Journal of Geoscience and Environment Protection, 2023, 11, 404-426
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

# Evolution of Sedimentation in a Headrace Canal for Hydroelectric Production Case of the Shongo Basin of the Inga Complex from February 2020 to May 2021 (Kongo Central Province/DR Congo)

**Omer Kawende Kalonda[1], Ivon Ndala Tshiwis[1,2], Boniface Mumbimb Atalatala[1], Clement N'Zau Umba-Di-Mbudi[1,2,3]**

[1]Geo-Hydro-Energy Research Group, University of Kinshasa, Kinshasa, Democratic Republic of the Congo
[2]Department of Geosciences, Faculty of Science and Technology, University of Kinshasa, Kinshasa, Democratic Republic of the Congo
[3]Polytechnic Faculty, President Joseph Kasa-Vubu State University, Boma, Democratic Republic of the Congo
Email: omerkawende@gmail.com, ivon.ndala@unikin.ac.cd, bonimumbim@yahoo, clement.mbudi@unikin.ac.cd

**How to cite this paper:** Kawende Kalonda, O., Ndala Tshiwis, I., Mumbimb Atalatala, B., & N'Zau Umba-Di-Mbudi, C. (2023). Evolution of Sedimentation in a Headrace Canal for Hydroelectric Production Case of the Shongo Basin of the Inga Complex from February 2020 to May 2021 (Kongo Central Province/DR Congo). *Journal of Geoscience and Environment Protection, 11,* 404-426.
https://doi.org/10.4236/gep.2023.115024

**Received:** March 9, 2023
**Accepted:** May 28, 2023
**Published:** May 31, 2023



## Abstract

The headrace of the Inga hydropower complex is experiencing siltation problems, reducing the exploitable draft and limiting the production capacity of the two main Inga hydropower plants during the low water period. During the 2019 low water period, several sediment slumps occurred in the Shongo basin, disrupting the production of hydroelectric power generated by the Inga 1 & 2 power plant, resulting in massive load shedding of power supply to downstream customers. The cardinal aim of this study is to determine the quantities of sediments deposited and those eroded, in order to know the evolution of sedimentation in the Shongo basin from February 2020 to May 2021. The results obtained show that the running index of the turbines alternators groups is determinant and influences the sedimentation process in the Shongo basin. The cleaning of the Shongo basin in terms of the spatial distribution of sedimentation from February 2020 to May 2021 is plausible.

## Keywords

Quantities, Erode, Deposede, Load Shedding and Index

## 1. Introduction

Sedimentation of water reservoirs has become a major problem for water resource management worldwide (Müller, De Cesare, & Schleiss, 2014; Althaus, De Cesare, & Schleiss, 2015; Fox et al., 2016; Sumi, 2018; Ren et al., 2021). According to (WCD, 2000; Schleiss et al., 2010; Schleiss et al., 2016), the rate of filling of dam impoundments exceeds the number of new projects being built worldwide. World Commission on Dams (2001) estimates the annual volume of water lost to be between 0.5% and 1%. Palmieri et al. (2001) state that 0.8% of water reservoirs are filled, representing an annual loss of 13 billion dollars worldwide. However, Schleiss et al. (2010, 2016) estimate that the annual investment spent to replace the volume lost due to sedimentation on average was 13 to 19 trillion ($1012) dollars.

In Europe, (Mekerta, 1995; Justrich, Hunziger, & Wildi, 2006; Schleiss et al., 2016) indicate that this is a worrying situation in some regions. For example, Patro et al. (2022) noted that out of a total of 543 large dams currently operating in Italy, the result of a study of fifty reservoirs shows that 12 have sediment accumulation problems, six of which are in a catastrophic situation, and another six will be in the same situation if appropriate measures are not taken.

According to (Boualem & Wassila, 2004; Patro et al., 2022; Müller, De cesare, & Schleiss, 2014), sedimentation is a major problem in many reservoirs in the US. A survey of reservoir managers identified that approximately 28% of reservoirs >250 ac in the US had moderate to high or high concern with sedimentation (Krogman & Le Miranda, 2016). These percentages vary by region; for example, sedimentation affects up to 51% of reservoirs in areas along the central plains of the US.

In the African continent with variations according to the regions are observed in particular in Malgrébin, (Kassoul et al., 1997; Remini, 1997; Boualem & Wassila, 2004) point out that the rate of sedimentation in the Algerian water reservoirs is the highest in the world because the Ghrib dam had recorded an annual accumulation in volume of silt equal to $3.2 \times 10^6$ $m^3$. In South Saharan Africa, Kouassi et al. (2007) inform that there is little data concerning the sedimentation of dams.

In Asia, several reports on the state of sedimentation in the dams of Java in Indonesia indicate that 2 billion·$m^3$ of sediment have been retained by the dams since their commissioning Heng (2013). According to Wu et al. (2020) the sediment load carried by rivers in China is 10% on a global scale. Dai et al. (2018) report that the construction of the Three Gorges Dam (TGD) accumulates $1.23 \times 10^8$ t of sediment per year and Yang, Zhang, & Xu (2007) report $1.51 \times 10^8$ t from 2003 and 2005.

According to Schleiss et al. (2016), more than 3/4 of scientific papers related to reservoir sedimentation have only been published in the period from 1970 to date. On the other hand, in the African continent most of the data on dam reservoirs come from Malgreb (Mammou & Louati, 2007; Boualem & Wassila, 2004), Zambia and West Africa. In East Africa, Amasi et al. (2021) states that there is a lack of data on sedimentation rates in hydroelectric reservoirs. The same is true for Central Africa, which has one of the world's largest hydropower reservoirs, the Congo River Basin, which drains 30% of Africa's hydropower potential and is second only to its American equatorial rival in terms of flow (Flügel, Eckardt, & Cotterill, 2015).

The Congo River accounts for 13% of the world's hydroelectric potential and 66% of Central Africa's potential (Gnassou, 2019). By way of illustration, the Amazon River drains 23% of water and the Congo at 10%, followed by Gages-Brahmaputra at 9.11%, and Yangzé at 8.15%. On the African continent, the Zambezi River accounts for 1.68%, the Niger River for 1.44%, and the Nile River for 0.72%. However, there are few scientific papers on reservoir sedimentation in this part of the world. However, a number of reservoirs for hydroelectric production have been built since the 1930s, including: Inga, Zongo, Sanga Mpozo, Mwadingusha, Koni, Seke, Bendera, Tshopo, Nsilo, Busanga, Imboulu and others are under construction. Moreover, the Oubangi River, the second largest tributary of the Congo, has a potential of 2000 MW. However, less than 60 MW are currently exploited and it is one of the least exploited regions in the world in terms of hydraulic resources (Nzango, 2018). Paradoxically, the electrification rate in rural areas was 1% in 2020 and 40.6% in urban areas (Gnassou, 2019).

However, the Inga 1 and 2 power plants cannot operate at full capacity, notably because of silting up to 30 million·m$^3$ on the Inga headrace canal (CRENK, 1988; SNEL, 2005, 2011; Fichtner, 2010, 2011; Artelia, 2014). This presence of sediment deposits (**Figure 1**) led the Société Nationale d'Electricité (SNEL S.A.) to reduce its energy production by up to half. This has resulted in the reinforcement of the load shedding system (SNEL, 2020). For example, during the 2019 low water season, several sediment slides occurred in the Shongo basin, disrupting the production of hydroelectric power generated by the Inga 1 plant.

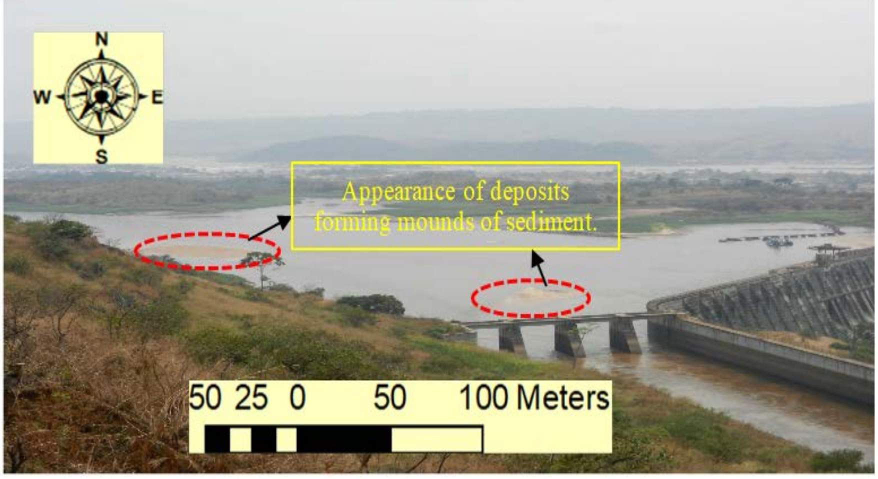


**Figure 1.** View of the Shongo basin channel, appearance of deposits forming mounds of sediment during the 2011 low flow (Alam, 2011c).

This work has the merit of arousing the interest and curiosity of researchers on sedimentation management, particularly in the reservoirs of the Inga dams (DRC) built as downstream diversions in the lower reaches of the Congo River. The feedback from the current hydraulic management of the Shongo basin in the Inga intake canal will allow us to address the sustainable management of sedimentation in the Congo River development project in its lower reaches. The latter has a potential of 70,000 MW in the section between Kinshasa and Matadi and is sufficient to electrify the entire African continent.

It is in this perspective that this work is carried out, with the aim of determining the quantities of sediment deposited and eroded, in order to know the evolution of sedimentation in the Shongo basin from February 2020 to May 2021.

## 2. Study Area

The Inga hydroelectric scheme is located in the western part of the DR Congo, in the province of Central Kongo (in the Sumbi sector, Seke-Banza territory, Bas-Fleuve district), 150 km from the mouth of the Congo River (the Atlantic Ocean) and about 225 km southwest of the provincial city of Kinshasa, and close to the village of Inga (Francou, 1977; Barrage Inga, 2019).

The Shongo basin is the main water reservoir for the supply of the Inga 1 and Inga 2 power stations. It measures approximately 98 hectares; along the Shongo basin are the PEXIV rockfill dykes, the Downstream Pass Dyke 1 and 2 and the Salvinias Canal. At the end of this basin is a gravity dam. On the right bank, this basin is bounded by the three intakes of the Inga 2 intake canal (**Figure 2**).

## 3. Methodology

The underwater configuration of a river is obtained hydrographic method of bathymetric surveys from data provided by GPS instrumentation and echo sounder. The GPS gives the X longitudes and the Y latitudes provided by the satellites. The echo sounder will transmit a signal that will be reflected back to the echo sounder. The distance to the bottom or depth Z will be determined by knowing the signal's travel time and speed. These data will be processed in a computer program.

Currently there are several methods to quantify the sediment deposited in a dam reservoir (Schleiss et al., 2016) among others empirical methods using mathematical equations. Topographic methods have been used by (Mekonnen et al., 2022) in Spain, Italy (Diaz, Mongil-Manso, & Navarro, 2014), in the reservoir of Obruk dam located in Çorum province in Türkiye (Ilçi et al., 2017) and are proving to be effective in assessing the volumes of sediments trapped by the reservoirs (Ramos-Diez et al., 2017). Geographic Information Systems are an important tool (Schleiss et al., 2016) allowing the overlay of several layers of information to be used in clustered or distributed models. According to (Mekonnen et al., 2022; Ilçi et al., 2017) sediment accumulation in a reservoir

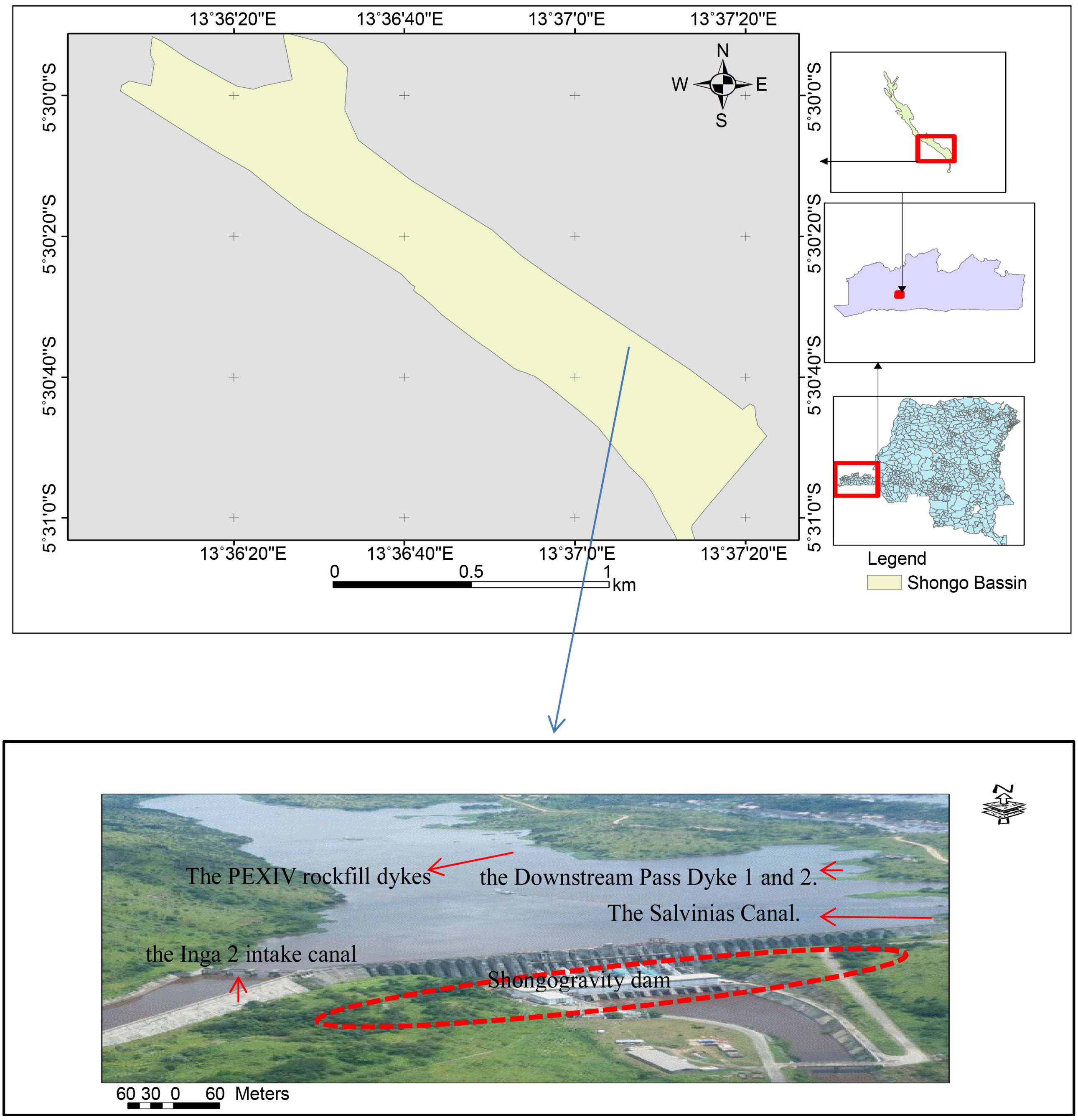


**Figure 2.** View of the Shongo basin (of the water reservoir), dam and central building of Inga 1 (Alam, 2011b).

can be estimated from repeated bathymetric measurements. According to Morris & Fan (1998) the difference between two campaigns makes it possible to obtain the volume deposited and to locate the deposition zones. Mammou & Louati (2007) presents some of these methods in his study on the temporal evolution of silting in Tunisian dams, notably the solid matter balances at the scale of a dam and the hydrographic method of bathymetric surveys by echo sounder.

Other methods requiring an extensive database using various types of data and information for better quantification of the reservoirs in a catchment area can be implemented, e.g. the Prism method used in Italy to determine the maximum potential volume of sediment stored in 912 check dams by combining the geometric characteristics of the reservoirs, silted structures and the sediment basin of seven catchments (Bombino et al., 2022).

This work uses the bathymetric hydrographic method to quantify sediment deposition in the Shongo Basin.

The method consisted of:

- ✓ The raising of the water level at the limnimetric scale on the upstream face of the Inga 2 dam;
- ✓ Positioning the boat on the profile to be surveyed: plunging the echo sounder probe to within 5 cm of the surface of the water coupled to the GPS for the recording of the geographical coordinates (X, Y, Z) of the various points, and following the profiles in parallel one after the other, from one bank to the other, by surveying several points along the profile;
- ✓ And finally to the processing of the data collected in the field with the help of software such as: Arc gis, Map info, Sagagis, Excel calculator, etc.; to identify the various bathymetry profiles.

The materials and equipment used in the execution of this work according to the rules of the trade and in complete safety are, in particular:

- ✓ 1 laptop GPS-Echo sounder interface computer (**Figure 3**);
- ✓ 1 single beam echo sounder;
- ✓ 1 YAMAHA canoe;
- ✓ 4 life jackets;
- ✓ GARMIN MAP 78 GPS;
- ✓ 2 lifebuoys.

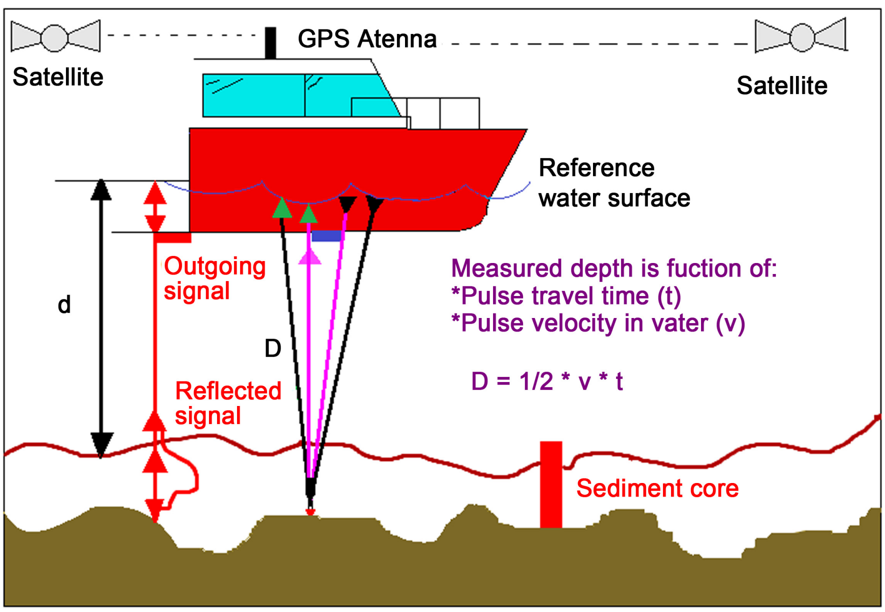


**Figure 3.** Depth measurement by echo sounder according to Iradukunda & Bwambale (2021).

According to Mammou & Louati (2007), the Digital Terrain Models (DTM) of the reservoirs are increasingly used to quantify the sediment deposited in a reservoir. GIS calculates sediment volumes over the entire reservoir area by comparing numerical surfaces, whereas the traditional approach applies an average surface method to calculate volumes based on a limited number of sections (Shaikh, 2021). In order to build and process a digital terrain model (DTM), it is necessary to choose a GIS software that can build and process Raster GIS files. During this study we used Qgis, Arcgis 10.8, Global Mapper.

Scanning of a paper map with the EDF 1972 and ICM 1990 profiles in jpg format;

- ✓ Geo-referencing of said digitized map with GIS software in UTM, zone 33 South, WGS 84;
- ✓ Projection of the said map with GIS software;
- ✓ Create a line vector shapefile;
- ✓ Editing sections on the geo-referenced map;
- ✓ Recording of the line vector shapefile converted into 33 cross sections of the Inga feeder canal. We note that this operation was necessary and allowed the channel sections to be calibrated to allow comparisons of past, present and future bathymetric profiles.

The construction of a DTM:

- ✓ The conversion of the AutoCad file into a "vector" type file, also called "shapefile", available at SNEL and readable by Gis software;
- ✓ The construction of a DTM of the inlet channel bottom by interpolating the bathymetry points and the existing shoreline during the various measurement campaigns.

We underline that a DTM allows us to obtain several pieces of information such as contour lines, rasters, accumulation areas, sediment volumes, water volume.

## 4. Results

This study uses the spatial and temporal analysis of four bathymetry surveys carried out in the Shongo Basin in the period February 2020 to May 2021 (**Figures 4-10**) and provides an assessment of sedimentation its extent and location.

**Figures 11-16** below show the shape of the sediment roofs deposited next to the Shongo dam by the inrush of the six generating units of the Inga 1 power plant in February, November 2020 and May 2021.

Using Gis software, ArcGIS, ArcMap, Arctoolbox, and Cutfill Tool, we can quantify the deposition and erosion of sediments in the Shongo basin by overlaying the bathymetry of the Shongo basin.

**Figures 17-19** locate and quantify the sediment deposition and erosion that has affected the ShongoBasin.

## 5. Discussions

In this work we focus on sediment deposition, particularly in the Shongo basin

Figure 4. Echosounder-GPS interface, bathymetric survey and bathymetric team in the Shongo basin.

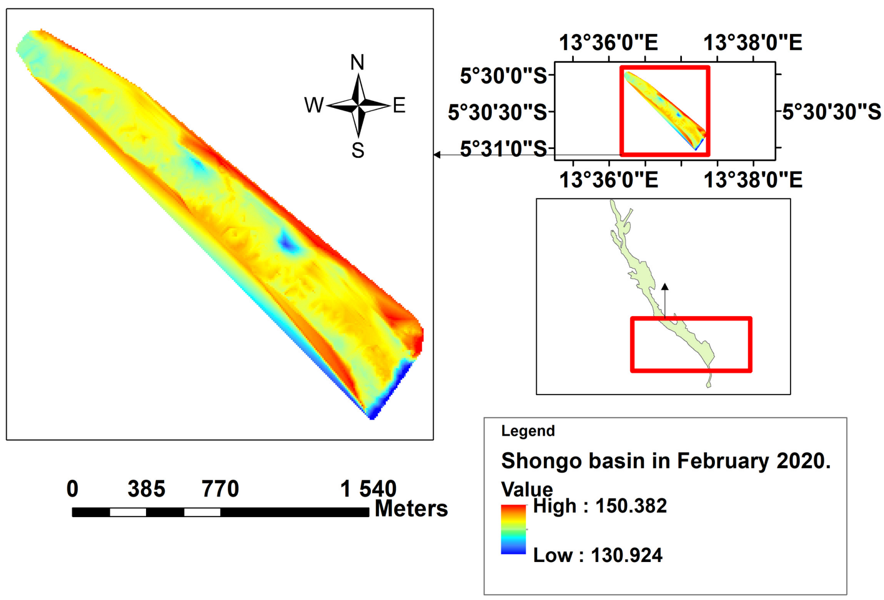


Figure 5. Bathymetry of the Shongo basin in February 2020.

located in the Inga intake canal.

The mechanism of reservoir sedimentation, according to Schleiss et al. (2016) the natural sedimentary cycle is a continuous coherent set of mechanical and

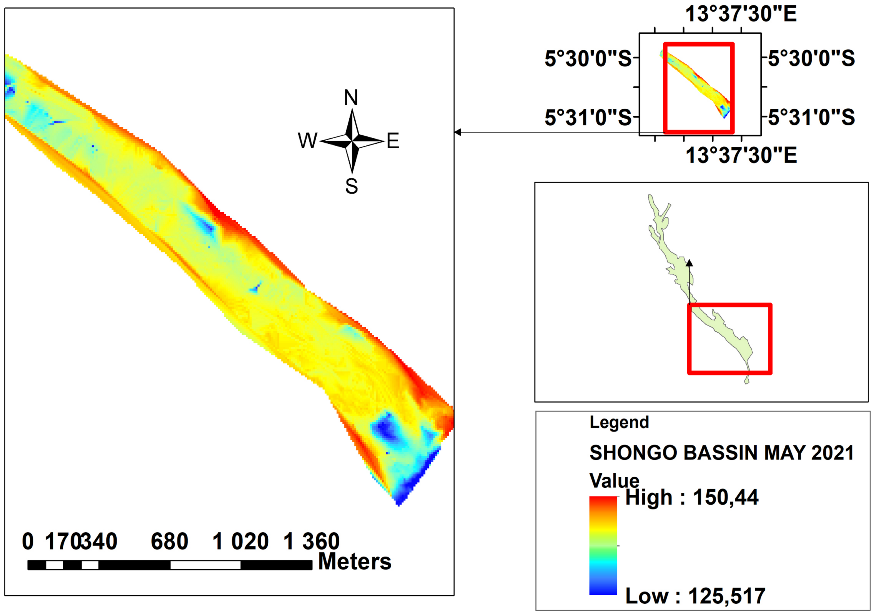


**Figure 6.** Bathymetry of the Shongo basin in May 2021.

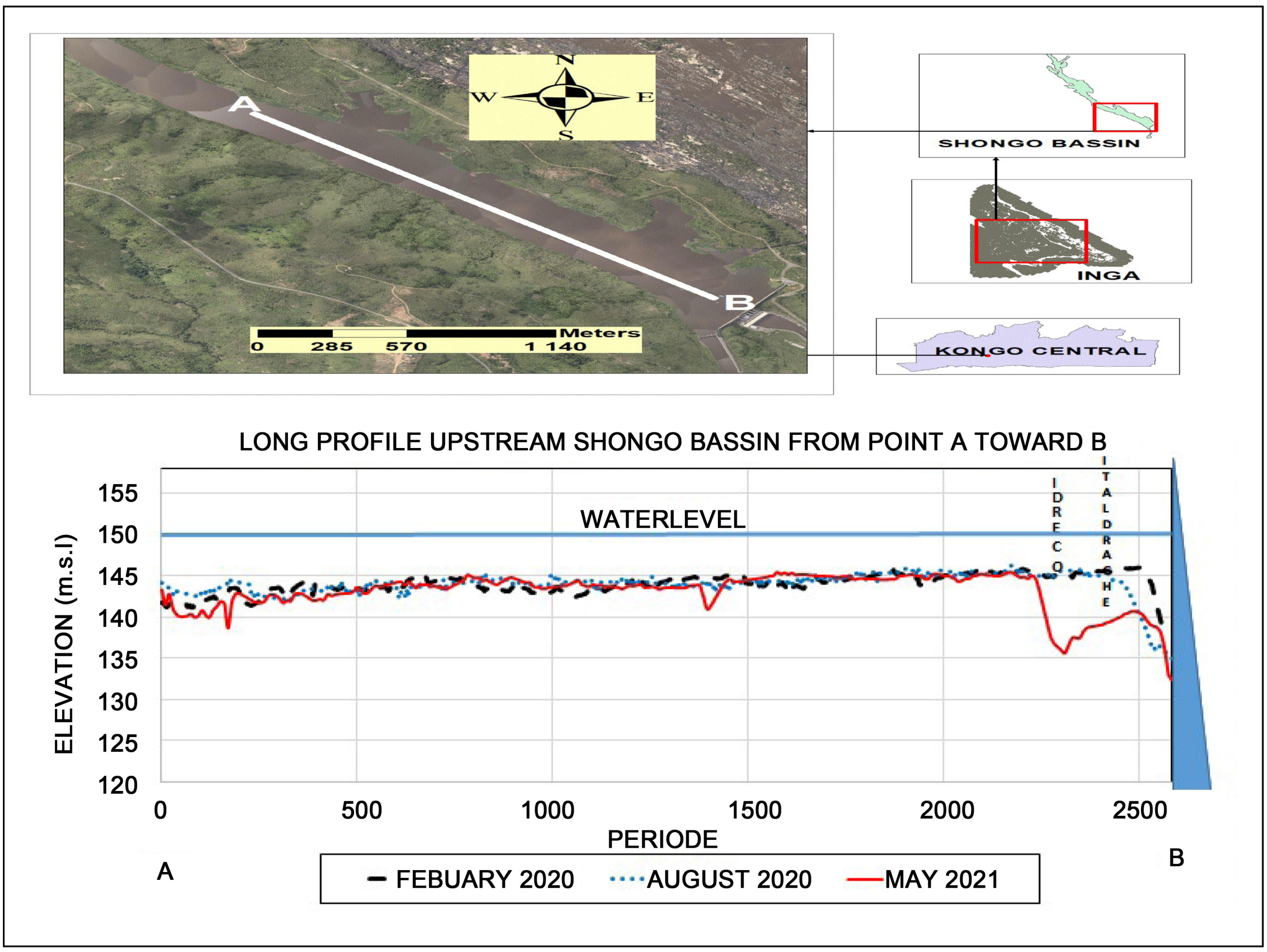


**Figure 7.** Longitudinal profiles of the Shongo basin for February, August 2020 and May 2021 from point A (2500 m from Shongo dam) to point B (Shongo dam).

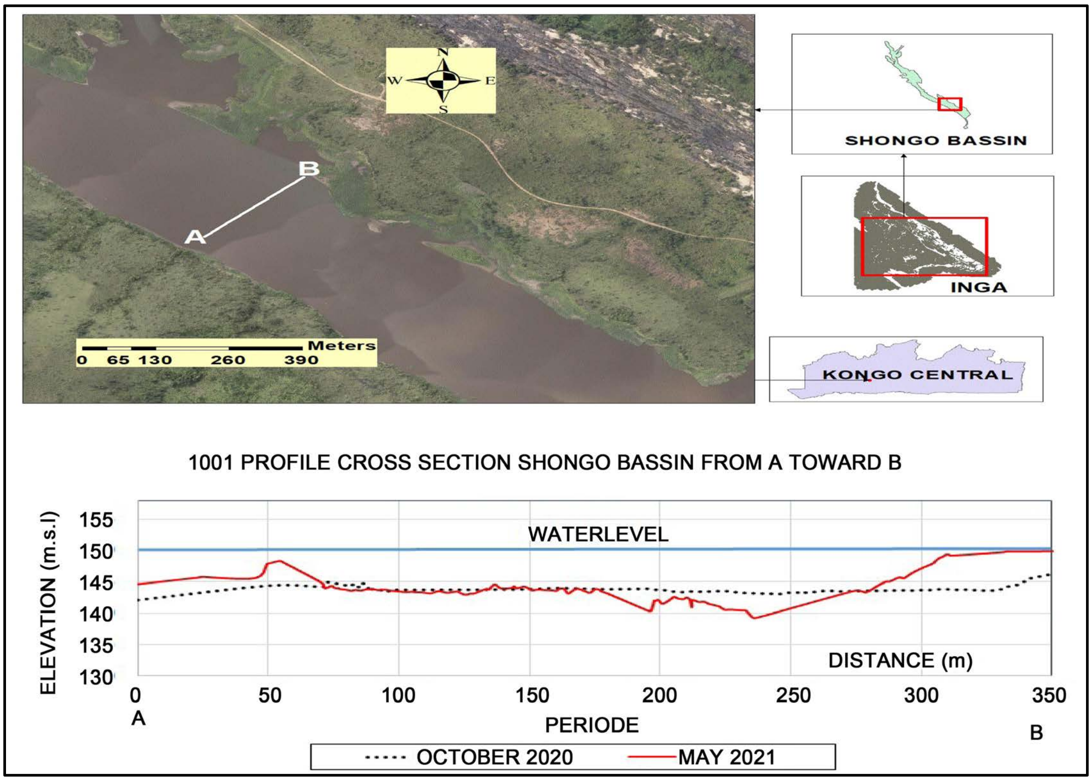


**Figure 8.** 1001 profiles of the Shongo basin for October and May 2021 from point A (Right Bank) to point B (Left Bank).

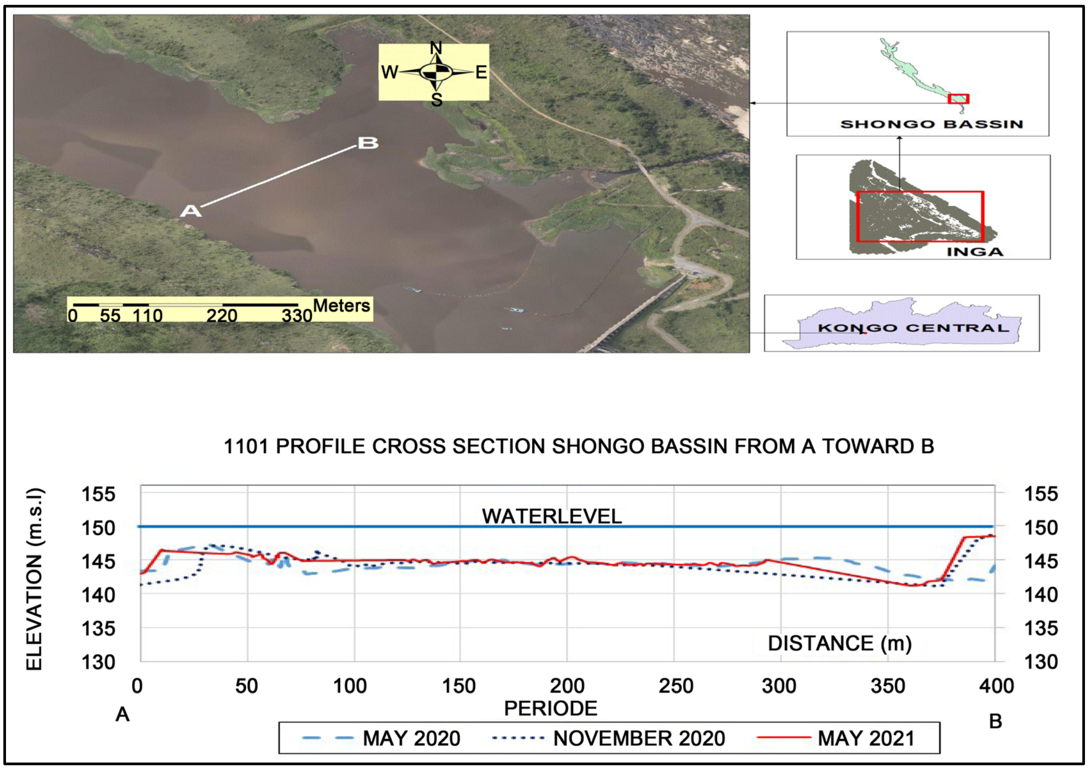


**Figure 9.** 1101 profiles of the Shongo basin for May, November 2020 and May 2021 from point A (Right Bank) to point B (Left Bank).

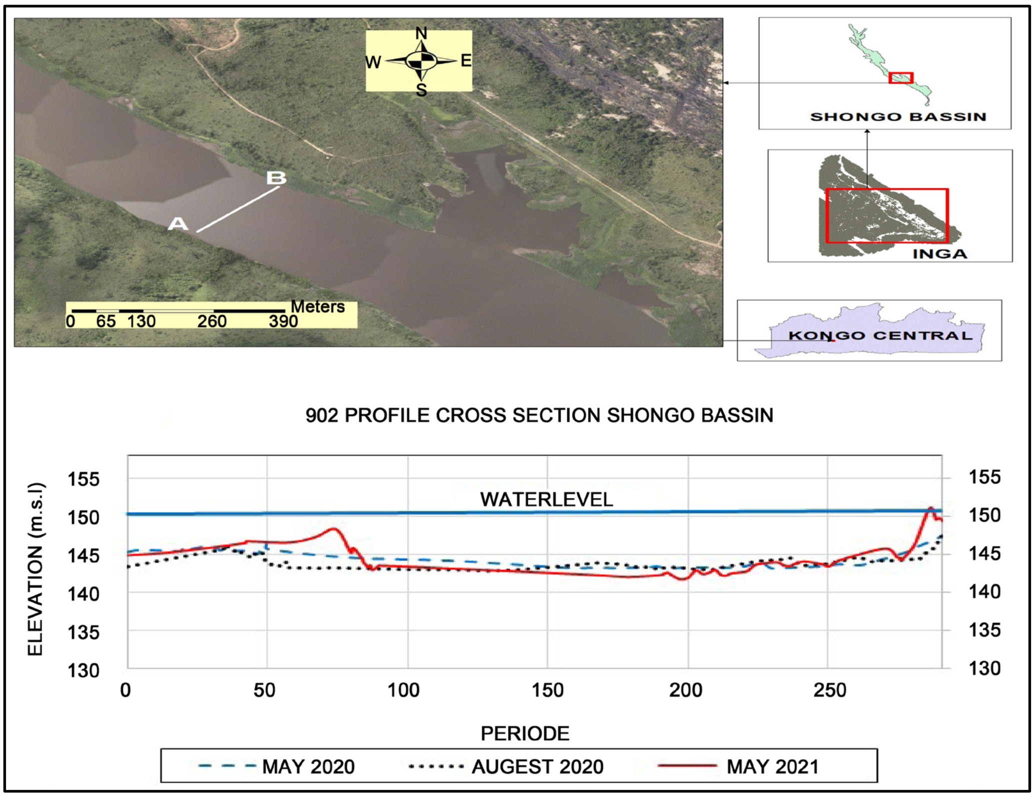


Figure 10. Profiles 1201 of the Shongo basin for May, October and May 2021 from point A (Right Bank) to point B (Left Bank).

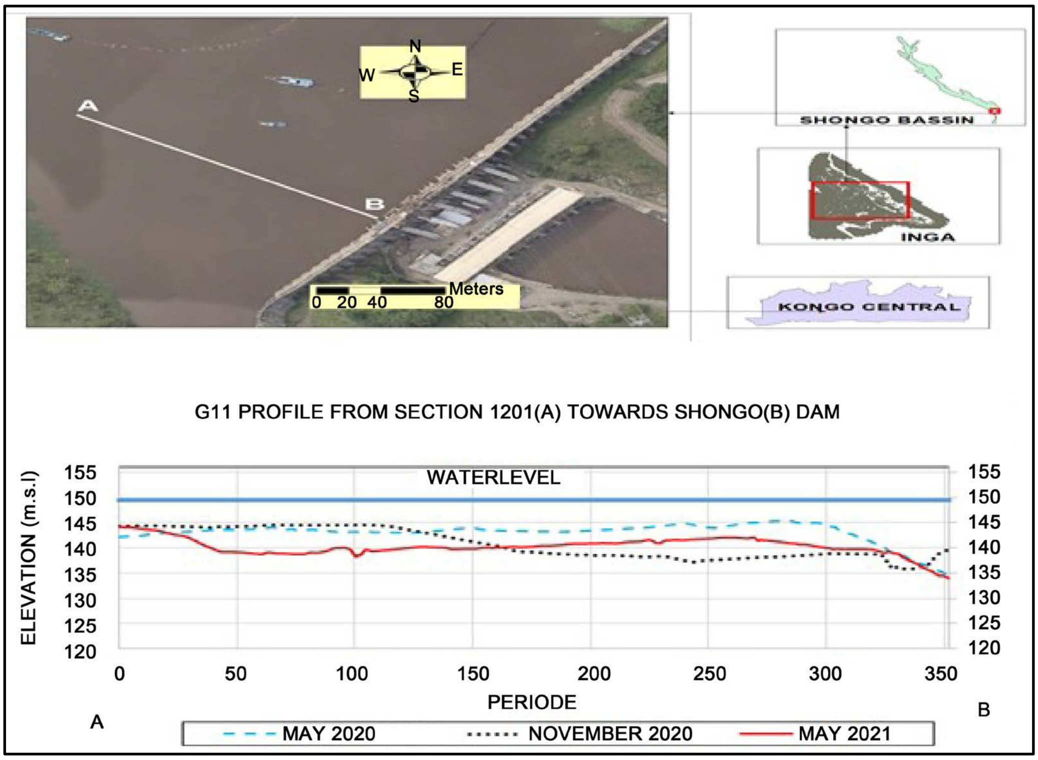


Figure 11. Silting profile in the Shongo basin of the alternator turbine group number 1 (G11) Inga Power Plant in February, November 2020 and May 2021 from point A (Upstream of the dam) to point B (Dam).

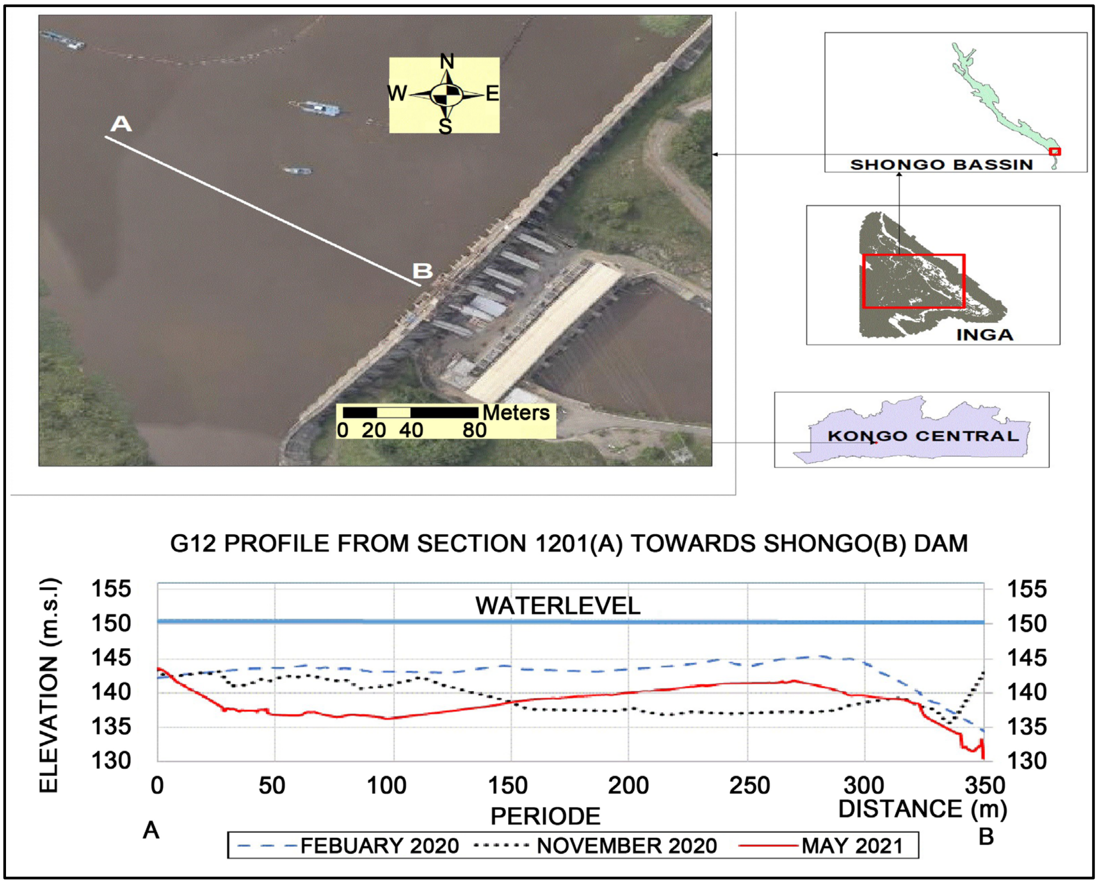


**Figure 12.** Silting profile in the Shongo basin of the alternator turbine group number 2 (G12) Inga Power Plant in February, November 2020 and May 2021 from point A (Upstream of the dam) to point B (Dam).

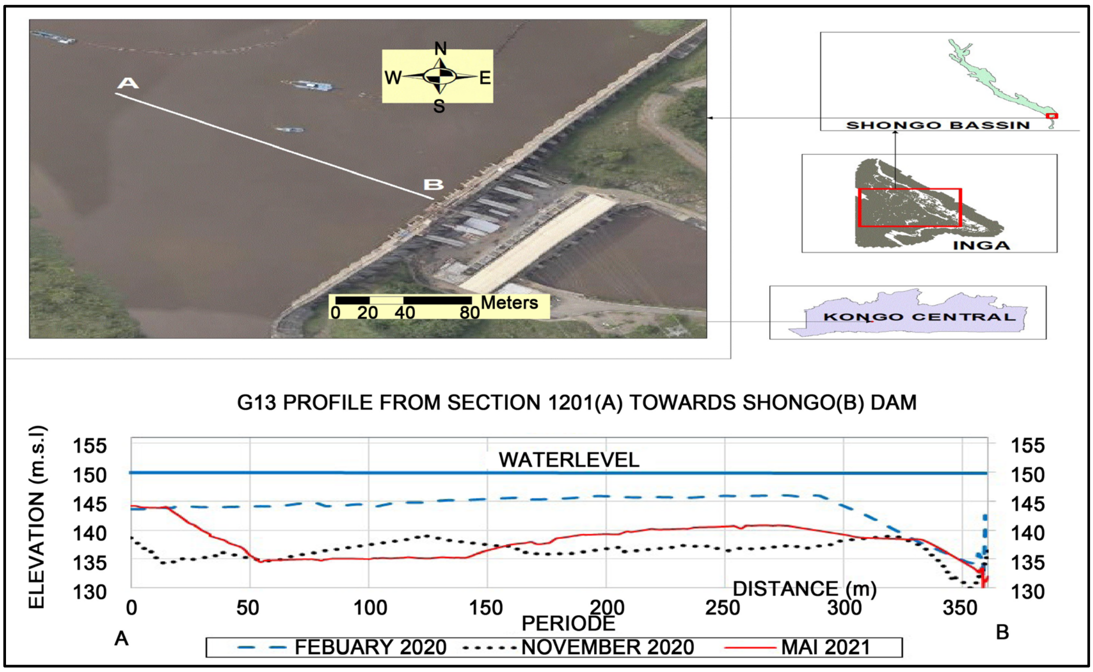


**Figure 13.** Silting profile in the Shongo basin of the alternator turbine group number 3 (G13) Inga Power Plant in February, November 2020 and May 2021 from point A (Upstream of the dam) to point B (Dam).

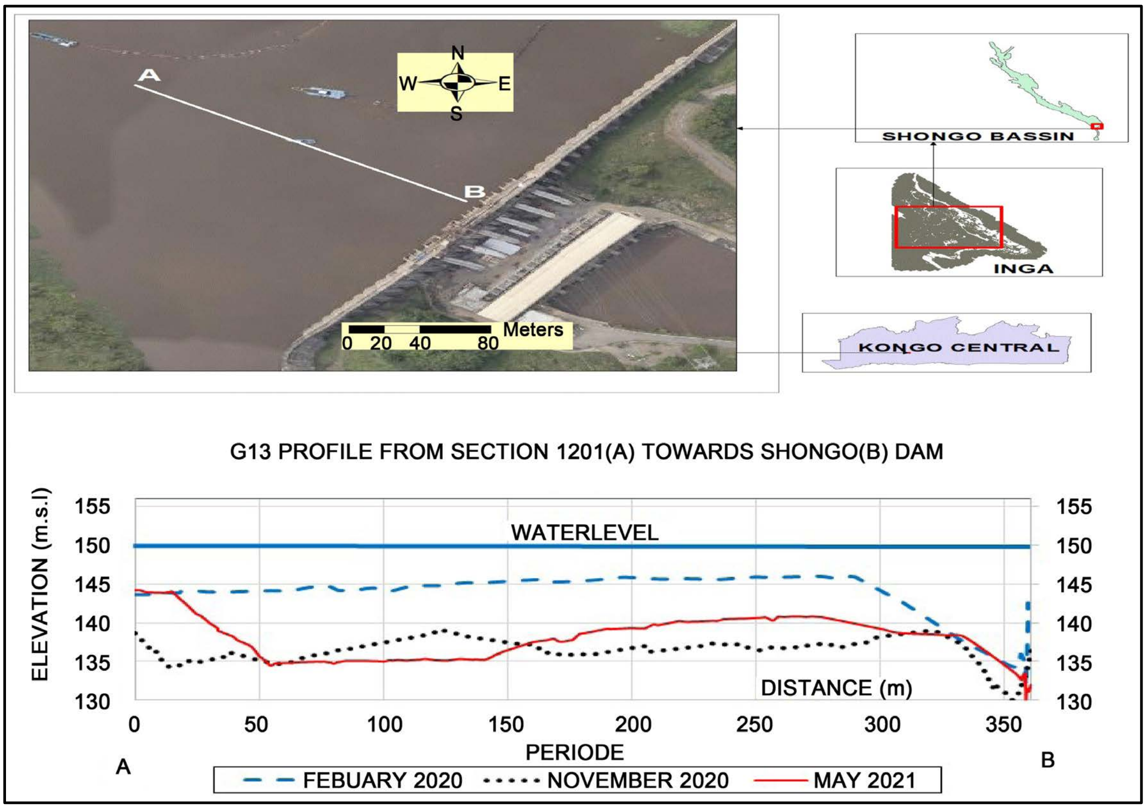


**Figure 14.** Silting profile in the Shongo basin of the alternator turbine group number 4 (G14) Inga Power Plant in February, November 2020 and May 2021 from point A (Upstream of the dam) to point B (Dam).

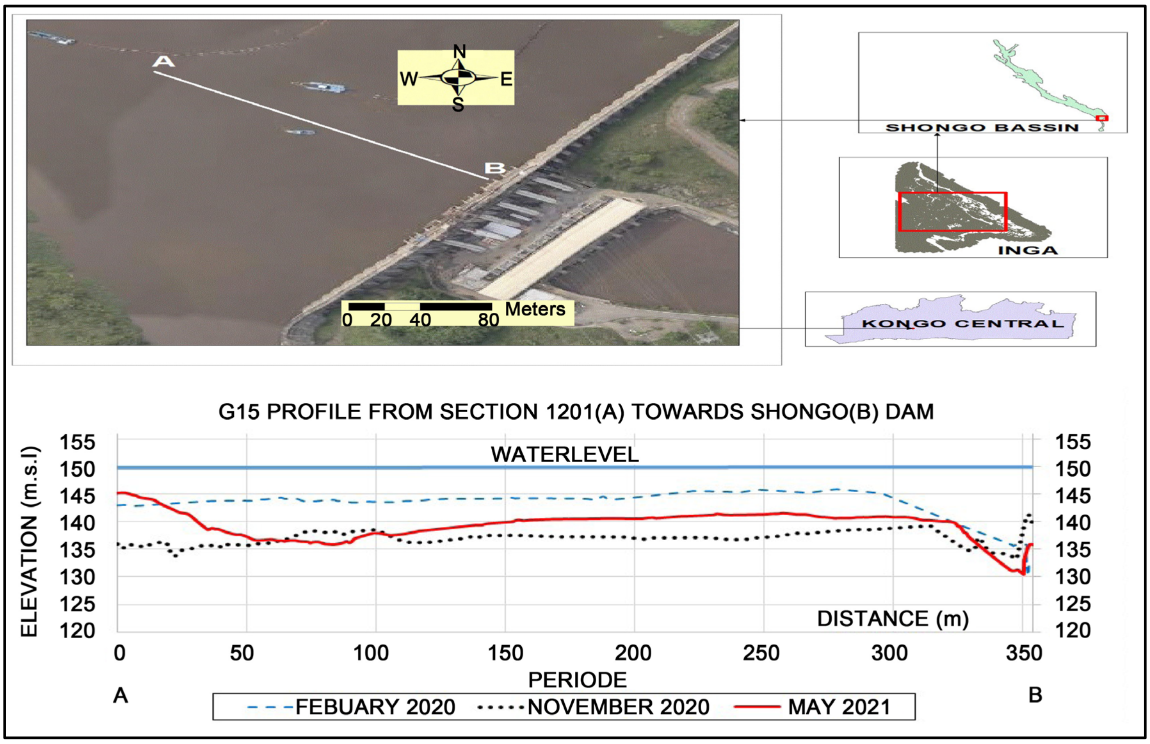


**Figure 15.** Silting profile in the Shongo basin of the alternator turbine group number 5 (G15) Inga Power Plant in February, November 2020 and May 2021 from point A (Upstream of the dam) to point B (Dam).

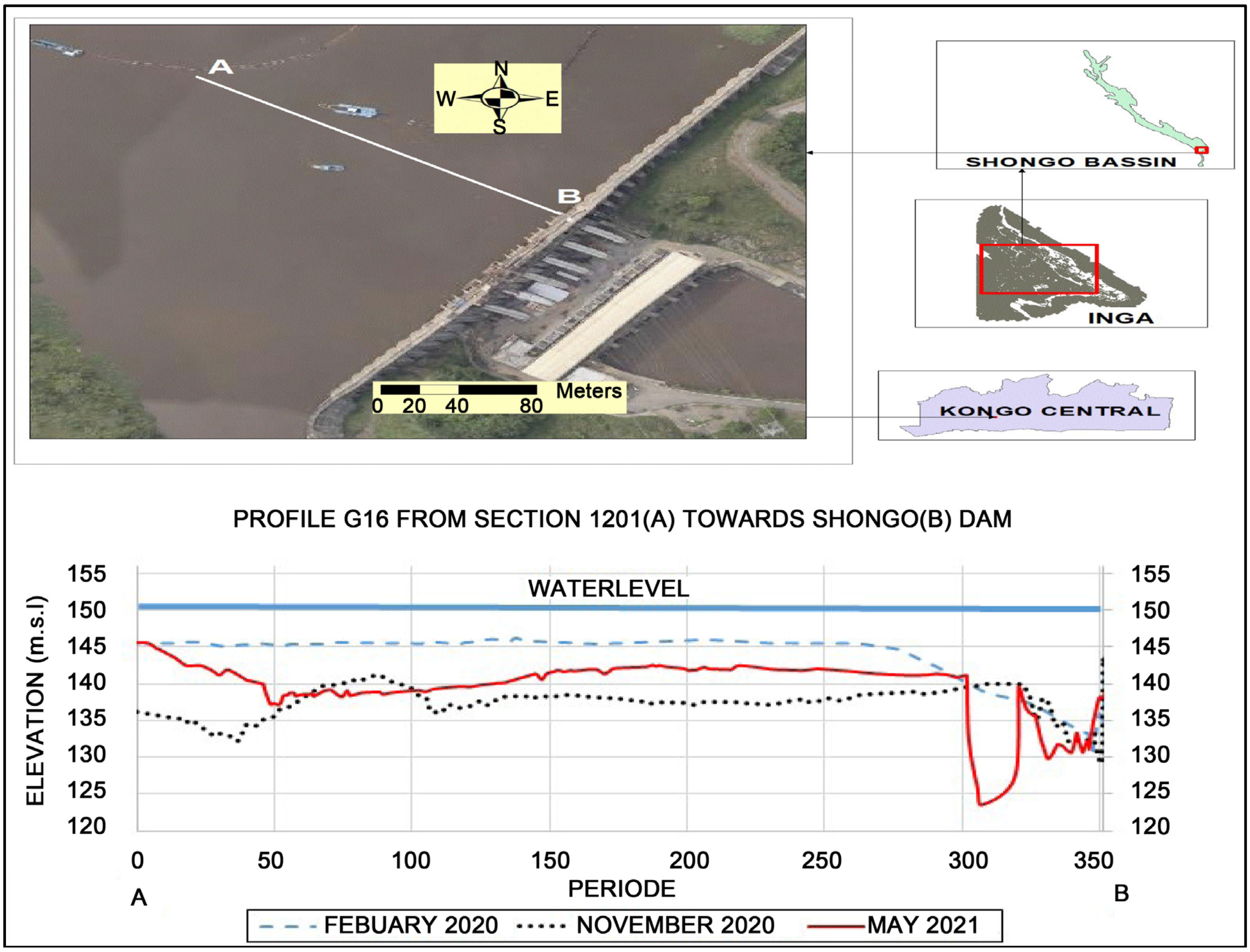


**Figure 16.** Silting profile in the Shongo basin of the alternator turbine group number 6 (G16) Inga Power Plant in February, November 2020 and May 2021 from point A (Upstream of the dam) to point B (Dam).

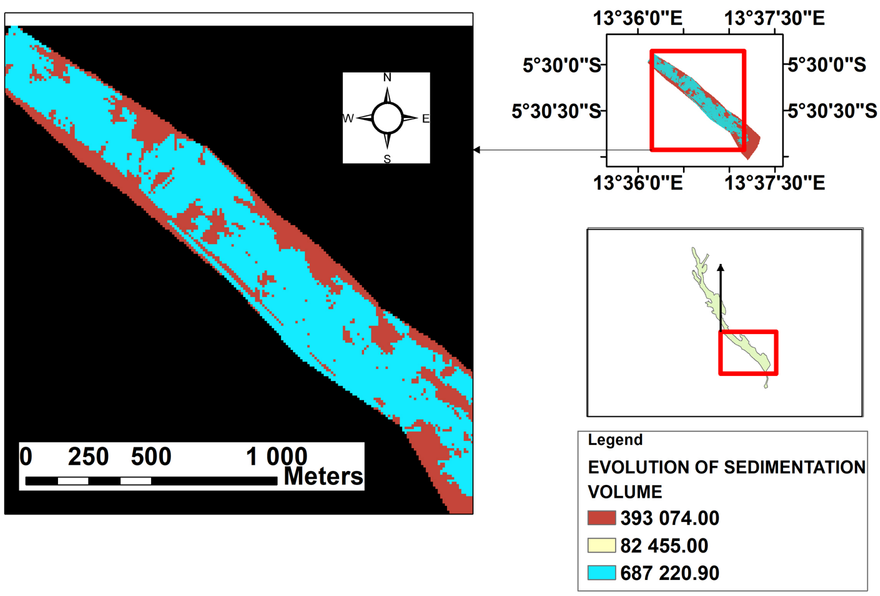


**Figure 17.** Dredge locations in the Shongo Basin and the amount of sediment deposited in the Shongo Basin between October 2020 and May 2021 which was 393074.00 m$^3$.

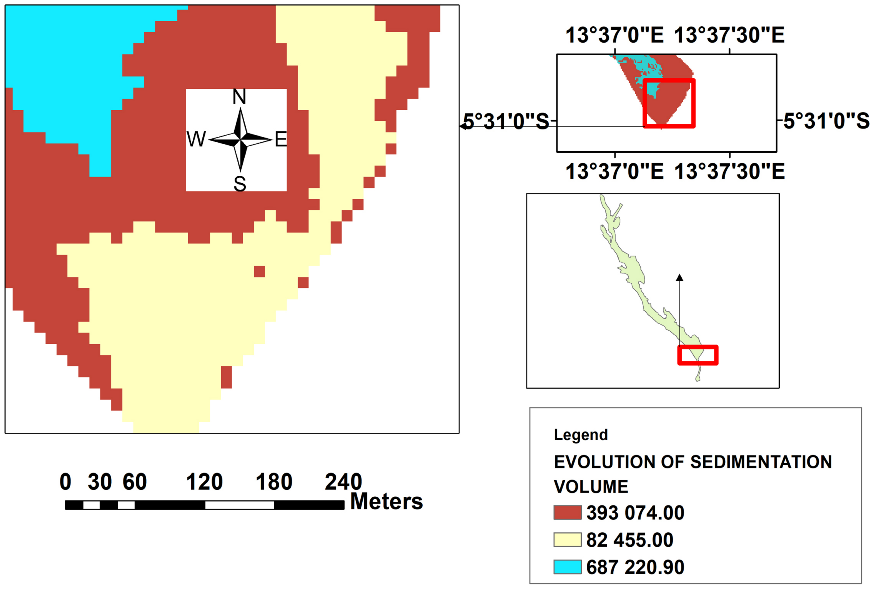


Figure 18. The amount of sediment eroded next to the Shongo Dam between October 2020 and May 2021 was 82,445 m$^3$.

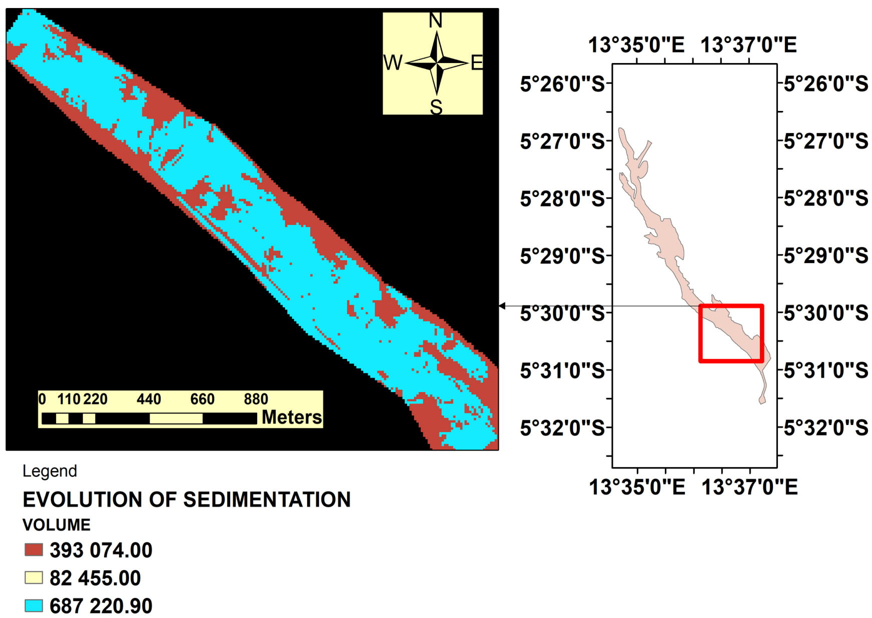


Figure 19. The amount of sediment eroded in the Shongo basin between October 2020 and May 2021 was 687220.90 m$^3$.

chemical processes along a river basin, consisting of three processes production, transport and deposition of sediments. These disintegrated rocks give rise to loose rocks. And these rocks in turn will be carried into the rivers by rain, wind, air, erosion, etc. The sediment is transported in three main modes in relation to the classes of sediment transported, i.e. scouring (sands, gravels and pebbles), graded suspension (fine sands) and suspension of clay and silt leaching (Camenen, 2017). In front of an artificial obstacle called a dam, the continuity of the water flow of a river willbe impeded (Lee, Lai, & Sumi, 2022). According to several authors (Schleiss et al., 2014; Randle, 2017), there will be an abrupt and rapid drop in velocities when river water enters a dam, and depending on the densities of the material, coarse material will be deposited rapidly, usually forming a delta.

Schleiss et al. (2016) states that the delta generally consists of three parts, from upstream to downstream: top-set: the coarse material, fore-set: the stratified zone and bottom-set (Morris & Fan, 1998; Sloff, 1997). The fine sediments consisting of silt, clay and silt will spread throughout the reservoir until they reach the intake structure. And if mitigation measures are not taken, the reservoir could fill up to 99% with sediment.

The results of this work indicate that over an eight month period from February 2020 to October 2020 (low water period), 574,972 $m^3$ of sediment was deposited in the Shongo basin. In contrast, the volume of sediment eroded is 584838.78 $m^3$ in the Shongo basin during the above period. The water intakes in the Congo River function as a pump and downstream we have the turbines of Inga 1 and 2. The sediment balance is relatively stable with a slight increase in erosion. According to Müller et al. (2014) the sediment balance only remains in equilibrium when there is a balance between the turbine and pump operations.

However, over a further eight months from October 2020 to May 2021 (a period with a lot of water in the canal), 393074.00 $m^3$ were deposited and 687220.90 $m^3$ eroded. This can be corroborated with (Kouassi et al., 2007) who state that out of 19450.44 $m^3$ of suspended matter that reaches the reservoir in the course of a year, 16278.12 $m^3$ are turbinated by the hydro-generators and only 3172.38 $m^3$/year are deposited in the reservoir of the Taabo dam, which does not have a bottom emptying structure like Inga. The installed capacity of the Taabo power plant is 210 MW.

For the specific case of the Shongo basin in the Inga intake canal, the evaluation of the sediment balance from February 2020 to May 2021 shows that there was less accumulation of sediment and m more eroded sediment turbinated by the Inga 1 and 2 hydroelectric power stations, thus a self-cleaning of the Shongo basin.

In the results of this work, the average daily turbine flows of the Inga 1 and 2 power plants are 2200 $m^3$/s from February 2020 to May 2021, equivalent to the operating rate of 10 operational generating units. This is in contrast to the flow rate used by (ENEL, 1984) of 410 $m^3$/s for about 3 generating units in operation. The silting up profiles of the Inga 1 generating units show that the water intake of the hydro-generators causes slumping and hydraulic dredging of the sediments deposited in the Shongo basin.

According to (Althaus et al., 2008), the release of sediment-laden water from power intakes and turbines is a promising possibility to manage the long-term problem of sedimentation processes in reservoirs. For suspended sediment to be carried into the intake, it must be suspended just in front of the intake.

This approach of increasing water flow velocities in the intake channel has also been singled out as a strategy to combat sedimentation by Schleiss et al. (2016).

Run-of-river plants with low water storage volumes often face high sediment loads starting very early in their operational lif—the case of Inga. Many plants experience high operating costs and accelerated rates of turbine abrasion. (Schleiss et al., 2008; Chhetry & Rana, 2015) have indicated that when sediments reach the hydromechanical part of the turbine generator sets, abrasion will accelerate and cause high maintenance costs. Abrasion will induce pressure losses with consequences on the efficiency of hydraulic machines.

At the level of the hydromechanical installations of Inga, corrosion followed by cavitation and abrasion only occupy the 3ème position as physico-chemical phenomena affecting the hydromechanical equipment in the last 4 decades of operation. This can be explained by the nature of the sediments and by the structure of the Midway water intakes, which essentially favour suspension because these water intakes on the Congo River are perched. According to Annandale et al. (2016) from a sustainability perspective, the release of fine sediments can significantly extend the operation of the project at the cost of a modest increase in turbine abrasion over the first decades of operation.

In the literature, (Remini, 1997, 2003; Schleiss et al., 2016) mention that mechanical dredging of sediments in water reservoirs is considered to mitigate sedimentation worldwide. Alam (2011a) believes that with the particle size composition of the sediments consisting mainly of fine sediments in the Inga intake canal, the effectiveness of desilting and maintenance of the Inga intake canal with a flushing structure is guaranteed. This is confirmed by the distribution of suspended sediments in a turbulent flow established by Rouse (1937) and verified in nature and on a model in a glass channel by several researchers (Sedimentation Engineering ASCE M&R No. 54).

Although the map elaborated by Wu et al. (2021) and Moukandi (2020) indicates that the Congo watershed has a lower solute dissolution index than the Amazon or Ganges-Brahmaputra watersheds, this means that the erosion rate is low compared to those of America or Asia. It confirms the previous studies on solid transport carried out in the Congo River referred to by Alam (2011a), in particular those carried out in Congo Laraque et al. (1993) and those carried out by various contractors in the framework of the maintenance and hydraulic management of the Inga intake canal.

However, the volumes quantified in terms of sediment deposition and erosion using the hydrographic method in the course of this work are significant at the scale of the Shongo basin compared to previous data (Kawende, 2020). Africa has tremendous water potential, yet it is vulnerable to current climate change. Better integrated natural resource management at the catchment level is needed (Fox et al., 2016; Schleiss et al., 2016; Pierrefeu et al., 2018; Lee, Lai, & Sumi, 2022). The rate of forest area loss in Africa has increased steadily since 1990, weakening the capacity of the continent's ecosystem to withstand the effects of climate change.

According to Gillet (2023) agriculture is the most obvious cause of deforestation in the Congo Basin. Combating deforestation phenomena and promoting reforestation. Esseqqat (2011) estimates the demand for domestic biomass energy in the DRC at 45 million cubic metres of wood per year and is responsible for the destruction of 400,000 hectares of forest each year. Governments in the sub-region should facilitate access to clean energy sources for the population in order to significantly reduce dependence on the use of charcoal (Imani & Moore, 2021). In the immediate term, encourage the population to use improved stoves and briquettes, and raise awareness and educate the population on sustainable development and the conservation of natural resources. Better management of housing estates and urbanisation in accordance with environmental standards, the list is not exhaustive.

An extensive literature is available on integrated reservoir resource management including surveyed articles (Yang et al., 2006; Mammou & Louati, 2007; Hu et al., 2009; Althaus et al., 2015; Schleiss et al., 2016; Fox et al., 2016). And theses (Adam, 2013) point out that the fight against reservoir sedimentation is carried out jointly in the catchment area, in the reservoir and at the level of the hydraulic structures.

## 6. Conclusion

At the end of this work, we can affirm that between the concentration of suspended solids and the running index of the alternator turbine groups combined with the dredging works of the Shongo basin, the sedimentation process is influenced more by the combination of the running index and the ongoing dredging works. This combined action is crucial to ensure hydroelectric production at the two largest hydroelectric power plants in the DR Congo during low water period.

The Inga 1 and 2 dams do not have flushing structures and the construction of these structures in the Shongo basin remains relevant in order to relieve the hydromechanical organs of the power plants in the long and medium term.

The sizing of the hydraulic structures and hydromechanical components of the future Grand Inga project, which will have turbine-generator units three to four times higher than the nominal power of Inga 2 and more than twelve times those of Inga 1, should take into account feedback from the current management of sedimentation in the Shongo basin.

At the regional level, there is a need for better integrated management of natural resources to be taken into account upstream in the countries of the Congo basin. The Inga intake canal is just one of many thermometers in the Congo basin. Increasingly larger amounts of sediment are being deposited in the Inga headrace or turbined by the Inga 1 and 2 hydroelectric plants, affecting the hydroelectric production of DR Congo. The question is open for further study.

## Acknowledgements

We would like to thank the Société Nationale d'Electricité (SNEL), the various companies and staff who carried out the bathymetry measurements in the hydraulic structure studied, which were used in this work.

## Conflicts of Interest

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

## References

Adam, N. (2013). *Gestion des sédimentsdans de grands reservoirs, Travail de fin d'étude réalisée en vue de l'obtention du grade de Master Ingénieur Civil des Constructions àfinalité approfondie, Université de Liège—Faculté des Sciences Appliquées année académique 2012-2013*.

Alam, S. (2011a). *Centrales d'Inga I et II, Problèmes d'ensablement du canal d'amenée et les solutions possibles Sultan Alam, Membre de Panel d'Expert, Inga*.

Alam, S. (2011b). *Projet présentation rapport Modèle hydraulique*.

Alam, S. (2011c). *Aménagements hydroélectriques d'Inga 1 et 2 1ière visite du Panel des experts Rapport préliminaire de visite*.

Althaus, J. M. I. J., De Cesare, G., & Schleiss, A. A. (2008). *Release of Sediment Laden Water through Power Intakes of Deep Reservoirs*. https://www.researchgate.net/publication/37463861_Release_of_sediment_laden_water_through_power_intakes_of_deep_reservoirs

Althaus, J. M. I. J., De Cesare, G., & Schleiss, A. J. (2015). Sediment Evacuation from Reservoirs through Intakes by Jet-Induced Flow. *Journal of Hydraulic Engineering, 141,* Article ID: 04014078. https://doi.org/10.1061/(ASCE)HY.1943-7900.0000970

Amasi, A., Wynants, M., Blake, W., & Mtei, K. (2021). Drivers, Impacts and Mitigation of Increased Sedimentation in the Hydropower Reservoirs of East Africa. *Land, 10,* 638. https://doi.org/10.3390/land10060638

Annandale, G. W., Morris, G. L., & Karki, P. (2016). *Extending the Life of Reservoirs: Sustainable Sediment Management for Dams and Run-of-River Hydropower*. International Bank for Reconstruction and Development/The World Bank. https://doi.org/10.1596/978-1-4648-0838-8

Artelia (2014). *Étude Hydraulique Analytique et sur modèle réduit hydraulique des moyens de désensablement du canal d'amenée de l'aménagement hydroélectrique d'Inga, Étude de phase 1, date: Août 2014, réf: 8 21 0111 R4*.

Barrage Inga (2019). https://fr.wikipedia.org/w/index.php?title=Barrage_Inga_I&oldid=163474288

Bombino, G., Barba, G., D'agostino, D., Denisi, P., Labate, A. et al. (2022). A Method for Estimating Stored Sediment Volumes by Check Dam Systems at the Watershed Level: Example of an Application in a Mediterranean Environment. *Journal of Soils and Sediments, 22,* 1329-1343. https://doi.org/10.1007/s11368-022-03163-6

Boualem, R., & Wassila, H. (2004). The Sedimentation in the Algerian's Dams. *La Houille Blanche, 90,* 60-64. https://doi.org/10.1051/lhb:200401008

Camenen, B. (2017). Effets des barrages sur la continuité sédimentaire. *La Houille Blanche, 103,* 19-24. https://doi.org/10.1051/lhb/2017052

Chhetry, B., & Rana, K. (2015). Effect of Sand Erosion on Turbine Components: Case Study of Kali Gandaki "A" Hydroelectric Project (144 MW), Nepal. *Hydro Nepal:*

*Journal of Water, Energy and Environment, 17,* 24-33. https://doi.org/10.3126/hn.v17i0.13270

CRENK (1988). *Etudes hydrologique et sédimentologie des aménagements hydro-électriques d'Inga; rapport n°1: Résultats des travaux préliminaires.*

Dai, Z., Mei, X. F., Darby, S. E., Lou, Y. Y., & Li, W. H. (2018). Fluvial Sediment Transfer in the Changjiang (Yangtze) River-Estuary Depositional System. *Journal of Hydrology, 566,* 719-734. https://doi.org/10.1016/j.jhydrol.2018.09.019

Diaz, V., Mongill-Manso, J., & Navarro Hevia, J. (2014). Topographical Surveying for Improved Assessment of Sediment Retention in Check Dams Applied to a Mediterranean Badlands Restoration Site (Central Spain). *Journal of Soils and Sediments, 14,* 2045-2056. https://doi.org/10.1007/s11368-014-0958-5

ENEL (1984). *Aménagements hydroélectriques d'Inga I et II: Rapport technique sur l'ensablement des ouvrages.*

Esseqqat, H. (2011). *Les Energies Renouvelables en République Démocratique du Congo.* http://www.unep.org/drcongo/

Fichtner (2010). *Réalisation des Etudes Bathymétriques et Hydrauliques pour le Canal d'Amenée d'Inga, Rapport final. Projet de Développement des Marchés d'Electricité pour la Consommation Domestique et à l'Exportation "PMEDE" Avenant N° 2.*

Fichtner (2011). *Note technique sur l'évaluation des procédures de dragage et de purge par vanne de chasse pour la remise en état de fonctionnement du canal d'amenée d'Inga, lots 3 et 4, reprofilage et travaux de dragage au canal d'amenée d'Inga.*

Flügel, T. J., Eckardt, F. D., & Cotterill, F. P. D. (2015). The Present Day Drainage Patterns of the Congo River System and Their Neogene Evolution. In M. J. de Wit, F. Guillocheau, & M. C. J. de Wit (Eds.), *Geology and Resource Potential of the Congo Basin* (pp. 315-337). Springer. https://doi.org/10.1007/978-3-642-29482-2_15

Fox, G. A., Sheshukov, R., Cruse, R. L., Kolar, L., Guertault, K. R., Gesch, R., & Dutnell (2016). Reservoir Sedimentation and Upstream Sediment Sources: Perspectives and Future Research Needs on Streambank and Gully Erosion. *Environmental Management, 57,* 945-955. https://doi.org/10.1007/s00267-016-0671-9

Francou, J. (1977). L'aménagement hydroélectrique d'Inga sur le Zaïre. *La Houille Blanche, 63,* 121-132. https://doi.org/10.1051/lhb/1977004

Gillet, P. (2023). Quelles sont les causes de la déforestation dans le bassin du Congo? Synthèse bibliographique et études de cas. *Biotechnologie, Agronomie, Société et Environnement, 20,* 183-194. http://publications.cirad.fr/une_notice.php?dk=580630

Gnassou, L. (2019). Addressing Renewable Energy Conundrum in the DR Congo: Focus on Grand Inga Hydropower Dam Project. *Energy Strategy Reviews, 26,* Article ID: 100400. https://doi.org/10.1016/j.esr.2019.100400

Heng, M. B. (2013). *La sédimentation dans les lacs de barrage à java, Indonésie processus, rythmes et impacts* (p. 301). Thèse Présentée pour obtenir le grade de Docteur de l'Université Paris 1 Panthéon-Sorbonne, LGP, UMR 8591 CNRS.

Hu, B. Q., Yang, Z. S., Wang, H. J., Sun, X. X., Bi, N. S., & Li, G. G. (2009). Sedimentation in the Three Gorges Dam and the Future Trend of Changjiang (Yangtze River) Sediment Flux to the Sea. *Hydrology and Earth System Sciences, 13,* 2253-2264. https://doi.org/10.5194/hess-13-2253-2009

ICM (1990). *Complexe hydroélectrique d'Inga, Ensablement du canal d'amenée des centrales d'Inga1 et 2.*

Ilçi, V., Ozulu, I. M., Alkan, R. M., & Uysal, M. (2017). *Determination of Reservoir Sedimentation with Bathymetric Survey. A Case Study of Obruk Dam Lake.*

Imani, G., & Moore-Delate, E. (2021). *Rapport d'étude de la consommation de bois-énergie et des équipements de cuisson de la ville de Kisangani*. Center for International Forestry Research (CIFOR). https://www.cifor.org/knowledge/publication/8063

Iradukunda, P., & Bwambale, E. (2021). Reservoir Sedimentation and Its Effect on Storage Capacity—A Case Study of Murera Reservoir, Kenya. *Cogent Engineering, 8,* Article ID: 1917329. https://doi.org/10.1080/23311916.2021.1917329

Justrich, S., Hunziger, L., & Wildi, W. (2006). Bilan sédimentaire et géochimique d'un barrage sans vidange. *Archives des Sciences, 59,* 141-150.

Kassoul, M., Abdelgader, A., & Belorgey, M. (1997). Caractérisation de la sédimentation des barrages en Algérie. *Revue des sciences de l'eau, 10,* 339-358. https://doi.org/10.7202/705283ar

Kawende (2020). *Rapport bathymétrique du canal d'amenée d'Inga/SNEL/DPO*.

Kouassi, K. L., Wognin, A. V. I., Gnagne, T. et al. (2007). Hydrologie et Évolution Spatio-Temporelle des Charges Solides en Suspension dans le lac du Barrage Hydroélectrique de Taabo (Côte D'Ivoire). *European Journal of Scientific Research, 18,* 464-478. http://www.eurojournals.com/ejsr.htm

Krogman, R. M., & Le Miranda (2016). Evaluation des réservoirs américains par rapport à l'état de l'habitat du poisson. *Gestion des lacs et reservoirs, 32,* 51-60. https://www1.usgs.gov/coopunits/publication/107666647040/None/Mississippi

Laraque, A., Bricquet, J. P., Olivry, J. C., & Berthelot, M. (1993). *Transports solides et dissous du fleuve Congo (bilan de six années d'observations), Grands Bassins Fluviaux, Paris, 22-24 novembre 1993*.

Lee, F.-Z., Lai, J.-S., & Sumi, T. (2022). Reservoir Sediment Management and Downstream River Impacts for Sustainable Water Resources—Case Study of Shihmen Reservoir. *Water, 14,* Article No. 479. https://doi.org/10.3390/w14030479

Mammou, A. B., & Louati, M. H. (2007). Évolution temporelle de l'envasement des retenues de barrages de Tunisie. *Revue des sciences de l'eau, 20,* 201-210. https://doi.org/10.7202/015813ar

Mekerta, B. (1995). *Étude des propriétés géomécaniques des sédiments d'envasement de la retenue du barrage de Génissiat. Autre*. Institut National Polytechnique de Lorraine. https://hal.univ-lorraine.fr/tel-01776462

Mekonnen, Y. A., Mengistu, T. D., Asitatikie, A. N., & Kumilachew, Y. W. (2022). Evaluation of Reservoir Sedimentation Using Bathymetry Survey: A Case Study on Adebra Night Storage Reservoir, Ethiopia. *Applied Water Science, 12,* Article No. 269. https://doi.org/10.1007/s13201-022-01787-0

Morris, G., & Fan, C. (1998). *Reservoir Sedimentation Handbook*. https://www.studmed.ru/view/morris-amp-fan-reservoir-sedimentation-handbook_5669f2438ec.html

Moukandi, N. G. D., Orange, D., Padou, S. M. B., & Laraque, P. D. A. (2020). Temporal Variability of Sediments, Dissolved Solids and Dissolved Organic Matter Fluxes in the Congo River at Brazzaville/Kinshasa. *Geosciences (Switzerland), 10,* 341. https://doi.org/10.3390/geosciences10090341

Müller, M., De Cesare, G., & Schleiss, A. (2014). Continuous Long-Term Observation of Suspended Sediment Transport between Two Pumped-Storage Reservoirs. Journal of Hydraulic Engineering, 140, Article ID: 05014003. https://doi.org/10.1061/(ASCE)HY.1943-7900.0000866

Nzango, C. (2018). *Les barrages de l'Oubangui: De l'impact hydraulique actuel à la pros-pective environnementale* (p. 275). https://hal.science/tel-01994173

Palmieri, A., Shah, F., & Dinar, A. (2001). Economics of Reservoir Sedimentation and Sustainable Management of Dams. *Journal of Environmental Management, 61,* 149-163. https://doi.org/10.1006/jema.2000.0392

Patro, E. R., de Michele, C., Granata, G., & Biagini, C. (2022). Assessment of Current Reservoir Sedimentation Rate and Storage Capacity Loss: An Italian Overview. *Journal of Environmental Management, 320,* Article ID: 115826. https://doi.org/10.1016/j.jenvman.2022.115826

Pierrefeu, G., Lauters, F., De Vandière, B., & Camenen, B. (2018). Mesure des flux et dépôts sédimentaires pour la gestion des ouvrages hydroélectriques sur le bassin du Rhône. In *26ème congrès des Grands Barrages* (20 p.). CIGB. https://hal.archives-ouvertes.fr/hal-01930743

Ramos-Diez, R., Navarro-Hevia, J., Fernánde, R. S. M., Díaz-Gutiérrez, V., & Mongil-Manso, J. (2017). Evaluating Methods to Quantify Sediment Volumes Trapped behind Check Dams, Saldaña Badlands (Spain). *International Journal of Sediment Research, 32,* 1-11. https://doi.org/10.1016/j.ijsrc.2016.06.005

Randle, T. J. (2017). *Sediment Analysis Guidelines for Dam Removal*. U.S. Department of the Interior, Bureau of Reclamation for the Federal Advisory Committee on Water Information, Subcommittee on Sedimentation, Denver, CO.

Remini (1997). *Envasement des Retenues de barrages en Algérie. Mécanisme et moyen de lutte par la technique du Soutirage* (342 p.). Doctorat d'état, E.N.P, Mars.

Remini (2003). Les barrages du Maghreb face au phénomène de l'envasement. *Revue Vecteur Environnement (Canada), 36,* 27-30.

Ren, S., Zhang, B. W., Wang, W.-J., Yuan, Y., & Guo, C. (2021). Sedimentation and Its Response to Management Strategies of the Three Gorges Reservoir, Yangtze River, China. *Catena, 199,* Article ID: 105096. https://doi.org/10.1016/j.catena.2020.105096

Rouse, H. (1937). Modern Conceptions of the Mechanics of Turbulence. *Transactions of the American Society of Civil Engineers, 102,* 463-543. https://doi.org/10.1061/TACEAT.0004872

Schleiss, A. J., & De Cesare, G. (2010). Physical Model Experiments on Reservoir Sedimentation. In *Hydrolink 2010/4* (pp. 54-57). International Association for Hydro-Environment Engineering and Research (IAHR).

Schleiss, A. J., De Cesare, G., & Althaus, J. J. (2008). Reservoir Sedimentation and Sustainable Development. In *International Conference on Erosion, Transport and Deposition of Sediments*.

Schleiss, A. J., De Cesare, G., Franca, M. J., & Pfister, M. (2014). *Reservoir Sedimentation*. Taylor & Francis Group. https://doi.org/10.1201/b17397

Schleiss, A. J., Franca, M. J., Juez, C., & De Cesare, G. (2016). Reservoir Sedimentation. *Journal of Hydraulic Research, 54,* 595-614. https://doi.org/10.1080/00221686.2016.1225320

Shaikh (2021). Sedimentation Analysis of Dam Using GIS. *International Research Journal of Engineering and Technology, 8,* 2725-2729. https://www.irjet.net

Sloff, C. J. (1997). *Sedimentation in Reservoirs*. PhD Thesis, Delft University of Technology.

SNEL (2005). *Rapport de bathymétrie sommaire du canal d'amenée d'Inga SNEL/DPO*.

SNEL (2011). *Projection power point, développement du site hydroélectrique d'Inga et des interconnexions électriques associées, Prof Kitoko, Coordonateur de la Cellule de l'Etude d'Inga/SNEL, 2011*.

SNEL (2020). *Il était une fois… Inga, aperçu sur le plus grand potentiel hydroélectrique* *disponible en RDC pour la RDC, pour l'Afrique et pour le monde*.

Sumi, T. (2018). Reservoir Sedimentation and Sustainable Development. In *26th ICOLD Congress*. ResearchGate.

WCD (2000). *Dams and Development a New Framework for Decision-Making, the Report of the World Commission on Dams*. Earthscan Publications Ltd.

World Commission on Dams (2001). Dams and Development: A New Framework for Decision-Making. *Environmental Management and Health, 12,* 444-445. https://doi.org/10.1108/emh.2001.12.4.444.2

Wu, J., Xu, N., Wang, Y. et al. (2021). Global Syndromes Induced by Changes in Solutes of the World's Large Rivers. *Nature Communications, 12,* Article No. 5940. https://doi.org/10.1038/s41467-021-26231-w

Wu, Z., Zhao, D. N., Syvitski, J. P. M., Saito, Y., Zhou, J. Q. et al. (2020). Anthropogenic Impacts on the Decreasing Sediment Loads of Nine Major Rivers in China, 1954-2015. *Science of the Total Environment, 739,* Article ID: 139653. https://doi.org/10.1016/j.scitotenv.2020.139653

Yang, S. L., Zhang, J., & Xu, X. J. (2007). Influence of the Three Gorges Dam on Downstream Delivery of Sediment and Its Environmental Implications, Yangtze River. *Geophysical Research Letters, 34,* L10401. https://doi.org/10.1029/2007GL029472

Yang, Z. H., Wang, Y., Saito, J. D., Milliman, K. X. et al. (2006). Dam Impacts on the Changjiang (Yangtze) River Sediment Discharge to the Sea: The Past 55 Years and after the Three Gorges Dam. *Water Resources Research, 42,* W04407. https://doi.org/10.1029/2005WR003970