Source: Moustafa 2013

9 High Groundwater Level and Deterioration of Ancient Egyptian Monuments

While many of the most famous ancient Egyptian tombs are located well away from and high above the Nile (e.g., Valley of the Kings, Valley of the Queens, Queen Hapsheut's Temple), some (e.g., Karnak, Luxor Temple, Memphis) are adjacent to either the Nile of irrigation and drainage canals or urban centers (e.g., the pyramids at Giza and the Sphinx). It has been noted that over watering of fields and the subsequent rising of the groundwater table has resulted in seepage into low-lying areas where some of the ancient monuments reside. The limestone rock, which serves at the building material for most of the monuments "wicks" the moisture and causes damage to them. As the moisture migrates to the surface of the monuments, it introduces salt to the stone, which weakens the rock's cementing agents. A secondary problem is that the moisture tends to make the foundations of the monuments less stable and more likely that the ancient structures will subside (Smith 1986).

There are on-going efforts to reduce the practice of over-watering of all agricultural fields in Egypt, including those with proximity to ancient sites. This problem was an unanticipated and serious impact of the AHD.

10 Evaporation from Lake Nasser/Nubia

The highest recorded water level at the AHD was 182 m above mean sea level in November 1999, while the lowest level recorded was 158 m in July 1988. Lake Nasser/Nubia covers an area of approximately 6000 km^2, 85 % of which is in Egypt and 15 % in Northern Sudan, The average depth is about 25 m with the maximum depth being 130 m.

Water loss from the reservoir due to evaporation is between 10 and 16 billion m^3 every year. The wide range is because evaporation volume is a function of the surface area of Lake Nasser/Nubia. This is equivalent to 20 to 30 % of the Egyptian allocation from the Nile Treaty of 1952. Egypt's demand for water has increased more than the other riparian nations of the Nile due to a rapidly growing population, upsurge in industrial activity and increase in the new reclaimed farmlands.

The idea of reducing evaporation losses from Lake Nasser has received increasing attention because of the increase in water demand and the decrease in water availability (Sadek et al.

1997). New research on ideas such as a pontoon framework and circular foam sheets is being performed. Another idea is to partially or fully disconnect some of secondary channels (khors) that do not contribute appreciably to the storage capacity of the Nasser Lake due to their shallowness, but highly contribute to evaporation from the lake due to their high surface area (Elba et al. 2014). They recommend disconnecting some of the khors based on their contribution to evaporation.

Another idea to reduce evaporation would be to create a new canal at the midpoint of the reservoir in order to circumvent a high number of secondary channels. The location of the canal is shown in Fig. 5. The canal will reduce the surface area of water in that part of the reservoir from 512 to 96 km^2.

Penman's evaporation formula was used by Kalifa et al. (2012) to determine evaporation in the area of Lake Nasser/Nubia affected by the proposed canal. They used the data from two meteorological stations shown in Fig. 6. Monthly evaporation amounts were calculated if the new canal was to be built. Annual evaporation from this area is now 1776 million cubic

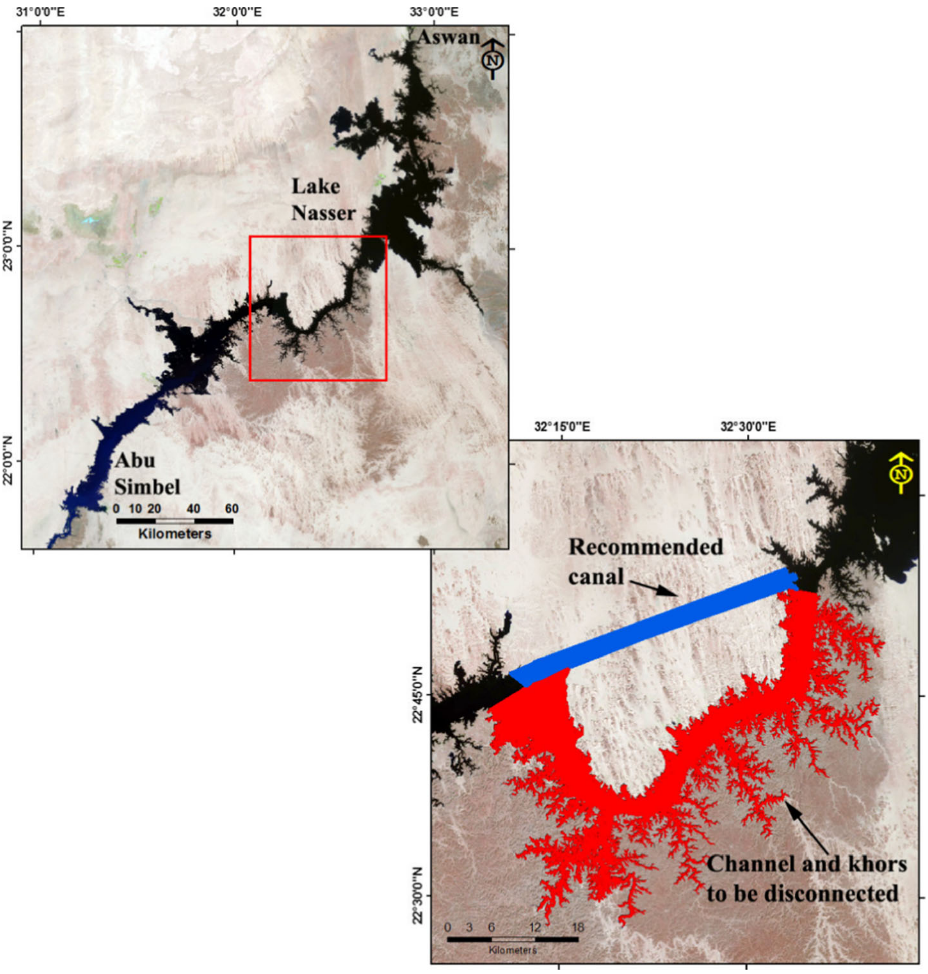

Fig. 5 Location of proposed by-pass canal

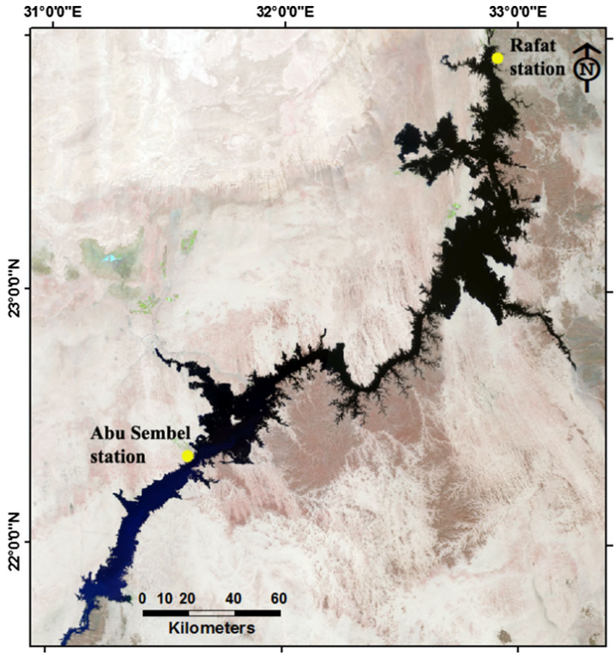

Fig. 6 Location of Raft and Abu Simble Meteorological Stations

meters. If the canal was built, evaporation losses would be only 327 million cubic meters. Therefore the new canal will save approximately 1450 cubic meters per year.

11 Waterlogging and Subsequent Soil Salinization in the Nile Delta

Prior to the AHD, basin irrigation had been used in Egypt for thousands of years. During the annual flood, water was diverted from the river and inundates fields until, eventually; it would seep into the ground. Minerals and nutrients would be deposited from the silt to replenish the soil. When used in a perennial irrigation, this scheme can result in overwatering and water logging. The problem is exacerbated by the presence of the year-round high water table resulting from high water levels in the channel. Evidence that the water table has risen along the Nile Valley since construction of the AHD is confirmed by piezo measurements (Smith and Abdel-Kader 1988). In low-lying areas, the water table is close to the ground surface.

Water downstream from the AHD has higher salinity than water entering the reservoir due to high evaporation rate. Nile water is reused several times before being discharged to the sea and each time is becomes more salty. A high concentration of salt in the irrigation water has a deleterious impact on soil fertility and crop production and is a limiting factor for some non-salt tolerant crops.

Farmers have uses progressively more chemical fertilizer since perennial irrigation was instituted. Artificial fertilizers were used before the AHD. The nutrients of the soil washed down from the Ethiopian Highlands were relatively low in nitrogen and so that was supplemented for centuries. Therefore, the AHD has been responsible for Egypt depending more on artificial fertilizers, but not entirely. Similarly, waterlogging was a problem before the AHD during particularly high floods, but the flood water had an entire year to either percolate into the soil or evaporate. Now, water saturates the soil year-round in many places and so degrades the productivity.

The total amount of crops grown and harvested in Egypt has increased since the AHD. The complete explanation for is increase is beyond the scope of this paper, but it is due to year-round cropping, improved seeds, less loss during harvest and mechanization. The year-round cropping was afforded by perianal irrigation thanks to the AHD.

12 Coastal Erosion

Although coastal erosion along the Egyptian Mediterranean Sea is a process that has been going on since ancient times, there is no question that implementation of the AHD exacerbated the process and is a serious problem and efforts to slow erosion have been largely unsuccessful. Four simultaneous processes are going on: (1) the AHD traps all of the sediment which used to feed the shoreline, (2) the sea level is rising and (3) the Delta is subsiding (4) dozens of drainage canals that connect to the sea send tons of sediment into the Mediterranean Sea annually. The sediment comes from fields throughout the Delta.

Topographic maps of Egypt's Mediterranean coast made by the Egyptian Survey Authority in 1945 were compared with Landsat satellite images taken between 1972 and 2014. It was evident that the coastline retreated primarily at near mouths of Nile branches, the Rosetta and the Damietta as shown in Figs. 7 and 8.

The annual rate of coastal erosion between the years 1990 and 2002 averaged 30 m along the Damietta peninsula. It decreased to about 20 m per year between 2002 and 2014. The decrease may due to coastal protection project established in the area including the installation of sea walls, rip-rap and levees shown in Fig. 9, but the protection devices have been unsuccessful elsewhere.

13 Conclusions

This study found that there have been long-term adverse impacts from the Aswan AHD. The most serious of these is coastal erosion, even though this process was ongoing prior to the AHD and certainly would have occurred due to sea level rise alone. Unfortunately, despite attempts to slow down erosion, the process is accelerating in some key areas and will probably continue to do so.

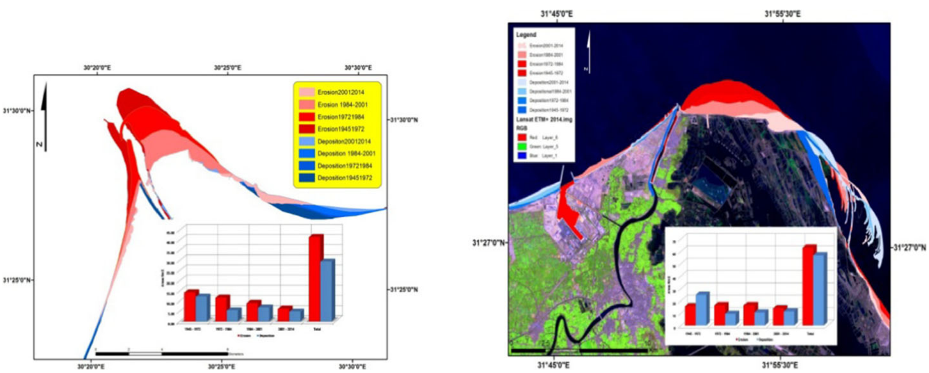

Fig. 7 Coastline changes along Rosetta (*left*) and Damietta (*right*) outlets between 1945 and 2014

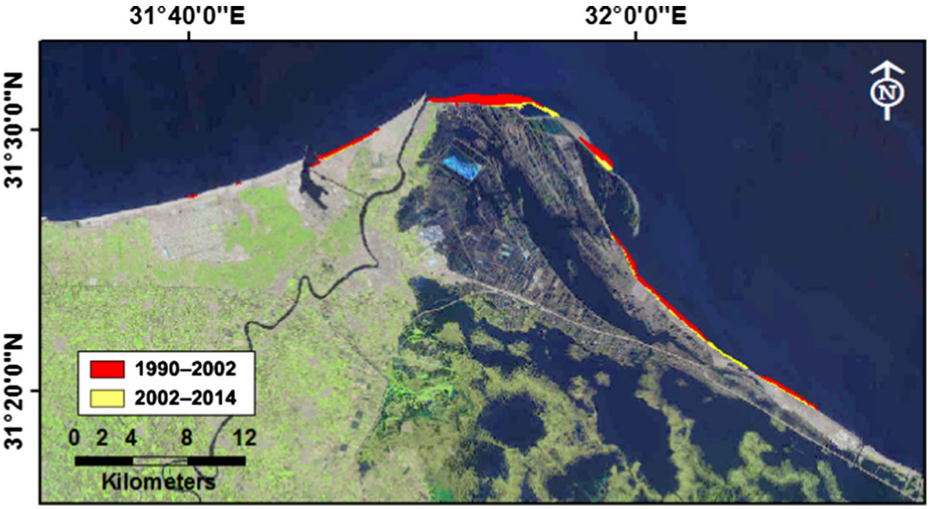

Fig. 8 Coastal erosion in the Damietta Region between 1990 and 2014

This will result in a loss of arable land in the Egyptian Delta due to the fact that the Delta is low relative to sea level, flat and it is sinking through subsidence.

Schistosomiasis did not increase in incidence or prevalence as a result of the AHD. Although the AHD's reservoir provided a suitable habitat for the diseases to flourish and also made access to the Nile easier year-round, public health measures and effective drugs have been successful in preventing and treating the disease.

Lake Nasser/Nubia's evaporation losses are high, but Egypt still has sufficient water to meet agricultural and domestic needs. The surface area of Lake Nasser/Nubia after it reached its operating level of 180 m above mean sea level was accurately estimated through topography

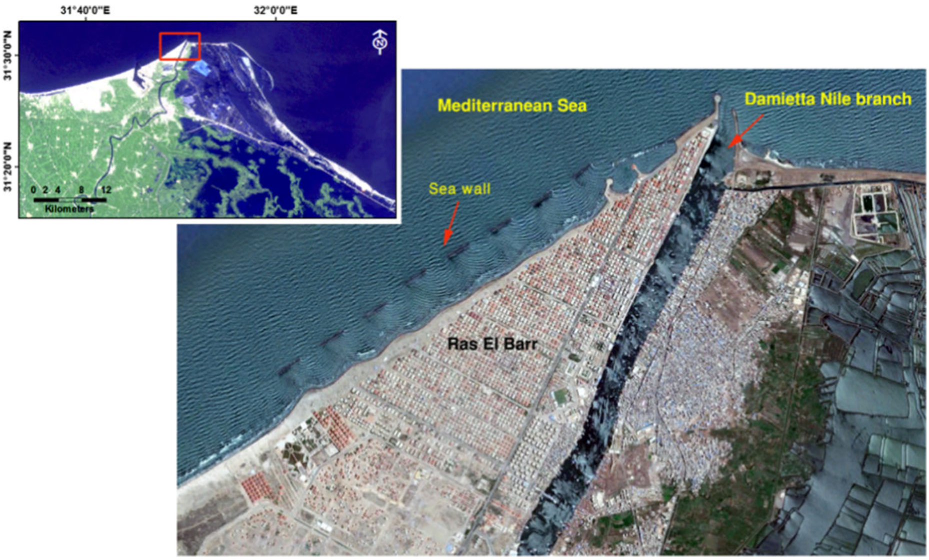

Fig. 9 Coastal protection device at Ras El Barr

surveys made by the AHD's planners. They knew that evaporative losses would be high relative to reservoirs in more temperate climates, but decided that the loss was acceptable given the many benefits of the AHD. It would be relatively easy to reduce evaporation by digging by-pass canals to cut-off shallow khors with large surface areas.

In Islamic cultures like Egypt, water is “free for all”, and it was anticipate that farmers would tend to over-water their fields when afforded year-round irrigation. Prior to the AHD, the strategy used by farmers in basin irrigation was that you could never capture too much water.

This concept and the fact that nobody paid for water led to water logging of the soils and subsequent salinization. This has been exacerbated by the fact that high evaporation in Lake Nasser/Nubia caused the Nile's water downstream from the AHD to become more saline.

The result is that soil fertility has decreased and agricultural production on an area and time basis has declined. However, this decline has been more than offset by the fact there are now three rather than one growing season and farmers can now rely on a steady over-year supply of irrigation water. There are no more droughts and no more floods.

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