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Review and Analysis of Africa's Lifelines: The Nile River and the Aswan High Dam

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Abstract

The River Nile in Africa is the world's longest river. It is approximately 6650 km from the mouth of the Mediterranean Sea to its headwater sources, the Blue Nile and White Nile. The Nile drainage basin is about 9674 million km^2 making it the third-largest drainage basin in the world. The primary research objectives are to document how the periodic flooding of the Nile River was controlled, how the Nile became Egypt's economic, agricultural, and urban development engine, and provide historical lessons for other countries to learn from when attempting to develop their own river resources and the need to balance many competing economic and environmental interests. A major task for any country attempting to develop their river resources will be to mitigate the negative environmental impacts of economic, agricultural, and urban development while realizing the economic benefits.

Keywords

Nile, Aswan High Dam, Lake Victoria, Flooding, Irrigation, Lake Nasser

1. Introduction

The Kagera River is the longest source of Lake Victoria water and is located in Eastern Africa. Two principal tributaries, the White Nile, and the Blue Nile, combine to form the Nile River. Nyabarongo River (Rwanda) and the Ruvyironza are sources of the Nile River [1] because they both flow into the Kagera River. The river is considered the Nile's distant source. The White Nile drains from Lake Victoria, in Jinja, Uganda. The Victoria Nile flows through Lake Kyoga and Lake Albert. The river emerges from Lake Albert as the Albert Nile and enters South Sudan at Nimule, where it is called the Mountain Nile [1]. The river joins Bahr el

Ghazal at Lake One to form the "*White Nile*", then continues northwards into the neighboring Sudan, where it merges with the Blue Nile to form the Nile River.

Lake Tana, Ethiopia is the headwaters of the Blue Nile. The Blue Nile flows for about 1460 - 1600 km through Ethiopia and Sudan before joining the White Nile [1]. Gilgel Abay is the main source of Lake Tana. From Lake Tana, the Blue Nile flows for about 30 km southwards and enters a 400-km-long Grand Canyon of the Nile. Between Lake Tana and the canyon, the river receives inflow from several rivers, including Walaqa, Wanqa, and Bashilo Rivers on the left bank and Tul, Abbya, Handassa, and Tammi Rivers, among others, on the right bank. The river flows northwestward to the border between Ethiopia and Sudan. In Sudan, the Blue Nile flows for about 650 km. The Dinder River confluences with the Blue Nile on the right bank at Dinder. The Blue Nile flows to Khartoum, where the river confluences with the White Nile to form the Nile River.

From Khartoum, the Nile flows in two distinct sections. The first section flows about 1380 km to Lake Nasser, with the river passing through a desert region. The second section flows about 80 km over five cataracts before reaching Sabaloka, the sixth and highest cataract [1]. From there, the river flows northwards for about 12 km through hills, then takes an S-bend at Barbar and flows for about 285 km. The Nile assumes a northward flow at the end of the bend at Dongola and crosses the third cataract before entering Lake Nasser.

Lake Nasser (Lake Nubia) stretches from northern Sudan into southern Egypt and is the world's second-largest artificial lake. From Nasser (below the Aswan High Dam), the Nile flows northwards to North Cairo. The river enters a delta region in North Cairo, where it splits into two distributaries, Damietta on the east and Rosetta on the west. The two distributaries empty into the Mediterranean Sea. The Nile Delta contains sediments, most of which come from the Ethiopian plateaus. The thickness of the silts varies between 15 m and 22 m and contains Africa's most fertile soil. In fact, soil fertility is enhanced by the presence of silts. In other terms, silts have great potential to renew soil fertility for agricultural exploitation at different scales.

The earliest recorded attempt to build a dam near Aswan was in the 11th century when the Arab polymath and engineer Ibn Alhazen was summoned to Egypt by the Fatimid Caliph, Al-Hakim bi-Amr Allah. The task required an early attempt at an Aswan Dam to regulate the flooding of the Nile [2]. His fieldwork convinced him of the impracticality of this scheme [3].

The Aswan High Dam is one of the world's largest embankment dams. The dam was built across the Nile in Aswan, Egypt, between 1960 and 1970 [1]. When it was completed, it was the tallest earthen dam in the world, eclipsing the States Chatuge Dam [4]. Construction of the High Dam became a key objective of the new regime of the Free Officers movement of 1952. The Aswan High Dam could better control flooding, provide increased water storage for irrigation, and generate hydroelectricity. The Aswan High Dam was seen as pivotal to Egypt's planned industrialization and has had a significant effect on the economy and culture of

Egypt.

The primary objectives of this work are to document how: 1) how the periodic flooding of the Nile River was controlled, 2) how the Nile River watershed became Egypt's economic, agricultural, and urban development engine, and 3) provide historical lessons for other countries to learn from when developing river resources while attempting to balance the many competing interests.

2. Study Site

2.1. Methodology

An attempt was made to identify approximately 100 documents related to the Nile River and Delta and the Aswan High Dam. The 36 documents which appeared to be the most relevant were reviewed and analyzed to determine how the Nile River flooding was controlled and how the river became an economic, agricultural, and urban development engine. The historical lessons learned, both positive and negative, were identified. In addition, the historical lessons learned, from the Nile River and Delta case study, were summarized for other countries to learn from when attempting to develop their own river resources and the need to balance many competing economic and environmental interests. As other countries plan to develop river resources to utilize the potential of a river as a lifeline, a major task will be how to mitigate the negative environmental impacts of development while realizing the economic benefits.

2.2. Physiography, Geology and Soils of the Nile Basin

In the Nile basin (**Figure 1**), the different physiographic regions have a unique combination of surface, slope, soils, topography, and vegetation. It is very rare to find a river basin with such rich diversity in the world. The topography of the Nile basin includes mountain ranges of the upper Kagera, White Nile, Blue Nile (**Figure 2**), and Tekeze-Atbara rivers—to wide flood plains from the lower reaches to the delta. The patterns of topographic variables (altitude, slope, and aspect) bring about the patterns, the heterogeneity and the complexity of climate, soil, vegetation, fauna, land cover and land use in connection with socio-economic interactions.

As concerns the geology of the Nile basin, Tertiary and Pleistocene sedimentary infill dominates the lower parts of the basin. Consolidated sedimentary rocks are highly variable and generally consist of low permeability mudstone and shale, as well as more permeable sandstones, lime stones and dolomites, forming some of the most extensive and productive aquifers. Besides sedimentary rocks, volcanic rocks are also present, occupying the uplands (mainly the Ethiopian highlands), where they form highly variable and productive aquifers.

About half of the soils found within the Nile Basin are sedentary, *i.e.*, they have been formed in situ on weathered bedrock. Colluvial sediments derived from the adjacent weathered bedrock are often found next to areas of sedentary soil and may support skeletal or immature (young) soils, which are dominant in mica

Figure 1. Map of the Nile River. Photo Credit: World Atlas.

(illite) and chlorite [5]. In general, the physical and chemical properties of recently formed sedentary soils closely reflect the nature of the parent rock from which they are derived. Apart from sedentary soils, the Nile basin has a rich diversity of other soils groups. According to the 2016 Nile Basin Water Resources Atlas, the Nile Basin has 17 dominant soil groups, with the major ones being Vertisols (18.5% of the total basin area), followed by Yermosols (16.7%), Ferralsols (9.9%), Arenosols (9.0%), Lithosols (7.4%), Xerosols (7.2%) and Cambisols (7.1%). Other major soil groups in the Nile Basin include Andosols, Fluvisols, Regosols, Luvisols, Nitisols, Gleysols, Solonchaks, Acrisols and Gleysols. According to Williams [6] (2019), the most fertile of these are the Andosols, derived from volcanic parent

Figure 2. Blue Nile Falls. Photo Credit: World Atlas.

rocks. In well-drained areas, soils derived from basalt are well oxidized to give rise to Ferralsols with the dominant clay minerals being iron oxides, kaolinite and illite. In poorly drained environments, the dominant clay mineral is smectite (montmorillonite) and the dominant soils formed are Vertisols, which expand when wet and shrink and crack as they dry out. These soils are widespread in the Ethiopian Highlands and are easily eroded during the intense rainstorms of the summer monsoon, bringing silt and clay to the lowlands of central Sudan and the flood plains of the Blue Nile, Atbara and main Nile [7]. These Vertisols derived from alluvial silts and clays are a characteristic feature of the arable lands of the Egyptian Nile Valley and the Gezira plain between the Blue and White Nile rivers in central Sudan. In general, these soils are very fertile because of their moderate to high clay content and a correspondingly high cation exchange capacity (CEC). The high CEC is mainly contributed by clay minerals, plagioclase, calcian-montmorillonite, and magnesian-calcite minerals [8]. Other major soil types such as dune soils, desert soils, polygenic soils and fossil soils occurring within the Nile Basin have been extensively described by [6]. Soils of the Nile basin constitute one of the most fertile in the world and have been a major driver of Egyptian civilization. This is why they are held in high regard, especially in Egypt.

2.3. Nile River Climate and Hydrology

No part of the Nile experiences a real Mediterranean or tropical climate. The basin area covering Egypt and Sudan does not receive any rainfall during northern winter, while the southern areas, including the Ethiopian highlands, receive heavy rains of up to 152 cm per year. The northern trade winds, prevailing over the basin from October to May, cause the arid climate experienced in most parts of the basin. The East African lake region experiences tropical climates, characterized by well-distributed rainfall and little temperature variations. Here, the mean temperature ranges between 16˚C and 27˚C. The remainder of the basin experiences a desert-like climate (**Figure 3**), characterized by high-temperature variations, a dry atmosphere, and little to no rainfall. The temperatures often exceed 38˚C in Aswan. Therefore, the consequences of elevated temperatures on the concerned region should not be ignored.

Very little was known about the Nile's hydrology before the 20th century. The only ancient records available were those the Egyptians made regarding the river's water levels. The periodic rise of the Nile remained a mystery until the 19th century. The role played by the tropical region on the Nile water levels was discovered in the 19th century. Today, its river regime is the best known of any great river.

High tropical rains in Ethiopia during the summer cause the Nile floods (**Figure 4**). The floods begin in South Sudan around April, with the Aswan feeling the

Figure 3. Camels on Nile shore. Photo Credit: World Atlas.

Figure 4. Flooding of parts of Khartoum of Sudan by the Nile River. Photo Credit: Encyclopedia Britannica.

Figure 5. Egyptian women collected water to meet their household water needs. Ancient ruins are shown in the background. Photo Credit: Wikipedia.

effect in July. The Nile water rises during August and September and begins to fall in November. The river's water is at its lowest level in March. Flooding is a regular occurrence but varies by volume and date.

Lake Victoria is the Nile's largest water source. Lake Victoria discharges about 23 billion m^3 of water annually into the Nile (Figure 5). In addition to Lake Victoria water, the Nile receives up to 20% of its water from the tributaries. The Nile's major tributaries are the Red Nile (Atbara River), which confluences with the Nile while on its way to the Mediterranean Sea. The Red Nile only flows during the rainy season in Ethiopia and dries up during the dry season. Other major tributaries are the White Nile and the Blue Nile. It should be noted that the Blue Nile is shorter than the White Nile. Typically, during rainy seasons, the Nile can receive approximately 85.6% of the water coming from the White Nile alone.

2.4. Flora and Fauna

Different plant zones exist along the Nile River, including tropical forests near the Nile-Congo divide. These tropical forests contain tropical plants such as bamboo, rubber, ebony, and coffee shrubs. Mixed savanna and woodland occur in the Lake Plateau and are characterized by perennial herbs, grass, and foliage trees. The Sudanese plains contain thin bushes, thorny trees, and grasslands. The area becomes swampy during the rainy season. Common vegetation on these plains include papyrus, reedmace, water lettuce, and water hyacinth.

The Nile system contains varieties of fish species, including the barbell, bolti, elephant-snout fish, Nile perch, catfish, spiny eel, lungfish, and tiger fish. The reptiles include monitor lizards, Nile crocodiles, soft-shelled turtles, and snakes. Hippos are only found in the Al-Sudd region.

3. Results

3.1 The Nile River and Aswan High Dam Case Study

Before the Aswan High Dam was built, even with the old Aswan dam in place, the annual flooding of the Nile during late summer had continued to pass largely unimpeded down the valley from its East African drainage basin. These floods brought high water with natural nutrients and minerals that annually enriched the fertile soil along its floodplain and delta (**Figure 6**). This predictability has made the Nile Valley ideal for farming since ancient times (**Figure 7**). However, the consequences of this natural flooding varied since high-water years could destroy the whole crop, while low-water years could create widespread drought and famine. Both these events continued to occur periodically.

As Egypt's population grew and technology increased, the ability and desire to

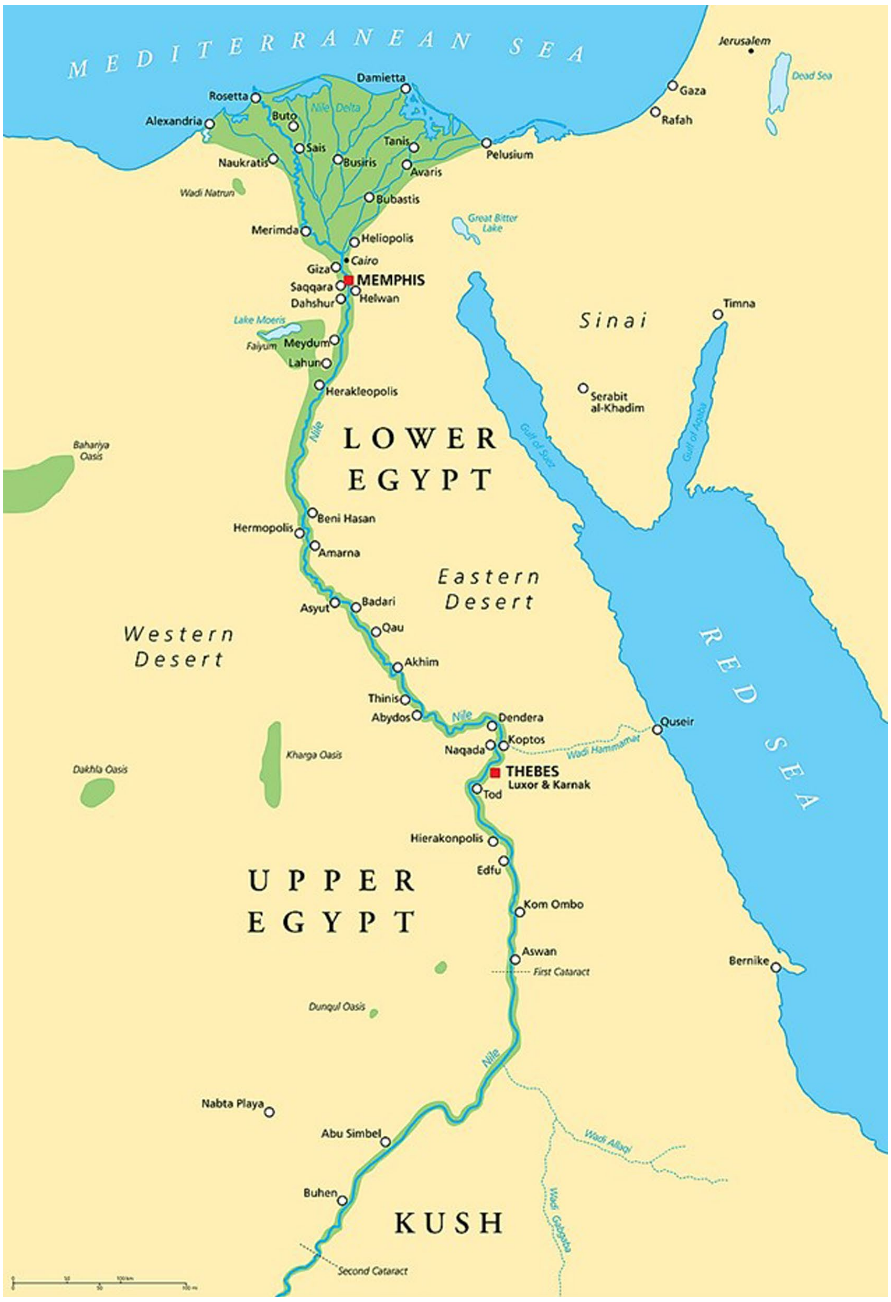

Figure 6. Lower Egypt map. Photo Credit: World Atlas.

completely control periodic Nile flooding developed. This resulted in the protection and support of farmland and its economically important cotton crop (Figure 8). The floods could be controlled by the Aswan High Dam (Figure 9) and the increased reservoir storage provided stored water that could be stored for later release over multiple years (Figure 10).

The Aswan Dam was designed by the Moscow-based Hydro Project Institute [9]. The dam was designed for both irrigation and power generation (Figure 11).

Figure 7. Irrigated food crops are grown using irrigation water from the Aswan Dam. Photo Credit: Mac Rychaet.

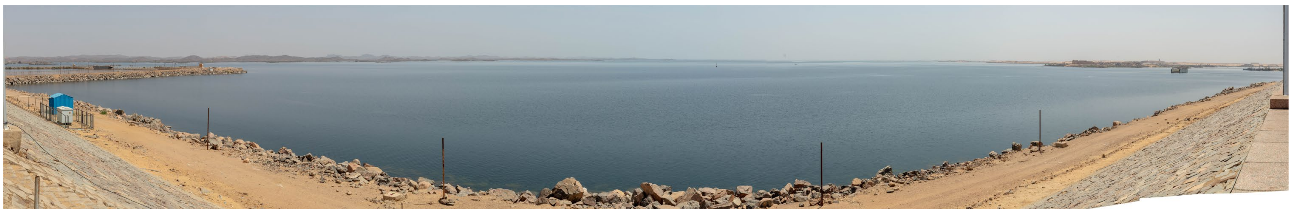

Figure 8. Aswan Dam. Photo Credit: Diego Delso.

Figure 9. Power pylons at the power plant of Aswan High Dam. Photo Credit: Vyacheslov Argenberg.

Figure 10. Nile shore picture. Photo Credit: World Atlas.

Figure 11. Aswan Dam Photo Credit: Encyclopaedia Britannica.

The dam incorporated a very deep grout curtain below its base. Most estimates indicate the dam will give at least 200 years of service before the reservoir will fill with silt [10].

3.2. Aswan High Dam Construction, 1960-1976

The Soviets also provided the machinery and expertise needed to build the rock and clay dam (Figure 12). The Soviet Hydro Project Institute designed the High Dam (Figure 13). Approximately, 25,000 Egyptian engineers and workers contributed to the construction of the dam.

Originally designed by West German and French engineers in the early 1950s and slated for financing with Western credits, the Aswan High Dam became the USSR's largest and most famous foreign aid project after the United States, the United Kingdom, and the International Bank for Reconstruction and Development (IBRD) withdrew their support in 1956. The first Soviet loan of $100 million

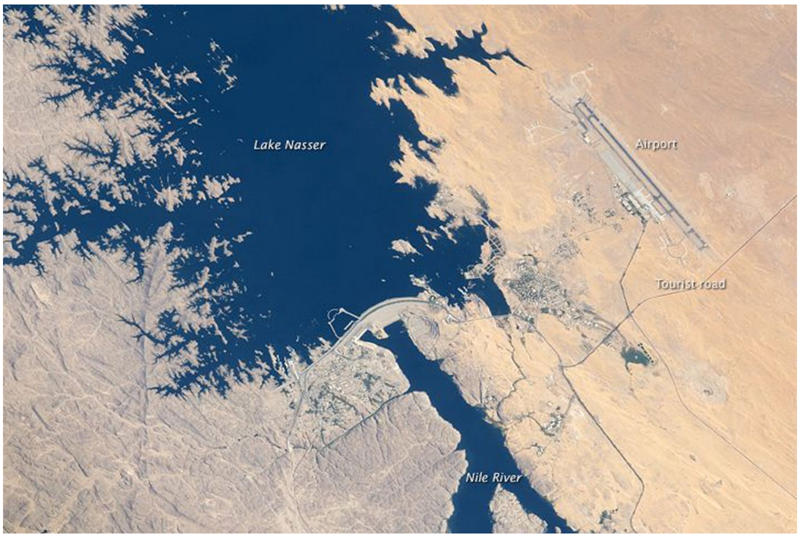

Figure 12. Aswan High Dam Reservoir in Egypt. Photo Credit: Encyclopedia Britannica.

Figure 13. The full Aswan High Dam. Photo Credit: Encyclopedia of Britannica.

to cover the construction of coffer dams for the diversion of the Nile was extended in 1958. An additional $225 million was extended in 1960 to complete the dam and construct power-generating facilities, and subsequently about $100 million was made available for land reclamation. These credits of some $425 million covered only the foreign exchange costs of the project, including the salaries of Soviet engineers who supervised the project and were responsible for the installation and testing of Soviet equipment. In 1960, construction began and was done by Egyptian companies on contract with the High Dam Authority. All domestic construction costs were paid by Egypt. Egyptian participation in the venture has raised the construction industry's capacity and reputation significantly [10]. Soviet credits covered virtually all the Aswan project's foreign exchange requirements. These included the cost of technical services, imported power generating and transmission equipment, and some imported equipment for land reclamation.

3.3. The Aswan High Dam

The Aswan High Dam construction started in 1960 and the first stage was completed in 1964. The High Dam (**Figure 12**) was completed in 1970 and the reservoir was filled in 1976. The Aswan High Dam is 3830 m long, 980 m wide at the base, 40 m wide at the crest, and 111 m high [11]. It contains 43,000,000 m^3 of material. At maximum, 11,000 m^3 per second of water can pass through the dam. Emergency spillways provide for an additional 5000 m^3 per second of discharge. The Toshka Canal links the reservoir to the Toshka Depression. The reservoir, named Lake Nasser, is 500 km long [11] and 35 km at its widest, with a surface area of 5250 km^2. It holds 132 km^3 of water.

3.4. Irrigation Scheme

Egypt's agriculture depends entirely on irrigation due to the absence of appreciable rainfall. With irrigation, two crops per year can be produced, except for sugar cane which has a growing period of almost one year. The high dam at Aswan releases, on average, 55 km^3 of water per year, of which some 46 km^3 are diverted into the irrigation canals. Almost 336,000 km^2 of land benefits from these waters producing on average almost two (1.8) crops per year in the Nile Delta and valley. The annual crop consumptive use of water is about 38 km^3. Hence, the overall irrigation efficiency is 38/46 = 0.826 or 83%. This is relatively high irrigation efficiency. The field irrigation efficiencies are much less, but the water losses are reused downstream. This continuous reuse accounts for the high overall efficiency. Egyptian-Dutch Advisory Panel and International Institute for Land Reclamation and Improvement table [12] shows the distribution of irrigation water over the branch canals taking off from the one main irrigation canal, the Mansuriya Canal near Giza.

The salt concentration in the Aswan reservoir water is about 0.25 kg/m^3, a low salinity level. At an annual inflow of 55 km^3, the salt influx reaches 14 million tons [13]. The average salt concentration of the drainage water discharged into the sea and the coastal lakes is 2.7 kg/m^3 [14]. At an annual discharge of 10 km^3 (not counting the 2 kg/m^3 of salt intrusion from the sea and the lakes), the salt export reaches 27 million tons. In 1995, the salt output was higher than the influx, and Egypt's agricultural lands were desalinizing. Part of this could be due to the large number of subsurface drainage projects executed in the last decades to control the water table and soil salinity [15].

Drainage through subsurface drains and drainage channels is essential to prevent a deterioration of crop yields from waterlogging and soil salinization caused by irrigation. By 2003, more than 20,000 km^2 had been equipped with a subsurface drainage system, and approximately 7.2 km^2 of water was drained from these area systems annually. The total investment cost in agricultural drainage over 28 years from 1973 to 2002 was about \$3.1 billion covering the cost of design, construction, maintenance, research, and training. During this period 11 large-scale projects were implemented with financial support from the World

Bank and other donors [16].

3.5. Effects of Aswan High Dam

The High Dam has increased agricultural production, employment, electricity production, and improved navigation which benefits tourism by reducing flooding and droughts (**Figure 14**). However, the dam flooded a large area, causing the relocation of over 100,000 people. Many archaeological sites were submerged while others were relocated. The dam is blamed for coastline erosion, soil salinity, and health problems.

Figure 14. Cairo on the banks of the Nile. Photo Credit: World Atlas.

The assessment of the costs and benefits of the dam remains controversial decades after its completion. According to one estimate [17], the annual economic benefit of the High Dam immediately after its completion was LE 255 million, $587 million using the exchange rate in 1970 of $2.30 per 1 LE. LE 140 million from agricultural production, LE 100 million from hydroelectric generation, LE 10 million from flood protection, and LE 5 million from improved navigation. At the time of its construction, the total cost, including unspecified "subsidiary projects" and the extension of electric power lines, amounted to LE 450 million. By not taking into account the negative environmental and social effects of the dam, its costs were estimated to have been recovered within only two years [17]. One observer notes: "*The impacts of the Aswan High Dam have been overwhelmingly positive. Although the Dam has contributed to some environmental problems, these have proved to be significantly less severe than was generally expected, or currently believed by many people.*" [18] Another observer disagreed and recommended that the dam should be torn down. Tearing it down would cost only a fraction of the funds required for "*continually combating the dam's consequential damage*" and 500,000 hectares of fertile land could be reclaimed from the layers of mud on the bed of the drained reservoir [19]. Samuel C. Florman [20] wrote about the dam: "*As a structure, it is a success. But in its effect on the ecology of the Nile Basin—most of which could have been predicted—it is a failure*".

Periodic floods and droughts have affected Egypt since ancient times. The dam mitigated the effects of floods, such as those in 1964, 1973, and 1988. Navigation on the river has been improved, both upstream and downstream of the dam. Sailing along the Nile is a favorite tourism activity, which is mainly done during the winter when the natural flow of the Nile would have been too low to allow navigation of cruise ships. A new fishing industry has been created around Lake Nasser, though it is struggling due to its distance from any significant markets. The annual production was about 35,000 tons in the mid-1990s. Factories for the fishing industry and packaging have been set up near Lake [21].

According to a 1971 CIA declassified report [10], although the High Dam has not created ecological problems as serious as some observers have charged, its construction has brought economic losses as well as gains. These losses derive largely from the settling in the dam's lake of the rich silt traditionally borne by the Nile. To date, the main impact has been on the fishing industry. Egypt's Mediterranean catch, which once averaged 35,000 - 40,000 tons annually, has shrunk to 20,000 tons or less, largely because the loss of plankton nourished by the silt, has eliminated the sardine population in Egyptian waters. Fishing in High Dam's lake may in time at least partly offset the loss of saltwater fish, but only the most optimistic estimates place the eventual catch as high as 15,000 - 20,000 tons. The lack of continuing silt deposits at the mouth of the river has also contributed to a serious erosion problem. Commercial fertilizer requirements and salination and drainage difficulties, already large in perennially irrigated areas of Lower and Middle Egypt, will be somewhat increased in Upper Egypt by the change to perennial irrigation.

3.6. Drought Protection, Agricultural Production and Employment

The dam also protected Egypt from the droughts in 1972-73 and 1983-87 that devastated East and West Africa. The High Dam allowed Egypt to reclaim about 2.0 million feddan (840,000 hectares) in the Nile Delta and along the Nile Valley, increasing the country's irrigated area by a third. The increase was brought about by irrigating what used to be desert and by bringing under cultivation 385,000 hectares previously used as flood retention basins [21]. About half a million families were settled on these new lands. The area under rice and sugar cane cultivation increased. In addition, about 1 million feddan (420,000 hectares), mostly in Upper Egypt, were converted from flood irrigation with only one crop per year to perennial irrigation allowing two or more crops per year. On other previously irrigated land, yields increased because water could be made available at critical low-flow periods. For example, wheat yields in Egypt tripled between 1952 and 1991 and availability of water contributed to this increase. Most of the 32 km^3 of freshwater, or almost 40 percent of the average flow of the Nile that was previously lost to the sea every year could be put to beneficial use. While about 10 km^3 of the water saved is lost due to evaporation in Lake Nasser, the amount of water available for irrigation still increased by 22 km^3 [22]. Other estimates put evaporation from Lake Nasser at between 10 and 16 km^3 per year [23].

The dam powers twelve generators each rated at 175 megawatts, with a total of 2.1 gigawatts. Power generation began in 1967. When the High Dam first reached peak output, it produced around half of Egypt's electric power (about 15 percent by 1998). The High Dam provided most Egyptian villages with electricity for the first time. The High Dam has also improved the efficiency and the extension of the Old Aswan Hydropower stations by regulating upstream flows [22].

All High Dam power facilities were completed ahead of schedule. The 12 turbines were installed and tested, giving the plant an installed capacity of 2100 megawatts (MW), or more than twice the national total in 1960. With this capacity, the Aswan plant can produce 10 billion kWh of energy yearly. Two 500-kV trunk lines to Cairo have been completed. The initial transmission problems, stemming mainly from poor insulators, were solved. Also, the damage inflicted on a main transformer station in 1968 by Israeli commandos has been repaired, and the Aswan plant is fully integrated with the power network in Lower Egypt [24]. By 1971 estimation, power output at Aswan, won't reach much more than half of the plant's theoretical capacity, because of limited water supplies and the differing seasonal water-use patterns for irrigation and power production. Agricultural demand for water in the summer far exceeds the amount needed to meet the comparatively low summer demand for electric power. Heavy summer irrigation use, however, will leave insufficient water under Egyptian control to permit hydroelectric power production at full capacity in the winter. Technical studies indicate that a maximum annual output of 5 billion kWh appears to be all that can be sustained due to fluctuations in Nile flows [24].

3.7. Resettlement and Compensations

During the 1950s, archaeologists and others began raising concerns about major historical sites that were about to be submerged by rising reservoir waters. UNESCO started rescue operations in 1960. These historic sites (**Figure 15**) included Abu Simbel [25].

In Sudan, 50,000 to 70,000 Sudanese Nubians were moved from the old town of Wadi Halfa (**Figure 16**) and its surrounding villages. Some were moved into a newly created settlement on the shore of Lake Nasser called New Wadi Halfa (**Figure 17**), and some were resettled approximately 700 km south to the semi-arid Butana plain near the town of Khashm el-Girba up the Atbara River. The climate there had a regular rainy season as opposed to their previous desert habitat in which virtually no rain fell. The government developed an irrigation project, called the New Halfa Agricultural Development Scheme to grow cotton, grains, sugar cane, and other crops. The Nubians were resettled in twenty-five planned villages. These settlements included schools, medical facilities, and other services, including piped water and some electrification.

In Egypt, the majority of the 50,000 Nubians were moved three to ten km from the Nile near Edna and Kom Ombo, 45 km downstream from Aswan in what was

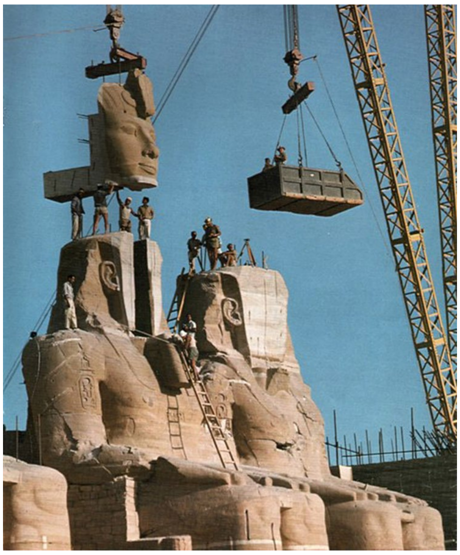

Figure 15. Statue of Ramses. Photo Credit: Swedish photograph. In public domain.

Figure 16. A picture of old Wadi Halfa. Photo Credit: Matson Photo Services.

Figure 17. View of New Wadi Halfa. Photo Credit: Betramz.

called "New Nubia" [26]. Housing and facilities were built for 47 village units whose relationship to each other approximated that in Old Nubia. Irrigated land was provided to grow mainly sugar cane [27] [28]. In 2019-20, Egypt started to compensate the Nubians who lost their homes following the dam impoundment [29].

Twenty-two monuments and architectural complexes were threatened by flooding from Lake Nasser, including the Abu Simbel temples, which were preserved by moving them to the shores of the lake under the UNESCO Nubia Campaign [30]. Also moved were Philae, Kalabsha, and Amada [31]. These monuments were granted to countries that helped with the works:

The Debod Temple to Madrid

The Temple of Dendur to the Metropolitan Museum of Art of New York

The Temple of Taffeh to the Rijksmuseum van Oudheden of Leiden

The Temple of Ellesyia to the Museo Egizio of Turin

These items were removed to the garden area of the Sudan National Museum of Khartoum [31].

The Temple of Ramses II at Aksha

The Temple of Hatshepsut at Buhen

The Temple of Khnum at Kumma

The tomb of the Nubian prince Djehuti-hotep at Debeira

The temples of Dedwen and Sesostris III at Semna

The granite columns from the Faras Cathedral

A part of the paintings of the Faras Cathedral; the other part is in the National Museum of Warsaw.

The Temple of Ptah at Gerf Hussein had its free-standing section reconstructed at New Kalabsha, alongside the Temple of Kalabsha, Beit el-Wali, and the Kiosk of Qertassi.

The remaining archaeological sites, including the Buhen fort and the cemetery of Fadrus, have been flooded by Lake Nasser.

3.8. Loss of Sediments

Lake Nasser behind the Aswan dam displaced more than 100,000 people and trapped large amounts of sediment. Before the construction of the High Dam, the Nile deposited sediments of various particle sizes—consisting of fine sand, silt, and clay—on fields in Upper Egypt through its annual flood, contributing to soil fertility. However, the nutrient value of the sediment has often been overestimated. Approximately, 88 percent of the sediment was carried to the sea before the construction of the High Dam. The nutrient value added to the land by the sediment was only 6000 tons of potash, 7000 tons of phosphorus pentoxide, and 17,000 tons of nitrogen. These amounts are insignificant compared to what is needed to reach the yields currently achieved in Egypt's irrigation [32]. Also, the annual spread of sediment due to the Nile floods occurred along the banks of the Nile. Lands far from the river, which never received the Nile floods before, are now being irrigated [33]. A more serious issue of trapping sediment by the dam is that it has increased coastline erosion surrounding the Nile Delta. The coastline erodes an estimated 125 - 175 m per year [34].

3.9. Waterlogging and Increase in Soil Salinity

Before the construction of the High Dam, groundwater levels in the Nile Valley fluctuated 8 - 9 m per year with the water level of the Nile. During summer when evaporation was highest, the groundwater level was too deep to allow salts dissolved in the water to be pulled to the surface through capillary action. With the disappearance of the annual flood and heavy year-round irrigation, groundwater levels remained high with little fluctuation leading to waterlogging. Soil salinity also increased because the distance between the surface and the groundwater table was small enough (1 - 2 m) depending on soil conditions and temperature to allow water to be pulled up by evaporation so that the relatively small concentrations of salt in the groundwater accumulated on the soil surface over the years. Since most of the farmland did not have proper subsurface drainage to lower the groundwater table, salinization gradually affected crop yields [17]. Drainage through sub-surface drains and drainage channels is essential to prevent a deterioration of crop yields from soil salinization and waterlogging. By 2003, more than 2 million hectares have been equipped with a subsurface drainage system at a cost from 1973 to 2002 of about $3.1 billion [35].

3.10. Health

Contrary to many predictions made prior to the Aswan High Dam construction and publications that followed, that the prevalence of schistosomiasis (bilharzia) would increase, it did not [36]. This assumption did not account for the extent of perennial irrigation that was already present throughout Egypt, decades before the high dam closure. By the 1950s only a small proportion of Upper Egypt had not been converted from basin (low transmission) to perennial (high transmission) irrigation. The expansion of perennial irrigation systems in Egypt did not depend on the high dam. In fact, within 15 years of the high dam closure, there was solid evidence that bilharzia was declining in Upper Egypt. *S. haematobium* has since disappeared altogether. Suggested reasons for this include improvements in irrigation practice. In the Nile Delta, schistosomiasis had been highly endemic, with prevalence in the villages at 50% or higher for almost a century before. This was a consequence of the conversion of the Delta to perennial irrigation to grow long staple cotton by the British. This has changed. Large-scale treatment programs in the 1990s using single-dose oral medication contributed greatly to reducing the prevalence and severity of *S. mansoni* in the Delta.

3.11. Other Effects

Sediment deposited in the reservoir is lowering the water storage capacity of Lake Nasser. The reservoir storage capacity is 162 km^3, including 31 km^3 of dead storage at the bottom of the lake below 147 m above sea level, 90 km^3 of live storage, and 41 km^3 of storage for high flood waters above 175 m above sea level. The annual sediment load of the Nile is about 134 million tons. This means that the dead storage volume would be filled up after 300 - 500 years if the sediment accumulated at the same rate throughout the area of the lake. Sediment accumulates much faster at the upper reaches of the lake, where sedimentation has already affected the live storage zone [34].

Before the construction of the High Dam, the 50,000 km of irrigation and drainage canals in Egypt had to be dredged regularly to remove sediments. After the construction of the dam, aquatic weeds grew much faster in the clearer water, helped by fertilizer residues. The total length of the infested waterways was about 27,000 km in the mid-1990s. Weeds have been gradually brought under control by manual, mechanical, and biological methods [22].

The catch of sardines (**Figure 18**) in the Mediterranean off the Egyptian coast declined after the Aswan Dam was completed, but the exact reasons for the decline are still disputed. Mediterranean fishing and brackish water lake fishery declined after the dam was finished because nutrients that flowed down the Nile to the Mediterranean were trapped behind the dam. For example, the sardine catch off the Egyptian coast declined from 18,000 tons in 1962 to a mere 460 tons in 1968, but then gradually recovered to 8590 tons in 1992. A scientific article in the mid-1990s noted that "*the mismatch between low primary productivity and relatively high levels of fish production in the region still presents a puzzle to scientists*" [37].

Figure 18. The catch of sardines in the Mediterranean off the Egyptian coast. Photo Credit: Daniel Ventura.

A concern before the construction of the High Dam had been the potential drop in river-bed level downstream of the Dam as the result of erosion caused by the flow of sediment-free water. Estimates by various national and international experts put this drop at between 2 and 10 m. However, the actual drop has been measured at 0.3 - 0.7 m, much less than expected [24].

The red-brick construction industry, which consisted of hundreds of factories that used Nile sediment deposits along the river, has also been negatively affected. Deprived of sediment, they started using the older alluvium of otherwise arable land taking out of production up to 120 km^2 annually, with an estimated 1000 km^2 destroyed by 1984 when the government prohibited, "*with only modest success*", further excavation. According to one source, bricks are now being made from new techniques that use a sand-clay mixture, and it has been argued that the mud-based brick industry would have suffered even if the dam had not been built [33].

Because of the lower turbidity of the water, sunlight penetrates deeper in the Nile water. Because of this and the increased presence of nutrients from fertilizers in the water, more algae grow in the Nile. This in turn increases the costs of drinking water treatment. Few experts had expected that water quality in the Nile would decrease because of the High Dam [21].

3.12. Appraisal of the Project

Although it is moot whether the project constitutes the best use of the funds spent, the Aswan Dam project unquestionably is and will continue to be economically beneficial to Egypt. The project has been expensive, and it took considerable time to complete, as is usually the case with large hydroelectric developments. Egypt now has an asset with a long life and low operating costs. Even so, the wisdom of concentrating one-third of domestic savings and most of the available foreign aid on a slow-growth project is questionable. Since 1960, GNP has grown 50%, but mainly because of other investments.

Egyptian authorities understood equivalent gains in output could have been achieved more quickly and more cheaply by other means. A series of low dams, like the barrages now contemplated, was suggested by Egyptian engineers as a more economical means of achieving up to 2000 MW (Megawatts) of additional generating capacity. US and World Bank agricultural experts had long recommended improved drainage, introduction of hybrid seeds, and other such low-cost alternatives to land reclamation as a means of increasing agricultural output, In other areas, most notably the once efficient cotton textile industry, investment was needed to forestall an output decline. Implementation of these and other alternatives has been postponed rather than precluded by the High Dam project.

However, the decision to concentrate Egyptian savings and energies on the Aswan project for a decade was heavily based on non-economic factors. Nasser undoubtedly believed that a project of considerable symbolic appeal was needed to mobilize the population behind the government's economic goals. He also apparently felt that the East and West would be more easily persuaded to bid against each other for a project of this scope.

The Aswan High Dam made an appreciable contribution to Egyptian GNP; however, the returns were well below what the planners had anticipated. The principal limiting factor on the High Dam's contribution to Egyptian output is a shortage of land suitable for reclamation. The high cost and long time required to bring reclaimed land to full productivity, and an inadequate water supply to meet power and irrigation goals simultaneously. The last limitation arises in part from the allocation in a 1959 agreement of more water to Sudan than was originally foreseen and in part from differences in the seasonal demand pattern of agriculture and the hydroelectric plant for the water. Irrigation requires very heavy use of water during summer months, while power generation needs to peak during the winter. Ecological problems created by the dam, most of which were anticipated, have not seriously harmed the economy, although a few minor industries have been damaged.

The dam is, nonetheless, a viable project. Eventually, the contribution to GNP equals as much as 20% of the total investment. Moreover, the dam and associated projects provided returns that at least offset the cost of operation, repayment of foreign loans, and amortization of domestic loans.

4. Summary

The Aswan High Dam was completed in 1970 at a cost of about $1 billion. The rock-fill dam across the Nile River at Aswan, Egypt, yields enormous benefits to the economy of Egypt. The Aswan High Dam permitted the annual Nile flood to be under human control. The dam impounds the floodwaters, releasing them to water hundreds of thousands of new hectares, to improve navigation both below and above the dam, when needed to maximize floodwater utility on irrigated land. The Aswan High dam can generate enormous amounts of hydroelectric power. The dam's 12 turbines can generate 10 billion kWh annually. The dam's reservoir also supports a fishing industry.

The environmental impacts of the Aswan High Dam have often been understated. High Dam construction has brought economic losses as well as gains. These losses derive largely from the settling in the dam's lake of the rich silt traditionally borne by the Nile. To date, the main impact has been on the fishing industry. Egypt's Mediterranean catch, which once averaged 35,000 - 40,000 tons annually, has shrunk to 20,000 tons or less, largely because of the loss of plankton nourished by the silt, which has eliminated the sardine population in Egyptian waters. Fishing in the High Dam's lake was at least partly offsetting the loss of saltwater fish. The lack of continuing silt deposits at the mouth of the river has also contributed to a serious erosion problem. Commercial fertilizer requirements and salination and drainage difficulties, already large in perennially irrigated areas of Lower and Middle Egypt, will be somewhat increased in Upper Egypt by the change to perennial irrigation.

Soil salinity also increased because the distance between the surface and the groundwater table was small enough (1 - 2 m) depending on soil conditions and temperature to allow water to be pulled up by evaporation so that the relatively small concentrations of salt in the groundwater accumulated on the soil surface over the years. Since most pre-1973 farmland did not have proper subsurface drainage to lower the groundwater table, salinization gradually affected crop yields.

Drainage through sub-surface drains and drainage channels was essential to prevent a deterioration of crop yields from soil salinization and waterlogging. By 2003, more than 2 million hectares have been equipped with a subsurface drainage system at a cost of about $3.1 billion.

A serious issue of trapping sediment by the dam has contributed to increased coastline erosion surrounding the Nile Delta. The coastline erodes an estimated 125 - 175 m per year. A vegetative barrier is needed along the coastline to reduce shoreline erosion. Thereby, the Nile shall be exploited in a sustainable manner.

The rock-fill dam across the Nile River at Aswan, Egypt, yields enormous benefits to the economy of Egypt. The Aswan High Dam permitted the annual Nile flooding to be under human control. The dam impounded the floodwaters, releasing the water to irrigate hundreds of thousands of hectares of agricultural land. It improved navigation both above and below the dam and when needed to maximize floodwater utility on irrigated land. The Aswan High Dam's 12 turbines generate 10 billion kWh annually. The dam's reservoir also supports a fishing industry.

5. Recommendations

The primary objectives of this research work were to document how: 1) the periodic flooding of the Nile River was controlled, 2) the Nile River watershed became Egypt's economic, agricultural, and urban development engine, and 3) provide historical lessons from the Nile River and Aswan Dam case study for other countries to learn from when attempting to develop their own river resources and the need to balance many competing economic and environmental interests. As other countries plan and create more hydropower dams to utilize the potential of a river as an energy lifeline, a major task will be how to mitigate the negative environmental impacts of development while realizing the economic benefits. Relevant protection of the ecosystem must be considered during all decision-making and the sustainability of the projects and that of the ecosystem. The reasonable achievement of such a goal is a challenge that requires proper integrated planning and environmental studies.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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