

Sedimentation Crisis of the Atbara Dam Complex

by

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Abstract

The Atbara River is one of the Nile River Tributaries. It originates from the Ethiopian Highlands and is the most northerly tributary of the Nile. The Atbara River has two branches: the Setit River (Tekeze River in Ethiopia) and the Upper Atbara River. The total catchment of the Atbara Dam Complex (ADC) is approximately 9700 km².

The Atbara River is a seasonal river with an average flow of 12.0 billion m³ (BCM). In 1964 Khashm Elgirba Dam (KED) was constructed downstream of the recent ADC, which has a storage capacity of 1.3 BCM. KED lost most of its storage capacity (65%) due to sedimentation.

ADC consists of two connected dams (Burdana on the Setit River and Rumela on the Upper Atbara River, besides KED). The two reservoirs are linked by a channel flowing from Burdana to Rumela, forming a large reservoir with a storage capacity of 3.700 BCM (Burdana 2.52 BCM and Rumela 1.18 BCM). The Main objective of ADC is irrigation, drinking water supply and hydropower generation.

In this paper, the sedimentation crisis that follows the first 5 years of ADC operation is examined and discussed. The impact of the sediment deposition in the ADC reservoir is evaluated, taking into consideration the Ethiopian Dam (T5) constructed upstream on the Tekeze River. Moreover, the sustainability of ADC to serve its purposes is discussed and reported. Based on 5 years of dam operation, the prediction of the future situation of ADC is brought forward with several recommendations. The behaviour of the ACD reservoir is carefully analysed and discussed, which leads to the fact that the future of the dam's sustainability is gloomy and requires more attention regarding its Operation Management.

Keywords: *Atbara Dam Complex, Reservoir, Sedimentation, Crisis, Storage, Operation Management*

1.0 Introduction

The construction of dams on numerous rivers throughout the world may be the greatest project of human beings in rivers and wadis. On the other hand, they have the greatest disturbance to the stream ecology and morphology. Most reservoirs are multi-purpose, having two or more of the following: irrigation, hydropower, water supply, flood control, navigation, fisheries, recreation, and environmental sustainability.

The Atbara, a seasonal River that originates from the Ethiopian Highlands (EH) and most of its sediments are clay and silt carried in suspension during the rainy season. Dam reservoirs built on these tributaries are experiencing an alarming loss in capacity due to sedimentation. In some reservoirs, the annual rate of capacity loss may approach 1.0 %.

KED reservoir in Sudan, for example, has lost 65% of its original capacity in less than 56 years with a corresponding reduction in irrigation area. Since sediment management is directly related to the lifetime span (sustainability) and the functionality of ADC, the present paper discusses this issue in depth. The location and layout of ADC are really complex. Therefore, its future is at risk unless it is well operated and managed.

2.0 Atbara River Basin

The Atbara River is seasonal; it flows during the period July-September, with high discharge (flood period). Following the later period, the river recedes in October, November and December; only base flow is available. From January to June, the river is almost dry. However, the construction of the Ethiopian Tekeze Dam (TK5) in 2010 has had a positive impact, as the river continues to flow all year round.

In the Sudan Water Resources Master Plan, which was issued in the 1970s, the Setit-Upper Atbara dam was proposed with a storage capacity of about 2.0 BCM and hydropower generation of 120 MW. However, recently two dams were suggested: Rumela and Burdana, where the former is on the Upper Atbara River and the latter on the Setit River. The two reservoirs have a storage capacity of 3.7 bcm and the installed hydropower capacity of 320 MW. The two dams' construction started in 2007. The main objective of the DCUA project is to create real development and welfare in the Eastern region of Sudan through the enhancement of agricultural production, hydropower generation and urban-rural potable water supply utilising the available water resources from the two seasonal rivers.

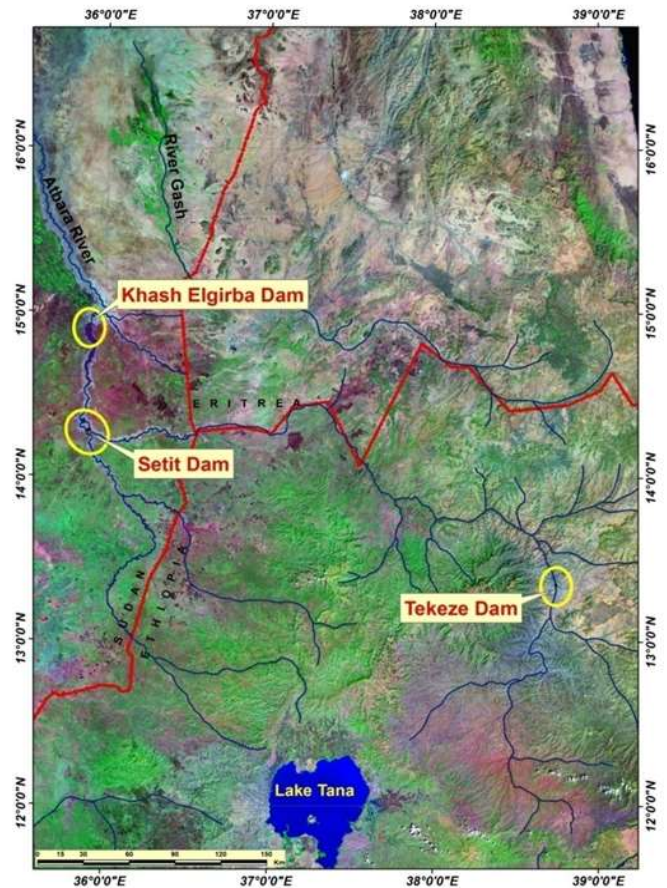


Fig (1) Layout of KED, DCUP and TK5

3.0 Soil Erosion and Land Degradation in Ethiopian Highlands (EH)

Several studies concluded that all types of land degradation occur in Ethiopia: soil erosion by water (sheet, rill and gully) and wind. Moreover, bank erosion, mass movement, biological, physical and chemical degradation are also taking place in the EH. The severity of erosion is noticeable from the formation of the deep, wide and large gullies everywhere, Plate (1). The EH Reclamation Study (EHRS) of 1984 for erosion assessment concluded that 1,900 million tons of soil were annually eroded from the EH, which is equivalent to an average net of 100 tons/ha soil loss, i.e. 8 mm depth, annual soil loss. Besides natural factors, e.g. torrential rainfall and the nature of the landscape, there are several causes that accelerate soil erosion in the EH and are mainly related to human activities. FAO (1985) indicated that the average annual yield declined from 1 to 3% on cropland (average 2.2 % for the EH) and up to 1% on grassland. Fig (2) shows what is happening in the Atbara River Basin System with respect to its natural flow characteristics. The peak of the rainfall/runoff and the peak of the discharge come 2 to 3 weeks before the peak of the sediment load. This is mainly attributed to the fact that the soil is bare in the EH, particularly before the rainy season starts in June, and the green cover is weak. Such a situation will have an impact on ADC reservoirs, i.e. the rate of sedimentation on the new dams is expected to be high, despite the presence of the recently constructed TK5 in one of the Tekeze River tributaries. Therefore, the best sediment management for both U/S and D/S countries in the NB is the catchment management through wise interventions to reduce the erosion rate in the first place.



Plate (1) Large Gullies, Ethiopian Highlands

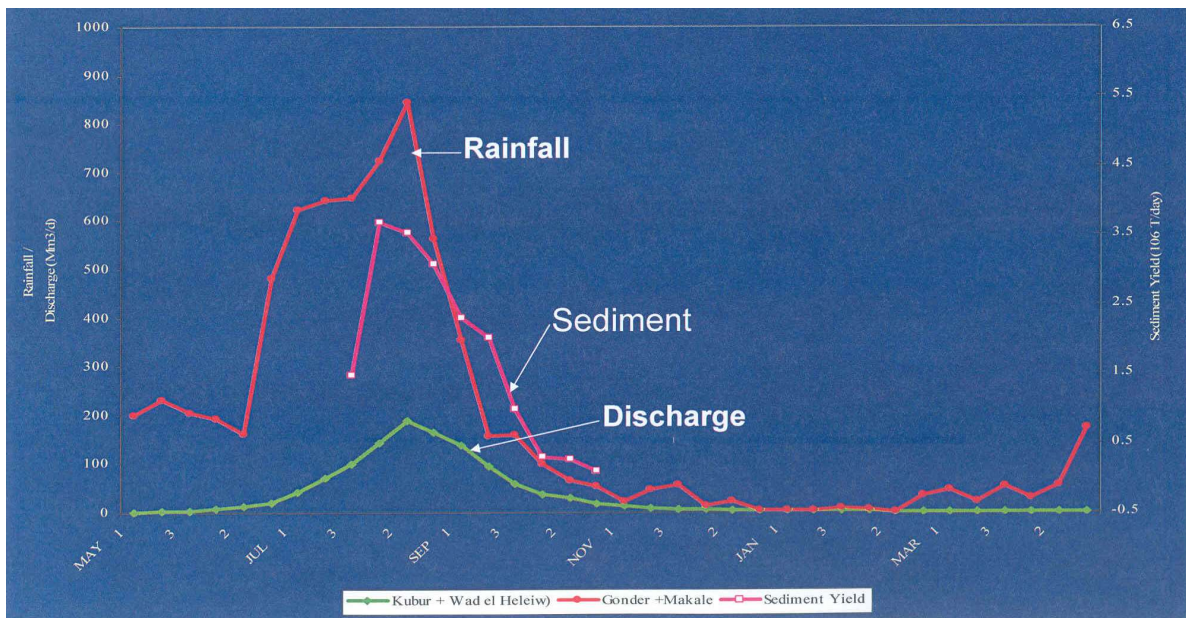


Fig (2) Comparison of Rainfall, Discharge and Sediment Yield in Atbara River

4.0 Nile River Basin (NB) Reservoirs Sedimentation

The problem of sedimentation in the NB, particularly in Sudan, has been reflected D/S in terms of sediment deposition in the reservoirs and the irrigation canalisation networks, causing flood risks, crop damage, pump intakes blockage, low production and hydropower generation difficulties. On the Nile system, there are several dam reservoirs: two in Uganda, two in Ethiopia and a third under construction (Grand Ethiopian Renaissance Dam (GERD)), six in Sudan and two in Egypt.

However, in the NB, several new dams are planned for different purposes. Assessments of sediment information in the NB show that suspended sediment dominates the total sediment in transport, and few meaningful studies of bed load transport have been undertaken for the Nile River system (Ahmed et al, 2008). Available data suggest that suspended sediment commonly accounts for approximately 90% of the total sediment load. The latter suspended sediment load has been considered by Several Researchers as a wash load. Reservoir surveys to determine the volume of deposited sediment and the loss in reservoir capacity using bathymetric surveys are usually carried out for larger reservoirs than for smaller ones.

5.0 Khashm ElGirba Reservoir (KED)

KED is constructed on the Atbara River, approximately 200 km D/S of the Ethiopian Border and 75 km D/S of the confluence of the Upper Atbara and Setit rivers. Annually, the Atbara River brings an average sediment concentration of 15,000 ppm, while it sometimes reaches a maximum of 30,000 ppm. The mean annual inflow of the Atbara River is known to be 12.0 BCM; however, from Fig (3), the average main flow is 13.0 BCM for the period (1980-2000). Based on the latter figure and the original reservoir capacity, the trap efficiency of KED reaches 86 %. The dam was initially filled in 1964 with a capacity of 1.30 BCM at an elevation of 473 masl, i.e. its storage capacity is only 10% of the inflow. The reservoir length is 80 km. In 1977, the storage capacity of the reservoir was reduced by 0.66 BCM due to sedimentation, which represents 50 % of its capacity, i.e. only 13 years after the first filling with an average of about 50 million m³ per year. Besides, the natural phenomenon of the heavy sediment load, Atbara River is characterized by steep slopes, ranging from 5 m/km along the 300 km from the starting point in the EH to the catchment outlet, and 25 cm/km for the 500 km from Setit river confluence with Upper Atbara River up to Atbara city, where the river meets the Main Nile. Further to the high sediment load in the Atbara River, the inappropriate reservoir operation policy exacerbated the loss of storage capacity in KED, causing severe water shortages during drought years and resulting in a decline in the crops cultivated areas. The situation has forced the hydropower generation to work only during the flood season. On the other hand, the Drinking Water Plant of Elgadarif City, constructed at ElShowak Headworks, which is located in the delta area of the reservoir, is at risk of being drowned. This is due to the gradual rise of the delta formed at the head of the reservoir by 12 m above the initial bed elevation. The sedimentation and debris problem at the turbine intakes is causing serious problems. The Ministry of Irrigation and Water Resources in the 1990s increased the full supply level of KED by 0.5 m; then, a few years later, it added another 0.5 m. Recently, at the beginning of this century, it added another 0.5 m to end up with 474.5 AMSL as a full supply level of the reservoir, Fig (4).

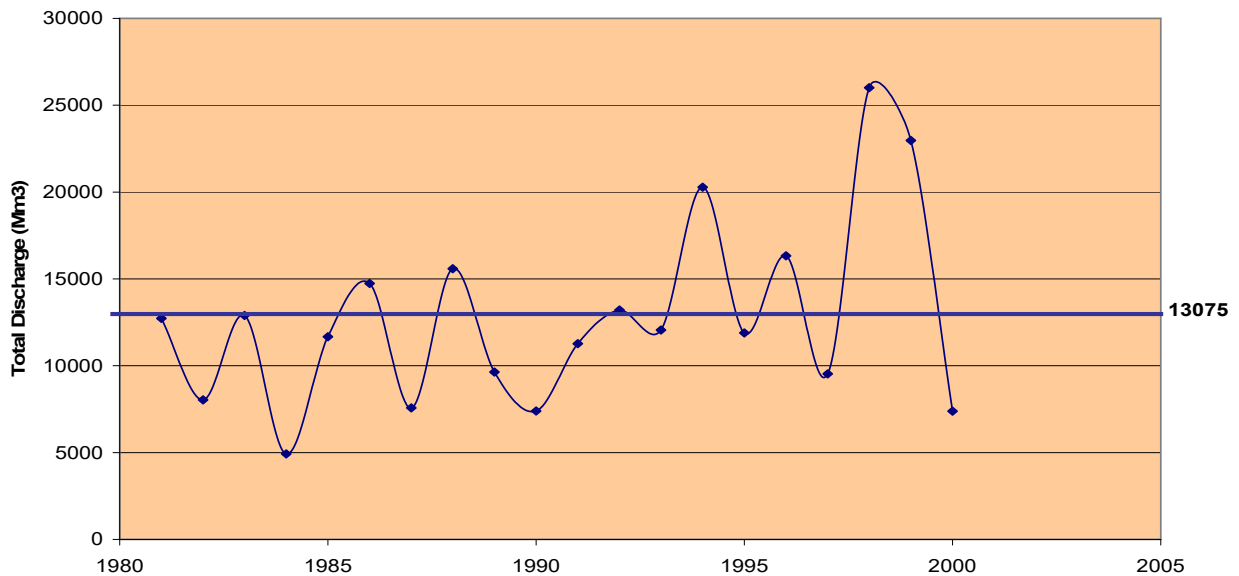


Fig (3) The Mean Annual Inflow of Atbara River

This is happening despite the dam crest level being 475.0 AMSL, and the earth embankment of KED level being 476 AMSL. Such a situation jeopardises the safety of the dam itself. The reason behind all these serious decisions is to increase the reservoir storage capacity (from 505 million m³ to 677 million m³), which will meet the downstream needs. Therefore, it is clear from this experience what ADC will face in the near future.

5.0 Lessons Learned from KED

- a- High sediment concentration during the rainy season.
- b- Peak of sediment concentration comes 2 to 3 weeks before the peak of the flow.
- c- To supply domestic water, reservoir emptying is delayed to create a command level for the pumping station at ElShowak town. This change in operation has contributed to the silting up of the reservoir, a set of negative impacts.
- d- Sedimentation and floating debris problems at the turbine intakes are causing serious problems, and hence frequent blockage of the turbine intakes, i.e. rapid reduction in the storage capacity of KED over time, Fig (4).

6.0 ADC Reservoir Sedimentation

There is doubt that the sedimentation issue has been considered as a top priority in ADC operation rules or management. Therefore, in 2007, before the actual dam construction, a bathymetric survey was carried out to establish the basic and original capacity of the dam reservoir. The experience gained from KED in the field of sedimentation management is taken into consideration.

Due to many obstacles faced by the ADC project, the construction period took more than 10 years to be completed in 2015. Unfortunately, there were only 3 bathymetric surveys available so far, carried out by the Ministry of Water Resources and Irrigation, which are presented in Figs (5, 6 and 7). It is clearly noted that the rate of sedimentation within the ADC reservoir is significantly high, even it is more so when compared to the KED one. In general, Burdana dam lost 26 % (2400 to 1766 mcm) while Rumela dam lost 23 % (1280 to 997 mcm) in the same period. However, both dams as DUCA, lost 25% (3,700 to 2,800 mcm). If we add the remaining capacity of KED to DUCA, the total present ADC capacity is 3300 mcm compared to originally 5000 mcm, i.e. is to

say with a total loss of 34 %. It can be concluded that what is happening in the ADC reservoir is considered among the highest rate of sedimentation worldwide.

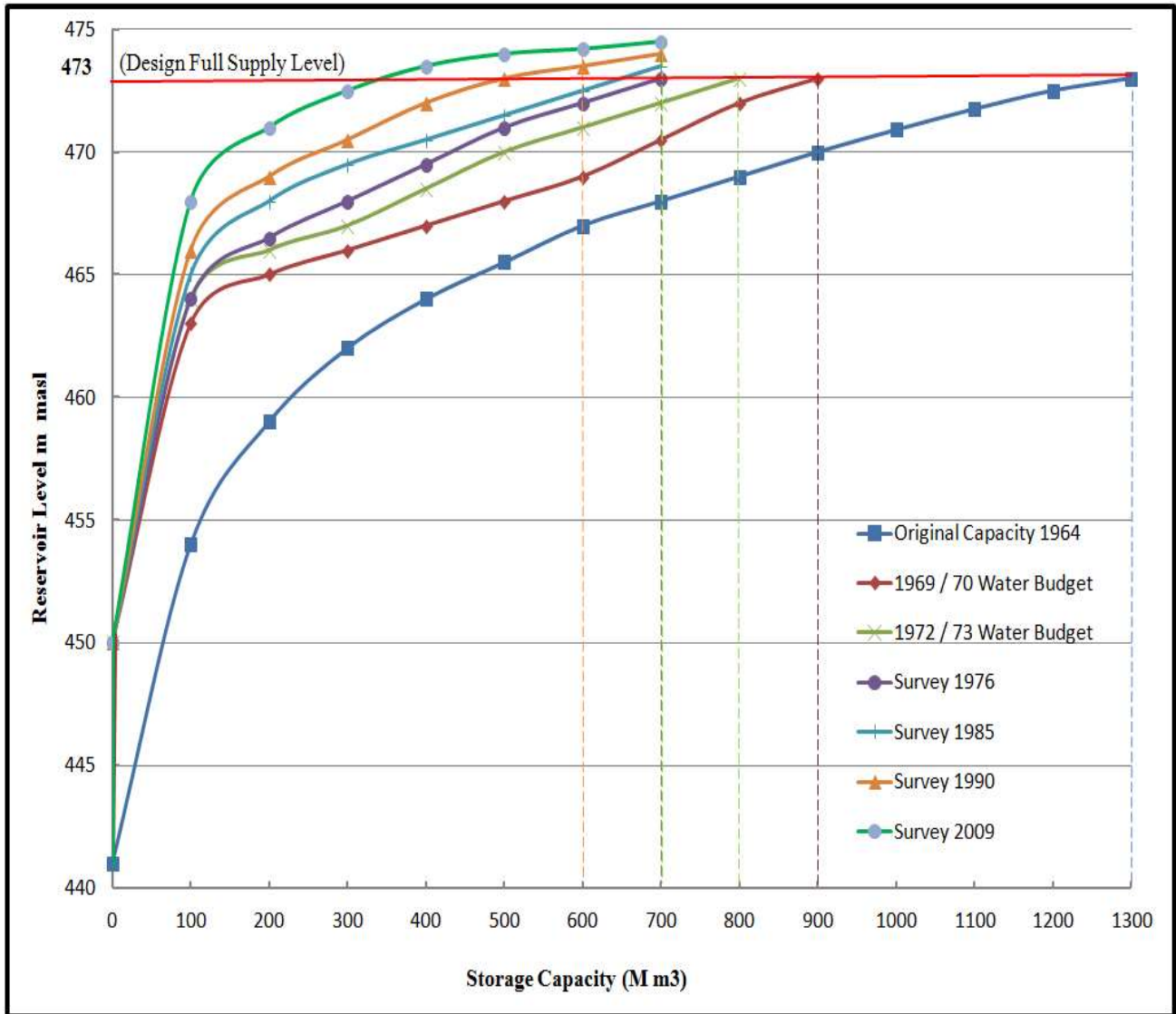


Fig (4) KED Storage Loss Rate at Different Levels

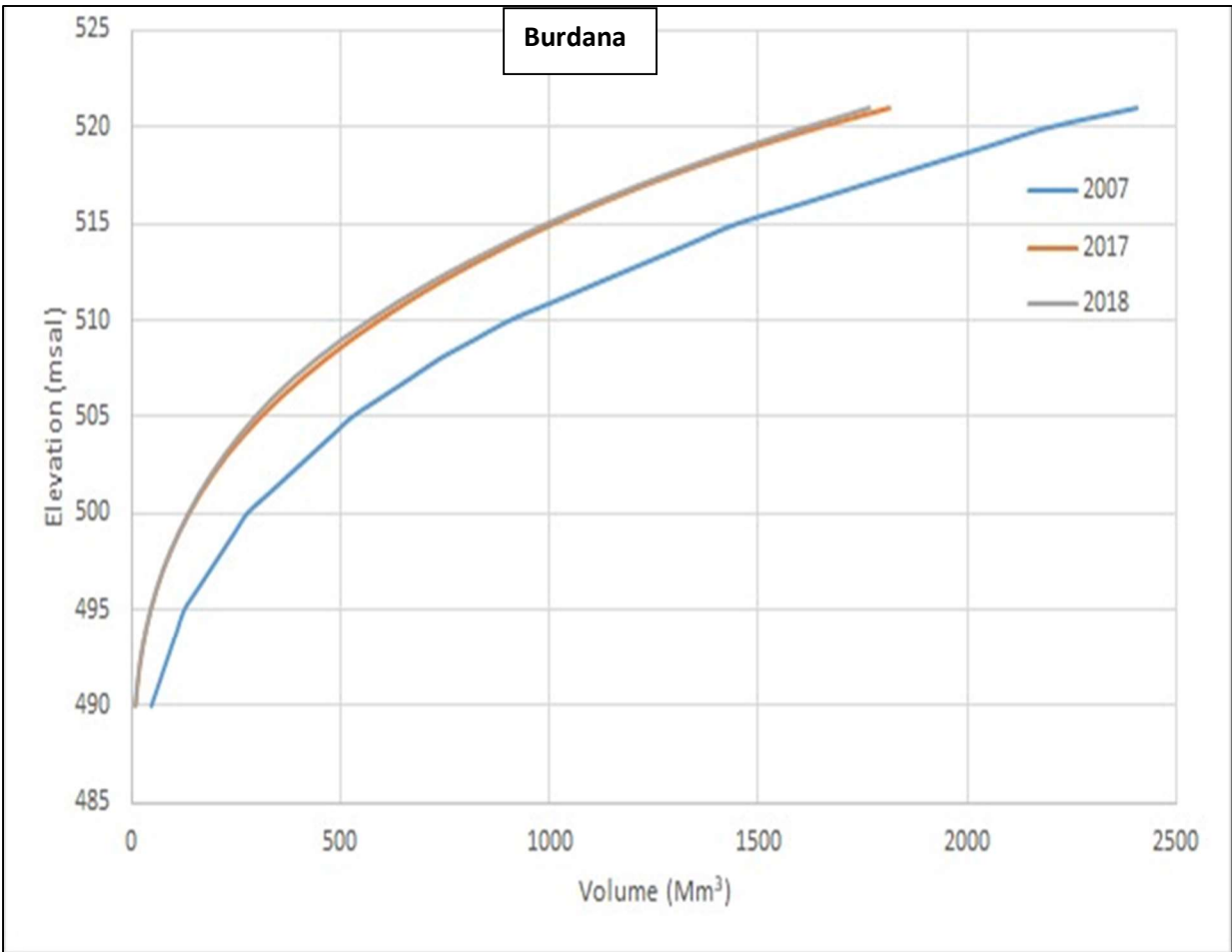


Fig (5) Capacity loss due to sediment deposits in Burdana Reservoir

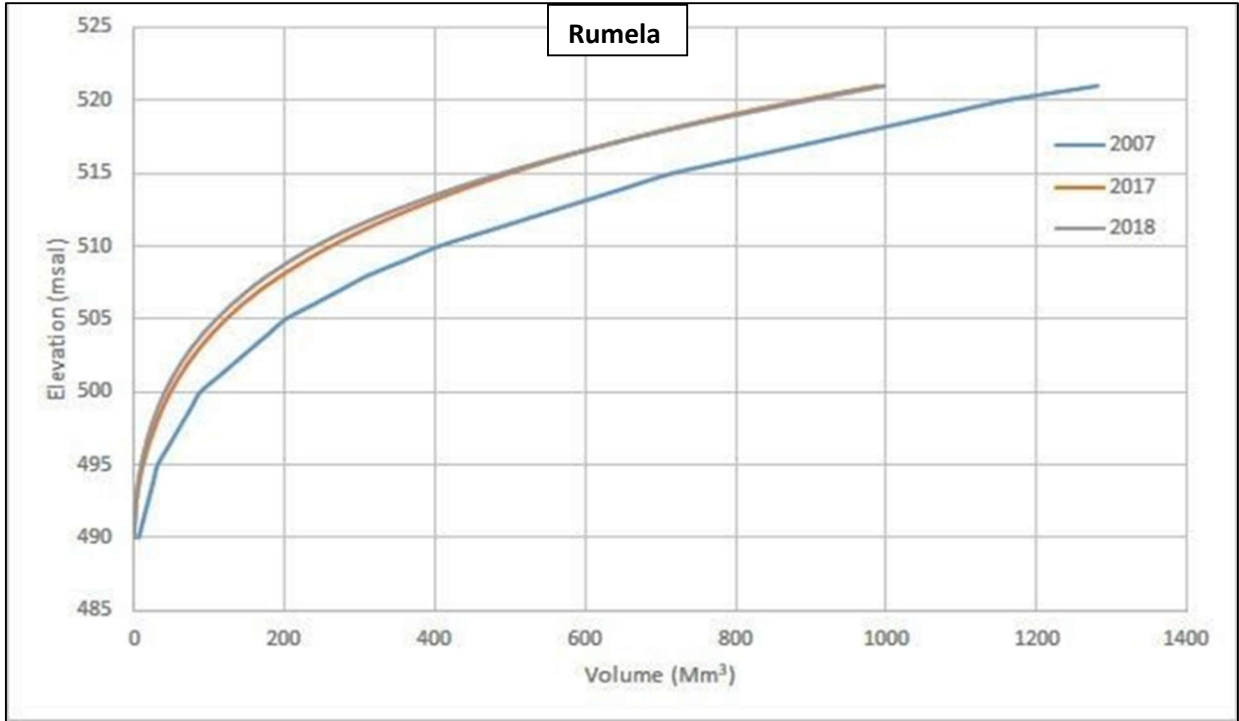


Fig (6) Capacity loss due to sediment deposits in Rumela Reservoir

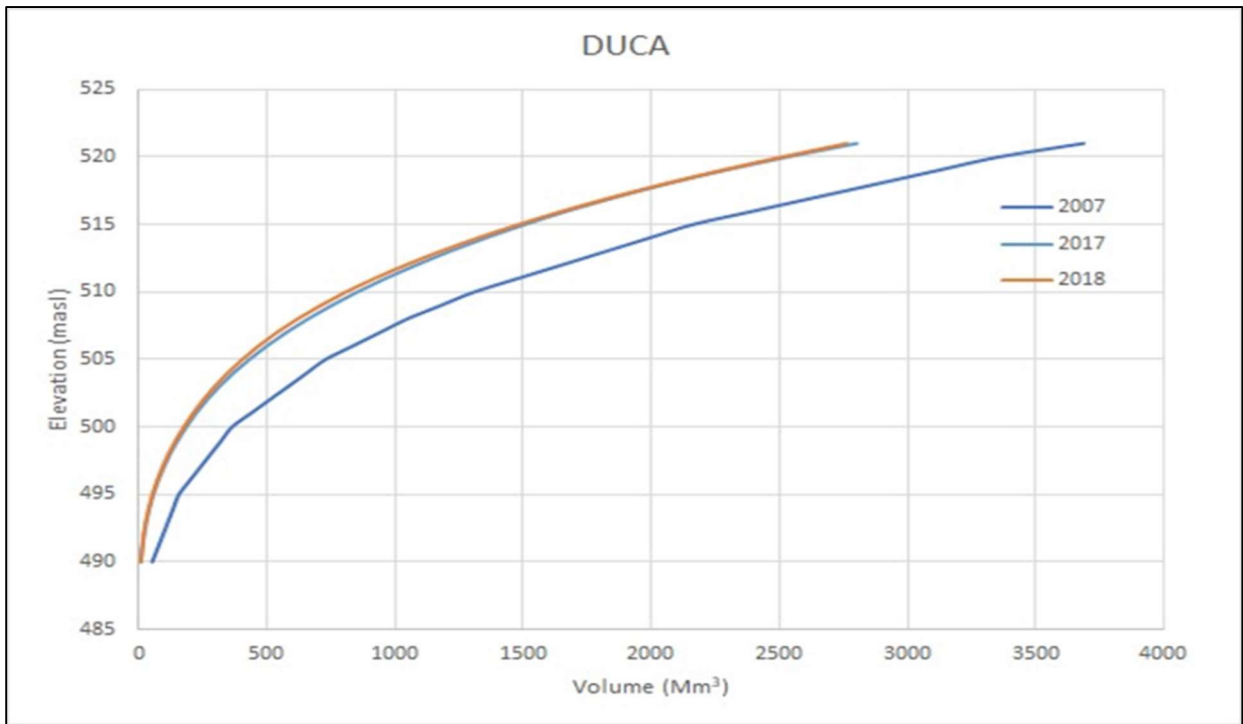


Fig (7) Capacity loss due to sediment deposits in DUCA Reservoir

If the dead reservoir storage was considered at the dam construction (2007), 1.180 BCM, the Author of this paper believes that the sediment deposited in the reservoir during this period is even worse than suggested by the designer. The dead storage might be almost full of sediments, unless a considerable amount of it is placed in the life storage zone, which in this case is even more serious. The present results of sedimentation put the ADC's future at high risk, or at least in jeopardy and a gloomy situation. It is believed that the condition of the ADC is attributed to the high sediment rate originating from the Ethiopian Highlands and to the dam management policy, which should consider the sediment crisis as a serious factor in developing the Operation Rules.

7.0 How ADC is going to be operated?

The ADC is composed of KED, Burdana and Rumela reservoirs, Figs (8a, 8b and 8c). The operation of the three reservoirs needs strict coordination to facilitate effective water resources management and satisfy the needs of all stakeholders in a balanced manner. Therefore, ADC should serve the following water users:-

- Irrigation requirements for the existing New Wadi Halfa Scheme plus - in the future – Upper Atbara Irrigation Project (UAIP)
- Hydropower generation,
- Domestic water supplies for New Halfa and Elgadarif cities.
- Environmental flow D/S of DCUA and further D/S of KED.

In addition to the above, the sediment should be managed in a manner to keep the reservoir capacity over a longer period of time.

8.0- Could Flushing help Sediment Management in ADC?

Flushing is a rapid drawdown of the reservoir level below the minimum Operation level to increase the flow velocity and hence erode deposited sediments. The sudden release of high water volume helps carry a large amount of sediment downstream. Flushing has been experienced in the KED reservoir since 1971.



Fig (8a) Layout of ADC and the Confluence

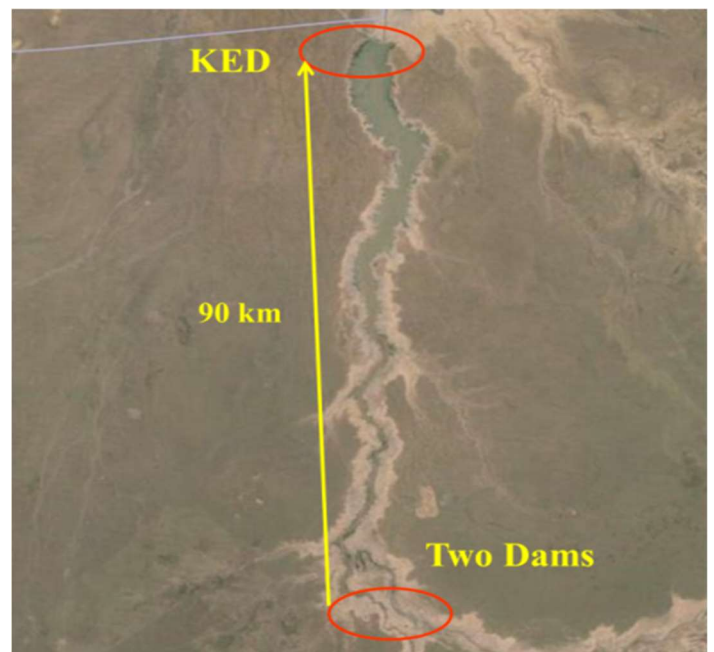


Fig (8b) Layout of ADC

Every year, when the inflow reaches 2,000 m³/s, the reservoir level is lowered from the minimum Operation Level of 465 to 445 AMSL. Lowering of the water level takes 12 hours. Then, the KED reservoir will operate at a level of 445 MASL for a period of 48 hours; hence, the reservoir is refilled to the minimum Operation Level, which usually takes about 12 hours.



Fig (8c) Rumela, Burdana Reservoirs and the Linking Channel

Full flushing of Burdana and Rumela reservoirs is achieved by rapidly lowering the levels in both Burdana and Rumela reservoirs from 509 to 495 AMSL by opening the deep sluices in both dams. The total flushed water volume is approximately 1.0 BCM. Learning from the experience with KED, it is advised to start flushing when the combined inflow from the two rivers reaches 3,000-4,000 m³/s, approximately equally divided between the Upper Atbara and Setit, to have a high flow velocity in the reservoir for a sufficiently long period (Mohamed et al, 2014). Flushing both reservoirs should start at the same time, taking into consideration that Burdana and Rumela differ significantly in size. Lowering the level of the Rumela reservoir to 495 masl will take about 24 hours, while for the larger Burdana, this may take up to 72 hours. Burdana reservoir could be drawn down up to a level of about 492 masl if necessary. It is advised to keep the reservoir at low levels for another 48 hours after the Burdana has reached 495 masl to have the maximum eroding effect. The total time needed for the flushing procedure is therefore 5 days, Fig (9), Mohamed et al (2014).

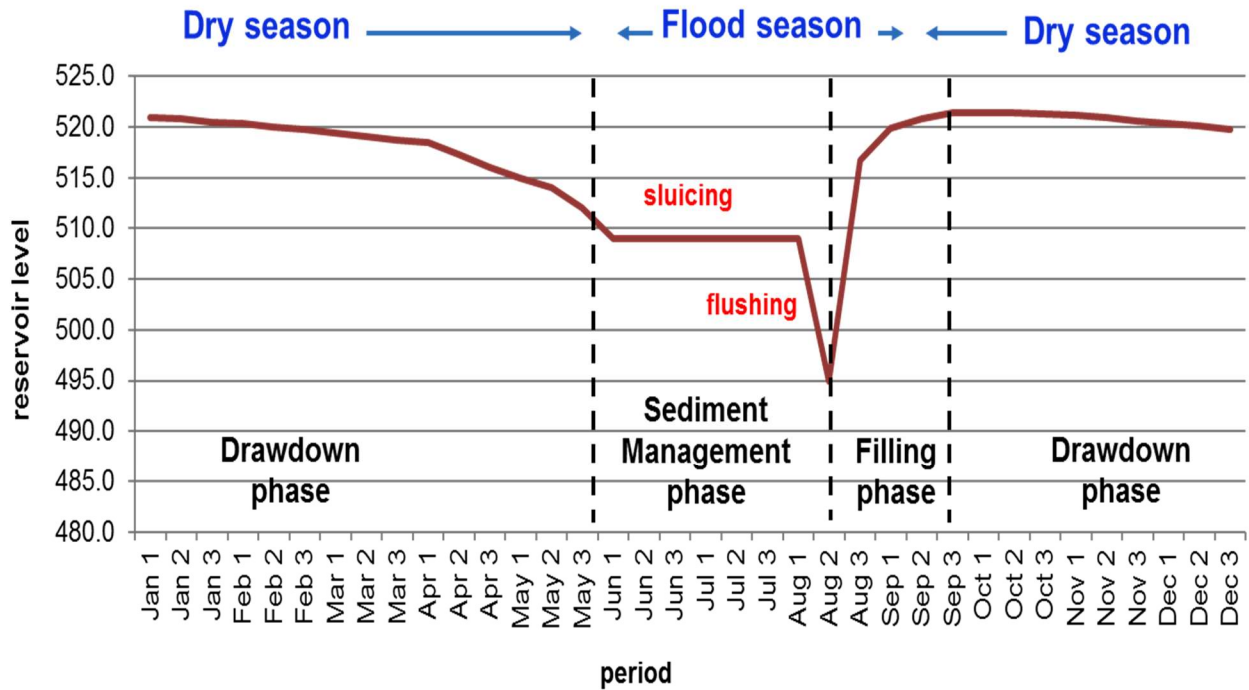


Fig (9) ADC Operation Rules Curve, Mohamed et al 2014

From a reservoir level of 506 masl, down, which is the bed level of the Connection Channel (CC), both reservoirs are fully disconnected, and the reservoirs could be operated separately when required. No doubt the relatively high flow velocities that occur in the CC when the reservoir levels are close to its bed level will create a high rate of bed erosion. Preferably, the rate of lowering in both reservoirs is therefore kept the same, to reduce these flow velocities and the subsequent risk of scouring, which is difficult to control.

9.0 Challenges facing ADC Operation

The three reservoirs need to be operated in conjunction at all times and in coordination with the U/S TK5 in Ethiopia. From KED, the existing irrigation systems are commanded, and UAIP will also be provided with water from these reservoirs. Flushing operations for Sediment management need to be synchronised for both reservoirs. The river is expected to carry less sediment due to trapping in the reservoir's U/S (TK5 exits), TK6 and TK7 (planned) along the Tekeze River. On the other hand, water availability will be affected, which may lead to a negative impact on all the development activities D/S in the near future. Although TK5 has been operating since 2010, the Sudanese side has no information whatsoever about its Operation Rules of the TK5 dam, a situation which puts ADC at *RISK*.

10.0 Discussions and Finding Remarks

- i- The general set-up of the two dams (Rumela and Burdana) together with the KED regarding locations and flow characteristics is very complex.
- ii- Although the Hydropower generation comes in second order, in a seasonal river coupled with high sediment flows, the operation of ADC will be more complex. If the reservoir inflow is lower than the power requirement at Rumela, power generation will

- rapidly halt. On the other hand, the irrigation and water supply needs will be in jeopardy. One of the solutions adopted to manage the sediment in the three reservoirs is *flushing*. However, flushing has limited added value in terms of minimising the annual sediment trapping ratio, but still has a positive effect. The challenge in ADC is that the three reservoirs must be operated in harmony. This means in the near future, the KED reservoir will no longer store any water due to the high sediment concentration released from the two upper reservoirs, Fig (8b). Hence, there is no water available for the new irrigated scheme, UAIP, and the Old New Wadi Halfa scheme will not be able to consume additional water. Therefore, the ADC will be operated to generate Hydropower for some time (or years to come) before we have new irrigation projects.
- iii- The Author of this paper believes that the governing factor in the operation of ADC should be sediment management to protect the reservoir storage capacity against sedimentation. This is the only way to keep the reservoir's life span reasonable and acceptable.
 - iv- It is a fact that the sluicing, when practised at relatively high-water levels, and short-time flushing are not successful in sedimentation management. The practice in KED resulted in a 65% loss of reservoir capacity, and effectiveness is limited to the river valley only and for a limited upstream distance (<5 km).
 - v- The uncontrolled CC linking Rumela and Burdana reservoirs, Fig (8c), is adding further complications to the sedimentation management issue. The two river branches differ in many ways regarding discharge means and peaks, timing, sediment loads, filling and emptying, structural facilities and U/S developments.
 - a. The CC is prone to annual sedimentation and may be filled up in a few years.
 - b. At the same time, depending on filling/emptying rates, the CC is prone to scour, especially the recently deposited sediment. This will generate a lateral inflow of huge sediment load, which may threaten the Hydropower intakes and turbines as well.
 - vi- The limited per day operation hours (2 to 3 hr/day) of the Hydropower cast doubts and throw many questions regarding the selection process of such high-capacity turbines (4 turbines with 80 MW each), which amounts to 320 MW. Are they economically justified? Are they compared to Merowe Dam 1250 MW (Average flow of 84 bcm of the Nile Main River) or Roseries Dam 280 MW (Average flow of 50 bcm of the Blue Nile River) against the flow of 12.0 bcm in the Atbara River?
 - vii- The delta formation in the active zone, propagation rates, and rates of both active and live storage loss in the two reservoirs are not well investigated, since the data available is rare (sediment deposition distribution).
 - viii- In 2015, the filling of the ADC reservoir started earlier in August, because of the low flows of the river, and only 2.0 BCM had been stored, hence there was no hydro-power generation.

11.0 Conclusions

a- After 5 years, the operation rules of ADC have proved to be so far are not convincing, since it is clear that they give Hydropower generation an upper priority regardless of the reservoir's sustainability. There is no doubt that the ADC using the suggested operating rules will lose a significant part of its storage capacity in the first few years of operation, Fig (6). However, the only way to protect ADC from serious sediment deposition is for the river to flow naturally during high sediment concentrations without storing water. The latter is not possible since the inflow will

not be sufficient to fill the reservoir; therefore, striking a balance between sediment deposition and filling of the reservoir is essential, which, from a practical point of view, is very difficult.

b- The flow current from Burdana reservoir through the linking channel (CC) to Rumela reservoir in front of the turbines will create a large loop, high flow circles and hence high sediment deposition, taking into consideration that the bed level of Burdana reservoir is higher than that of Rumela by 3 m. This might lead to frequent blockage of the Turbines' Intakes, which implies a reduction of the hydropower generation or complete stoppage.

c- The future proper operation of ADC is dependent mainly on the cooperation between Ethiopia and Sudan, e.g. the TK5 dam and any future dam upstream. This is necessary to operate all the dam reservoirs in the Atbara River Basin System in Harmony.

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