Chapter 18

Reservoir Sediment Management Practices in Sudan: A Case Study of Khashm El-Girba Dam

Elhadi Adam and Mohammed Suleiman

Abstract The sedimentation problem is a hot issue currently affecting the operations of reservoirs and irrigation networks in Sudan. Most of the rivers that cross Sudanese borders come from the Eastern African Plateau, which acts as a sediment source for the Nile River and its tributaries. Khashm el-Girba Dam (KEGD), which crosses the Atbara River in Eastern Sudan, is a multipurpose dam that was constructed in 1964. The Atbara River is a branch of the Nile River system, and the river carries a large amount of sediment during the flood period. Seven years after construction, in 1970, the dam faced a critical problem that could have led to a disaster; it was discovered that, due to sediment deposition, the water storage was not enough to satisfy the downstream requirements. This study discusses the sediment management practices used in KEGD and their impacts on maintaining the reservoir capacity. Practices including operation policy (OP), trap efficiency (TE), sluicing, sediment sluicing, and flushing operation (FO) were discussed. The adopted management practices succeeded in removing a considerable amount of silt and maintaining the lifetime of the reservoir.

Keywords Sluicing • Flushing operation • Bathymetric survey • KEGD

18.1 Introduction

18.1.1 General

Reservoir sedimentation is a global challenge affecting the life cycle and sustainability of reservoirs. Annually, reservoirs lose considerable amounts of storage capacity due to sedimentation. Globally, 1 to 2% of the total storage capacity of reservoirs is lost annually (Yang 2003). Figure 18.1 shows the percentage loss of

E. Adam (✉)

Faculty of Engineering, University of Kassala, Kassala, Sudan

M. Suleiman

Dam Complex of Upper Atbara, MoWRI, Atbara, Sudan

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Fig. 18.1 Percentage of annual reservoir loss worldwide. *Source* Yang (2003)

reservoir capacity worldwide. From the figure, China has the highest loss (2.3%), and the Sudan loss rate is approximately 0.83%.

For most dam schemes around the world, there are concerns that the rate of storage capacity loss due to sedimentation is much larger than was catered for in the original dam designs. The majority of dams allow for a dead storage capacity to accommodate the sediment that will be deposited. However, there is no guarantee that sediment will settle in this specified zone, and as a result, the operational life span of a reservoir may be reduced sooner than anticipated.

18.1.2 Sediment Management

Sediment is produced as a result of weathering agents (erosion and the wearing away of land surfaces) (Strand and Pemberton 1982). Climate change and the increased frequency of climate extremes (floods and drought) have increased the sediment yields from reservoir catchments. Water resource development projects are most affected by sediment transported by water (Raghunath 2006). Catchment characteristics (such as areal extent, soil types, land slopes, vegetation cover, and climatic conditions) play important roles in the sediment generation process and have great influences on sediment movement and distribution (Raghunath 2006). The key factors ensuring the sustainability of reservoirs are achieved by applying reservoir sediment management strategies.

In the literature, worldwide practices have shown a variety of management options. The selection of an appropriate method is region-specific, and a method can be applied in certain regions but not in other regions (Yang 2003). The methods available as enumerated by Annandale et al. (2016) are watershed management in the upper catchment to reduce sediment inflow into a reservoir, construction of small dams upstream to control the sediments entering a reservoir, methods that use flow hydraulics to reduce the load accumulation entering a reservoir and methods consisting of hydraulic dredging of existing sediment. According to Annandale, all of these methods have been tried worldwide, and none of them provide complete mitigation.

Several factors should be considered, such as factors pertaining to sedimentation characteristics (rate of discharge, concentration, etc.), factors pertaining to catchment characteristics (physical and hydrological features, land use/land cover), environmental considerations as well as downstream considerations, and socio-economic factors. More than one technique or a combination of management strategies may also be applied at a given reservoir, either sequentially or concurrently, to control sediment deposition (Kantoush et al. 2010).

18.1.3 Sediment Management Practices in Sudan

By the end of the 1960s, dam projects of different kinds were constructed in Sudan. These projects play tremendous roles in agricultural development, power generation, flood control and water supply, and many other purposes. However, most of the agricultural development projects in Sudan were situated in semiarid to arid regions. The main water supplies for these projects emerge from the Ethiopian Plateau through the Blue Nile and Atbara Rivers. Rivers coming from this area carry torrential flows with large sediment loads, which are conveyed further downstream to the relatively low-lying lands of Sudan. Drought, which occurred in the 1980s, and the food security practices adopted by the Sudanese government for irrigated areas without consideration of sediment mitigation measures have had great impacts on the increase in sediment loads in reservoirs.

Considerable sediment loads are deposited in the reservoirs and irrigation networks, reducing the capacity of the reservoirs and the efficiency of the irrigation networks. Figure 18.2 shows the volume of discharged sediment carried by the Nile River and its tributaries. As seen in the figure, the Atbara River, on which KEGD was constructed, comes in second after the Blue Nile.

The average annual suspended sediment load in the Nile River has been estimated to be 140×10^6 tons per year (ElMonshed et al. 1997), of which

Fig. 18.2 Sediment loads of the Nile River and its tributaries. *Source* Osman (2018)

Table 18.1 Reduction in the storage capacities of Sudanese reservoirs due to sedimentation

Name of dam	River	Year of construction	Design capacity (Billion)	Present capacity (Billion)	Reduction (%)
Sennar	Blue Nile	1925	0.93	0.36	60
Jebel Aulia	White Nile	1939	3	3	0
KEG Dam	Atbara	1964	1.3	0.6	54
Roseires	Blue Nile	1966	3.2 (before heightening)	1.9 (before heightening)	40
Merowe	Main Nile	2009	12.4	11.4	8
Dam Complex of Upper Atbara (DCUA)	Atbara	2015	3.7	2.8 (Survey 2017)	24

approximately 37% is produced by the Atbara River. Table 18.1 shows Sudanese reservoirs and the changes in their capacities that have occurred during their life-times (Osman 2018).

In Sudan, reservoir sedimentation management sometimes has a great negative impact on water resource projects. For example, reservoir management has serious impacts on the hydropower generation potential. To remove sediments from hydropower intakes, the upstream water levels must be lowered and maintained as low as possible to flush the sediment-laden water. This process has great impacts on the head and amount of generated power. However, recently, the heightening of Roseires Dam, as well as the new Great Ethiopian Renaissance Dam (GERD), has added more management abilities to the sedimentation problem in the Roseires reservoir and the irrigation canalization system in Sudan; on the other hand, these changes will reduce soil fertility due to sediment trapping.

In general, the objectives of the reservoir operating rules in Sudan are to preserve a sufficient amount of water to satisfy needs and to minimize sediment deposition. Many sediment management methods have been applied in Sudanese practices to restore reservoir volumes. Among these methods, regulation rules were found to be the most effective. The operation of reservoirs is performed while taking into consideration effective ways to avoid the period of the maximum possible sediment deposition quantity and pass the sediment downstream safely. Drawdown has been practiced in some reservoirs, and other reservoirs use sediment sluicing during the rainy season and begin storing water only after the passage of the peak of the flood season. Sluicing and dredging are practiced in Roseires Dam (Blue Nile), only sluicing is practiced in Sennar Dam (Blue Nile), storing is practiced in Jabel Aulia Dam (White Nile), a combination of sluicing and flushing is practiced in KEGD (Atbara river), and sluicing and sediment sluicing are practiced in Merowe Dam (Main Nile).

18.1.3.1 Roseires Dam

Roseires Dam, on the Blue Nile, was provided with low-level sluicing gates that have discharge capacities capable of passing the average annual river flows. In the case of hydropower generation in Roseires reservoir, the function of the low-level sluices is to pass the bulk of larger sediment particles to minimize the impact of sediment on the turbines. The removal of already-deposited sediments is costly and impractical, and this process is very limited for most of the reservoirs in the Nile. Sediment removal by dredging is regularly performed in the Roseires reservoir in front of the powerhouse intakes before the occurrence of floods. However, in Merowe Dam, the sediment that accumulates in front of the power intakes is removed using sluice gates 26 m below the power intakes.

In the first ten years of its operation, Roseires reservoir lost 17% of its overall capacity, which represents 90% of the to-date storage capacity. By the end of 1992, Roseires reservoir lost 37% of its original capacity, which represents 100% of the dead storage capacity and a considerable part of the live storage capacity.

GERD, after construction, will act as a natural settling basin that will reduce the amount of sediment entering Roseires reservoir, prevent the blockage of irrigation canals and pump station intakes, improve hydropower generation efficiency and effectiveness, prevent the blockage of power plant inlets, and reduce abrasion on turbines.

18.1.3.2 Sennar Dam

Sennar Dam was constructed in 1925. During the period from 1925 to 1981, the rate of sedimentation in Sennar reservoir never exceeded 0.5% per year compared to its original capacity, which represents a 28% reduction in the overall reservoir capacity (Ahmed 2008). During the abovementioned period, the Blue Nile usually flowed naturally (all the inflow discharge was passed) without storing water during the flood period. This perfect performance of the reservoir was attributed to the excellent design of the dam. However, after 95 years, Sennar Dam lost 71% of its original reservoir capacity.

Figure 18.3 shows the operation rules for Sennar Dam. From the figure, the sediment concentration is very high (>6000 ppm) during the start of the flood season (July–August). According to the operation rules for different reservoirs in Sudan, the reservoir level is usually maintained at a minimum level during this period to allow all the sediment-laden water to pass, and then the filling program starts.

18.1.3.3 Merowe Dam

From lessons learned in the sediment management practices of Roseires reservoir, a new technique was applied to Merowe Dam to control the accumulation of

Fig. 18.3 Sennar Dam operation rules. *Source* Osman (2018)

sediment in front of the powerhouse. There are six sediment sluices arranged in the power intake dam 26 m below the intake opening beside the normal sluice gates. The cross sections of these sediment sluices are tapered at the downstream ends. The flow-through each sluice is controlled by main radial gates placed at the downstream ends of the sluices. Due to the high flow velocities (22–24 m/s) and the high sediment concentrations, the sediment sluices are steel-lined (Osman 2018).

18.1.3.4 Irrigation Network Sedimentation

Most of the irrigation water in Sudan is diverted from sediment-laden rivers that originate from the Ethiopian Plateau. The Blue Nile and Atbara Rivers carry flows with high sediment concentrations during the rainy season. Most of these sediment loads are introduced to the irrigation networks of existing agricultural schemes, such as Gezira and Managil.

The Gezira Scheme (GS) is one of the largest agricultural schemes in the world. To restore the canalization system, desilting and aquatic weed clearance have been practiced since the establishment of the scheme in 1925.

The Hydraulic Research Center (HRC) of the Ministry of Water Resources and Irrigation (MoWRI) of Sudan, carried out, from 1988 to 1996, sediment studies in the Gezira canalization system (irrigation water supply from Sennar Dam). The study concluded that 5% of the sediment was deposited in the main canals, 22%

Fig. 18.4 Average quantities of silt removed from canals (2003–2010)

was deposited in the major canals, 33% was deposited in the minor canals, and 40% passed to the fields (Ahmed 2008). The same study was conducted by the HRC for the Halfa Irrigation Scheme (which is irrigated from KEGD), and comparable results were obtained (Fig. 18.4).

At the beginning of the Gezira Scheme, the removal of 5–7 million m³ of sediment was considered satisfactory (World Bank 2000). In 1999, MoWRI recorded that 41 million m³ of sediment was removed from the canalization system, but some researchers believe that this value is not realistic or scientific considering the past experience and the amount of sediment that enters the GS annually (Ahmed 2008). This amount of sediment removed causes many irrigation difficulties; during sediment removal, the canalization system is over excavated, and the cross sections of the canals are widened.

Most of the operation and maintenance (O/M) costs of the irrigation networks in the Sudanese irrigation schemes go to sediment and aquatic weed clearance. These two problems create many irrigation difficulties, such as increases in O/M costs, delays in sowing times, water shortages, and decreases in crop productivity, which in turn lead to reductions in crop yields.

The water supply used for irrigation is conveyed through a system of canals that are exposed to sediment deposition from silt-laden water. The growth of aquatic weeds provides traps for suspended silt if the water velocity is low and thus increases siltation in the canals, which might also raise the water level in the fields. Many efforts have been made to mitigate sediment and aquatic weeds in irrigation schemes in Sudan with little success. Figure 18.4 shows the average quantities of silt removed from the canals of the New Halfa project during the years 2002–2010; the silt in these canals was delivered by the Atbara River.

18.1.3.5 Khashm El-Girba Dam (KEGD)

In this study, the focus was on sediment management practices in Sudan with special emphasis on sediment management in KEGD.

18.2 Sediment Management in KEGD

18.2.1 Background

Khashm el-Girba Dam (KEGD) was constructed in 1964 across the Atbara River to reserve water for resettlement of the displaced from Wadi Halfa area (North of Sudan) due to the construction of the Aswan High Dam (South of Egypt). The main purposes of KEGD are irrigation, hydropower generation and domestic water supply.

The Atbara River is a tributary of the Nile River that emerges from Ethiopia (Fig. 18.5). The watershed area of the river is 112,000 km², the average annual discharge is 12×10^9 m³ (14% of the average annual flow of the Nile), and the reservoir length is 80 km. The Atbara River is characterized by its potential to carry torrential inflows with significant amounts of silt estimated at 85 Mt. annually (Odeyer 2007; Garzanti et al. 2006). Silt-laden water affects not only KEGD reservoir but also the irrigation networks in the New Halfa Agricultural Scheme.

During dry spells within the rainy seasons, the main source of water supply for irrigation is sediment-laden water, which exposes the irrigation networks to sediment deposition. Some of the consequences of deposited sediment are decreases in irrigation efficiency, increases in maintenance costs, and subsequent decreases in farmer incomes, which lead to socioeconomic problems.

A few years after its construction, KEGD lost a considerable amount of its reservoir capacity. The initial reservoir capacity of KEGD decreased from 1.32×10^9 to 0.62×10^9 m³ (MoWRI 2009). The annual rate of siltation is estimated to be 0.9%. Due to siltation and the formation of deltas, the reservoir has shrunk in surface area and storage capacity. Figure 18.6 shows how the reservoir capacity depleted overtime during the period from 1964 to 2014. As shown in the figure, the loss rate was very rapid during the early period of operation (1964–1971). After adopting a certain sediment management strategy (sluicing + flushing), which started in 1971 and then stopped and continued in 1974, the rate of sedimentation decreased, and the lifetime of the reservoir was preserved.

One of the techniques used in KEGD to manage sediment was the construction of the Dam Complex of Upper Atbara (DCUA). The DCUA was proposed after the construction of KEGD in 1964 to supplement the content deficit in the KEGD reservoir; it was completed and in operation in 2015. The construction of new dams in the upper catchment area in Ethiopia (e.g., Tekeze) will further reduce the sedimentation problem in the Atbara River.

Fig. 18.5 Map of the location of KEGD on Atbara River

Fig. 18.6 KEGD reservoir storage depletion over time

18.2.2 Sediment Yield and Measurement

Sediment measurements are essential for monitoring the total sediment loads, and having long records of sediment data is very important. Water discharge and sediment concentration must be simultaneously measured over relatively long periods of time. Direct measurements of sediment are considered the most reliable method

for determining sediment yield; these measurements are accomplished by either bathymetric surveys of reservoirs or sampling sediment discharges. Empirical relationships, empirically checked procedures, and trap efficiency can also be used for sediment estimations.

The measurement of suspended sediment in KEGD is practiced during the flood period. Normally, three samples per day are taken, but during a flushing operation (FO), more samples were taken (every three hours). The in situ samples were analyzed by the percentage volume of sediment, while parts of the same samples were sent to a laboratory for weight analysis (gram per liter, g/l or part per million (ppm)).

18.2.3 Trap Efficiency (TE)

When sediment-laden water approaches a reservoir, the velocity of the flow decreases, causing a decrease in the sediment transport capacity of the water. Part of the sediment load passes through the gates and flows downstream, and a considerable amount of sediment is deposited in the reservoir. Trap efficiency (TE) is a measure that expresses how much of the inflowing sediment may be trapped and deposited in a given reservoir.

TE is the ratio of the deposited sediments to the total inflowing sediments over a given period within the economic life of a reservoir (Hadley and Walling 1984). TE depends on several factors, such as particle size, sediment load, and flow characteristics (Ji 2006). From the available literature, two empirical methods can be used to estimate the TE of a reservoir: the Brune curve (1953) and Churchill curve (1948) (Annandale et al. 2016). The Brune curve relates TE to the average annual residence time in the reservoir, and the relative size of the reservoir is determined by dividing the storage volume by the mean annual flow volume entering the reservoir. This ratio is known as the capacity/inflow ratio (Annandale et al. 2016). Brune curves are not applicable for reservoirs with scouring sediment; however, the TE of KEGD can be computed for the period when the sluicing method is applicable (the period from 1964 to 1974, during which there was no flushing operation).

According to the operation rules applied to KEGD, there are three categories of operation: the low-level flood period, filling period, and abstraction or drawdown period. During the low-level period, the reservoir is operated at its lowest level with its deep sluice gates opened to pass floodwaters, and insignificant sediment deposition occurs in the main channel of the reservoir (sluicing period; low TE). During the filling period, a significant amount of sediment is deposited in the reservoir bottom and on its banks, and the TE percentage is expected to have a significant value. The third period has no contribution to sediment deposition due to insignificant inflows and clear water. TE requires an accurate measurement of the sediment that is transported into a reservoir as well as the sediment that is discharged through spillways (Annandale et al. 2016; Atkinson 1996).

18.2.4 Operation Policy of KEGD Reservoir

The operation of the KEGD reservoir is divided into four periods: the first filling, the period between the first and second filling, the second filling, and the abstraction period.

18.2.4.1 The First Filling

In the first filling, the minimum operational level at the beginning of the dam operation on June 30 is 462.00 m. The first filling may begin on July 1 or later if the mean flow of the river has risen above 15 Mm³/day to raise the reservoir level to 462.00. However, if the level of the reservoir is above 462.00 m at the end of June, water is released so that the level of 462.00 m can be reached and maintained by 10 to 15 July.

18.2.4.2 Period Between the First and the Second Filling (Flood Period)

This period extends from the beginning of July to the end of August, and most sediment-laden water is discharged during this period. This type of operation is known as the sediment sluicing period. Flushing operations are normally conducted during this period, in which the river is allowed to erode itself by leaving the dam gates fully opened. Figure 18.7 explains how the operation rules are implemented as well as the flushing operation and sediment concentration during the flushing operation.

Fig. 18.7 Operation policy of KEGD

18.2.4.3 Second Filling

The second filling begins (a) on August 25 if the inflow either has not risen above 100 Mm³/day or has previously reached above that rate and fallen, (b) on a date later than August 25 after the inflow has fallen below 100 Mm³/day. However, for the high flood season, the second filling should start on a date no later than the 6th of September. The second filling takes 45 days to reach the maximum operating pool level at 473.00 a.m.s.l.; this maximum level was raised to 474.00 in 1989 due to sediment deposition. During this period, the water contains some suspended sediment that is deposited in the reservoir bottom and lateral shelves.

18.2.4.4 Abstraction period

After filling the reservoir to a full level of 474.00 m, the inflow exceeds the downstream requirements. The excess surplus is discharged downstream of the dam through deep sluice gates until the inflow equals the requirements. Then, the gates are closed, and the electrical power machines are stopped because irrigation water has the first priority. Abstraction from reservoir storage starts after the inflow water becomes less than the downstream requirements.

All the downstream stakeholders gather in the dam headquarters to decide the abstraction policy based on their needs. The water allocation is confirmed in this meeting. The different stakeholders include representatives of the domestic water supply, crop requirements, sugarcane requirements, freehold, forestry, and downstream requirements.

18.2.5 Sediment Flushing

Sediment flushing describes the process of clearing existing accumulated sediment using the hydraulic method in a reservoir. Sediment flushing is not effective unless the river is left to flow naturally; i.e., if the reservoir is drawn down to a level at which the flow conditions over the deposits reach those of the original river; in such a case, effective erosion over the delta starts from both ends.

18.2.6 Sluicing of Sediments

Sluicing sediment-laden water and storing clean water have been practiced since the beginning of KEGD operations. Sluicing or partial drawdown describes the lowering of water levels in a reservoir for a few weeks or months during the flood season. The principal purpose of sluicing is to pass the high sediment flows carried by flood flows through the lower gates.

18.3 Flushing Operation (FO)

Flushing represents a necessary regular annual activity for keeping silt deposits clear from the water intakes and for preserving reservoir storage (SOGREAH 1971). Flushing operations have been applied successfully in many reservoirs worldwide and have been found to be inexpensive in many cases (Garzanti et al. 2006).

Kantoush et al. (2010) considered flushing to be the only economical approach to swiftly restore the storage capacity of reservoirs with severe deposition. Worldwide experience confirms that low-level outlets that have sufficient capacities to increase drawdown and add more control to water levels during flushing operations will lead to effective flushing (White 2006).

The World Commission on Dams (2006) decided to study the guideline considerations for efficient flushing operations, which include the hydraulic conditions, quantity of water available for flushing, mobility of reservoir sediments, storage capacity of the reservoir, sediment deposition potential, shape of the reservoir basin, operational limitations, downstream impacts, and site-specific factors.

Flushing was introduced for the first time in KEGD for a single year in 1971. Then, FO stopped, but continued in 1974 when the coupling of sluicing and flushing significantly reduced the rate of deposition (Bathymetric Survey of KEG Dam 1990). Twenty million tons of sediment can be removed in one FO in KEGD; i.e., approximately 40 million tons could be removed if FO were carried out twice in the same flood season (Jonson and Phelipon 1974). Figure 18.8 shows the development of the bed level of the reservoir and the accumulation of sediment during the period from 1962 to 2009 in KEGD.

Fig. 18.8 Longitudinal profiles for three different bathymetric surveys. *Source* Reprinted from Mohamed (2013) copyrights 2013

18.3.1 Impacts of Flushing Operations

Although flushing operations are considered the most effective method for managing sediment accumulation in reservoirs, FO might have negative impacts on dams and the environments further downstream. The following section describes some of the negative impacts of FO.

18.3.1.1 Deep Sluice Abrasion

Large quantities of sediment particles that pass through the deep sluice gates during FO cause abrasion to the sill beams and concrete (Fig. 18.9). The only precaution that can be taken to limit this wear is to keep the reservoir level low to limit the flow velocity (Johnson and Phelipon 1974). Abrasion might increase leakage through deep sluices, which is a serious problem affecting preserved stored water. Leakage might cause deformation problems in the dam structure itself.

18.3.1.2 Driftwood

If floods are above average, wood is forced to spill by raising the reservoir level or is forced to pass through deep sluices when floods are below average. However, driftwood accumulates at pump-turbine intakes and compensation gates. This driftwood is sometimes carried by running water back from canals through pumps with the aid of backwaters from compensation gates. Figure 18.10a, b shows pump turbine-intakes blocked by driftwood and silt during 2005.

Figure 18.11 shows the accumulation of sediment downstream of a dam due to insufficient flushing discharge, which seriously affects the downstream environment and ecosystem.

Fig. 18.9 Abrasion to a sill beam and concrete

Fig. 18.10 **a** Pump-turbine intakes blocked by driftwood and silt, and **b** flushing of driftwood and silt by backwater (2005)

Fig. 18.11 Accumulation of silt downstream due to insufficient discharge in flush operations

18.4 Bathymetric Survey

The main purpose of conducting bathymetric surveys of a reservoir is to determine the storage capacity, loss of storage volume, and distribution of deposited sediment within the reservoir and to provide data on sediment accumulation by comparison to an earlier survey (usually the original survey).

Bathymetry is the process through which the bed level of a reservoir is mapped. To map a reservoir bed, the topography of a given area is surveyed before a reservoir is filled. Once the reservoir is filled, bathymetric surveys are used to monitor possible changes at the bottom surface. These surveys are useful from time to time because, over time, sediment builds up in reservoirs, and these surveys can help determine the amount of sediment that has been deposited. Different survey methods have been conducted to map the KEGD reservoir. Figure 18.12 shows the results of bathymetric surveys conducted in KEGD, and how the storage drastically changed before the flushing operations were adapted in 1974. From the figure, during the period from 1964 to 1974, a rapid reduction in reservoir capacity occurred. When the flushing operation was introduced in 1974, the sediment accumulation decreased noticeably. After 1990, the reservoir almost reached a state of equilibrium.

Fig. 18.12 Change in reservoir bed level of KEGD during the period from 1964 to 2009. *Source* Reprinted from Mohamed (2013) copyrights 2013

18.5 Conclusion

The deposition of silt is a serious problem affecting the storage capacities and lifespans of reservoirs. This study was carried out to discuss the sediment management practices in Sudan, with special reference to Khashm el-Girba Dam (KEGD), and the effects of storage management practices on maintaining the lifetime of the reservoir. During the 1990–2009 period, the average annual sediment inflow to the Atbara River was 86 Mt. Nearly 40% of the storage capacity of KEGD has already been filled with sediment soon after dam construction. The coupling of sluicing and flushing in 1974 significantly reduced sediment deposition in the reservoir. The sediment management strategy that followed in KEGD increased the lifetime of the reservoir. Building Tekeze Dam in Ethiopia in 2009 and the Dam Complex of Upper Atbara (DCUA) in Sudan in 2015 further helped regulate Atbara River flows and control the amount of sediment discharged to KEGD.

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