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Review Article

Use of Radioactive Tracers and Nucleonic Gauges to Solve Problems Related to Sediment Transport in Inga I and II Dams' Channels and the Origin of Stagnant Water in Some Dam's Plots Faced by the INGA Site

O Kawende Kalonda[1], R Nkulu Kashale[1], J Kapiamba WA Mbambabo[2], LP Kaja Mukinay[3] and D Kabeya Ngalamulume[3]*

[1]National Electricity Company (SNEL), B.P.500 Kinshasa/Gombe, Democratic Republic of Congo

[2]Ministry of Energy, Boulevard du 30 Juin no 5963 Kinshasa/Gombe, Democratic Republic of Congo

[3]Laboratory for Non-Destructive Control and Applications of Radioisotopes in Industry (General Atomic Energy Commission/Regional Center for Nuclear Studies of Kinshasa (CGEA/CREN-K), B.P.868 Kinshasa XI, Democratic Republic of Congo.

***Corresponding Author:** D Kabeya Ngalamulume, Laboratory for Non-Destructive Control and Applications of Radioisotopes in Industry (General Atomic Energy Commission/Regional Center for Nuclear Studies of Kinshasa (CGEA/CREN-K), B.P.868 Kinshasa XI, Democratic Republic of Congo.

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Abstract

The site of INGA offers the opportunity to construct a series of connected dams capable to produce 45.050 MW. To date, only two connected dams have been constructed namely Inga I and II. Inga III project is still in progress. This paper presents the challenge of sediment transport in channels of intakes water for turning turbines and stagnant water of unknown origin in some dam's plots faced by INGA site. The NDT on concrete, radiotracers and nucleonic gauges or X rays density gauges are among methods particularly used to solve some problems posed by the above challenge for the maintenance of the two connected dams. Specifically, the paper is reporting, by giving some collected data respectively produced by the DR Congo General Atomic Energy Commission through the CREN-K (Centre Régional d'Etudes Nucléaires de Kinshasa), Kinshasa University and the Congolese Company of Electricity (SNEL), the fruitful partnership between SNEL and CREN-K for the period going from 1986 up to 2022.

Keywords: Sediment Transport; Stagnant Water; Radiotracers; Nucleonic Gauges; Geological Structures

Introduction

The site of INGA located in the Democratic Republic of the Congo offers the opportunity of construction of a series of connected plants with the same dams capable to produce 45.065 MW. The water impoundment is located at 15 km as the crow files from the dam to its intake. Nowadays, the Renaissance dams of Ethiopia is the biggest African hydropower plants and dams with 6000MW [1]. In the world, the three Gorge dam in China produces 22 000 MW. The water line is of 667 km [2,3]. On the other hand, Congo River, with a min flow of 42.000 m^3/s is the deepest river in the world with 500 m at Inga. It is the second by his min flow after Amazon River: 100.000 m^3/s. Given the potentiality of the big Inga hydropower project, African Union (AU) places this project as a priority for energy supply to all African countries. To date, only two connected dams have been constructed namely Inga I and II. Inga III project, which is a part of the big Inga project is still in progress. In this paper, we are analyzing the challenge of sediment transport in channels of intakes water for turning turbines and stagnant water in some dam's plots faced by INGA site. The NDT on concrete [4], radiotracers and nucleonic gauges or X rays density gauges are among methods particularly used to solve some problems posed by the above challenge for the maintenance of the two connected dams. Moreover, the paper is reporting, by giving some collected data respectively produced by the DR Congo General Atomic Energy Commission through the CREN-K (Centre Régional d'Etudes Nucléaires de Kinshasa), Kinshasa University and the Congolese Company of Electricity (SNEL), the fruitful partnership between SNEL and CREN-K for the period going from 1986 up to 2022.

The site of Inga is located in the South-West of the Democratic Republic of the Congo, about 40 km from the city of Matadi in the province of Congo Central. The history of its mapping can be found in books by authors: P. Geulette [5], J.H Pirenne [6] and F. Campus [7]. The Inga hydroelectricity dams are approximately localised at 13°36'16" of longitude Est and 5° 29'40" of latitude south.

Figure 1: Figure 1a) and b) show two scales of the Inga site map.

The digging of the channel was made following a natural depression, a former secondary arm of the Congo River, whose slope are formed by a series of outcrops of amphibolites, gneiss, micaschiste, quartzite, granite laminate, interstratified rhyolite and "microdolérite" [8-13].

S. Geulette [5], J. H. Pirenne [6], F. Campus [7] assert that the project of development of the site of Inga began since the Belgian colonization of Congo and it consisted in the development of a large dam on a large valley called Bundi (figure 1) on the site of Inga that would produce about 4000 MW. Unfortunately in 1950 there was no demand to absorb this production. The idea of building the Inga I and II dams emerged in the small valley of NKOKOLO located in the same site than this of Bundi and was achieved after Congo's independence [14]. The project Inga I was inaugurated on 1972 and Inga II, on 1982.

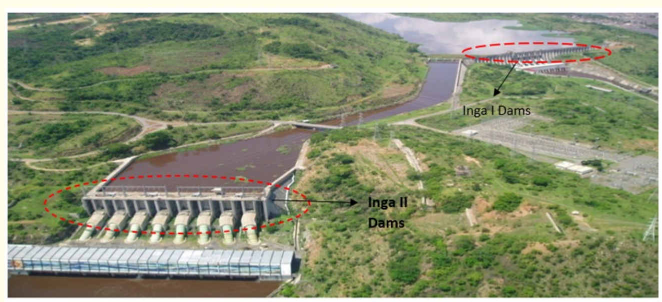

Figure 2: Figure 2 shows the Inga I and II dams.

The two plants present the following energetic characteristics:

- INGA I PLANT: 6 turbines of 58,5 MW fed each by 140 m^3/s. The total power is estimated to be 351 MW for 840 m3/s.

- INGA II PLANT: 8 turbines of 178MW fed each by 300 m^3/s with a total power estimated to be 1.424 MW for 2400 m^3/s

The average annual flow of Congo River is 42,600 m^3/s in the following interval [21,400 m^3/s, 83,400 m^3/s]. The Inga I and II power stations are fed by supply channels with two water intakes: a first outlet of 8,400 m of length and ± 160 m of width at the entrance and 40 m at the bridge, leading to the upstream channel (currently in service). This represents a total volume of Q = 2,200 m^3/s to feed six Inga I groups and five Inga II plant groups. The second intake of 1.500 m long, parallel to the first, opens into the upstream channel and was inaugurated in 2018 to supply the other three groups of the Inga II power plant.

Figure 3: Figure 3a) offers a view of the Congo River in the Inga site. Figure 3b) offers a view from the Congo river of two parallel water intakes feeding the Inga I and II power plants during construction and after the commissioning of the second intake of the Inga feeder channel in 2018, (Artélia 2018 Pictures).

The today's world wide yearly loss of storage capacity due to sedimentation is already higher than the increase of capacity by the construction of new reservoirs for irrigation, drinking water and hydropower. Thus the sustainable use of the reservoirs is not guaranteed in long term [15].

The Congo River carries approximately 30,000,000 tons of suspended solids and 100,000,000 tons of solution material each year to the Atlantic Ocean [16]. The proportion of the load suspended Reach 50mg per liter and contains only sand, clay and silt [17,18]. This important solid suspended load constitutes a permanent danger of sedimentation for ports works and hydroelectric power stations. The channel that derives a part of the Congo River toward the Inga I and II dams is concerned by this sedimentation phenomenon. Before reaching turbines this water is drained on 9 km on the following structures:

- The upstream canal,
- The Fwamalo pool,
- The Fwamalo canal,
- The Fwamalo pool.

Theoretically, one thought that the Fwamalo pool, in which speed of water from the upstream channel is reduced, might help to separate coarse particles in order to protect downstream works (Fwamalo Canal and Shongo pool) against sand deposits. In other words, the Shongo pool (downstream) where the speed of water does not exceed 0, 05 m/s would be a zone of clay sedimentation and silt that constitutes the slime [19]. Section II describes the use of nucleonic gauges JTD3 and Dens-X to asses sediment transport in channels of Inga I and II dams. Section III addresses the problem concerning the stagnant water on some plots in Inga dams I and II. A conclusion is provided in section IV.

Use of nucleonic gauges jtd3 and dens-x to assess sediment transport in channels of inga I and II dams

Here after is given results of the first turbidity measurements made in March 1988 with the help of the nucleonic gauge JTD3. It shows the evolution of sand and slime deposits in the Channel of the hydroelectric power stations of Inga since its beginning, that is, from 1972. A first bathymetric map has been set up and the passage between the sanded and slimmy zone précised.

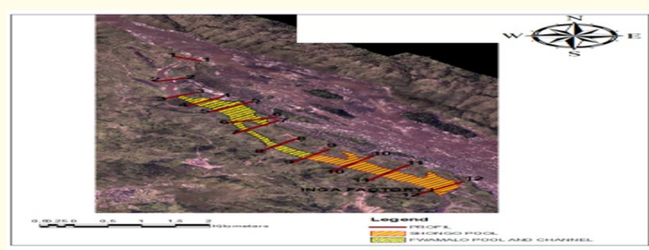

Figure 4: Figure 4 represents the respective localization of JTD3 monitoring's bathymetric profiles.

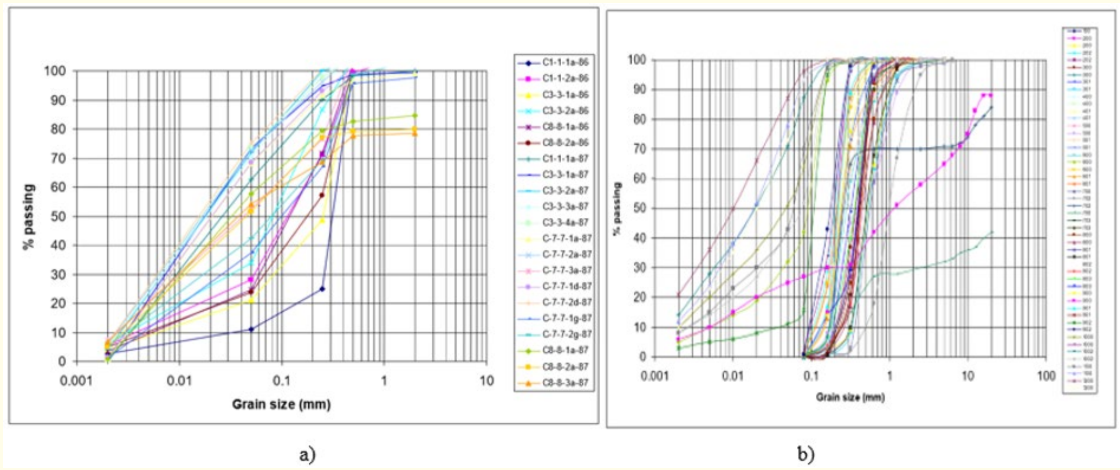

Figure 5: Figure 5a) show the particle size distribution for different cross-sections along the feeder channel in August 1986 and September 1987 (CRENK, 1988). Figure 5b) show the particle size distribution for different cross-sections along the feeder channel in 1990 (University of Kinshasa, 1990).

Sample period	Section	Sample	Depth	Velocity (m/s)		Material in suspension(mg/l)	
				Point	Average	Point	Average
August 1986	C1-1 (S1)	1S1a	2.5	1.77	1.8	221*	35
	C1-1 (S1)	2S1a	5.5	1.82		35	
	C3-3 (S2)	1S2a	4	1.33	1.26	38	51.5
	C3-3 (S2)	2S2a	6	1.18		65	
	C8-8 (S4)	3S4a	3.4	1.33		45	66
	C8-8 (S4)	4S4a	5	0.76	1.045	87	
September 1967	C1-1 (S1)	1S1a			1.553	39	39
	C3-3 (S2)	1S1a	0.9			20	29.5
		2S1a	4.1			30	
		3S2a	5.3		1.052	35	
		4S2a	5.8			33	
	C7-7 (S3)	1S3a	0.8			26	
		2S3a	6.2		1.048	30	
		3S3a	7.3			41	32.8
		1S3d	1.4			43	
		2S3d	6.4		0.711	24	
		1S3g	1.1			139	
		2S3g	5.2		0.732	101	
	C8-8 (S4)	1S4a	1			36	
		2S4a	5		0.913	40	
		3S4a	6.6			68	
		1S4d	4.8			47	47.4
		2S4d	6.1		0.832	52	
		1S4g	5.4		0.675	56	
		2S4g	7.1			33	
	C11-11 (5S)	1S5a	1		0.005	27	
		2S5a	8			41	
		3S5a	12			36	
		1S5d	1			45	34.3
		2S5d	8			37	
		1S5d	12			16	
		2S5dd	12			38	
	Water turbines	Inga I group I	-			47	
		Inga I group 4	-			30	38.5
		Inga II	-			8	8
		Head race can	-				

Table 1: The table 1 summarises results of sampling on august 1986 and September 1987 (CREN-K).

The above table is based on data obtained from samples taken on the Congo River and in the Inga channel CGEA/DRC-C.R.E.N.-K. (1988, 1986, and 1987) the following mean sediment concentrations are reported:

- During the July-August low water period: 35mg/l;
- At the rising waters from September to October: 60mg/l;
- During the flood from November to January: 90mg/l.

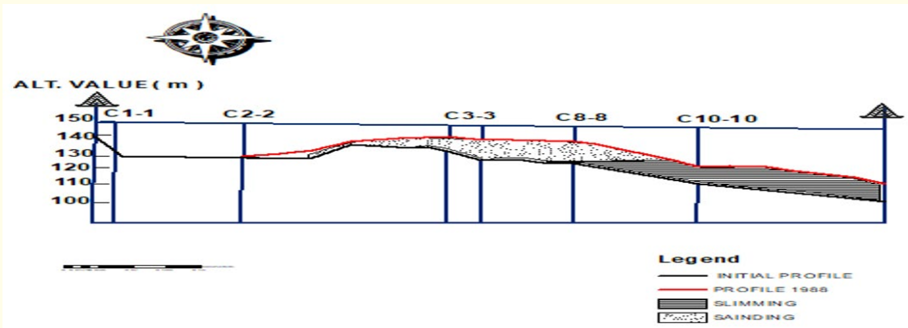

Figure 6: Figure 6 shows the longitudinal profile of the channel of the power stations of Inga achieved by the Cren-K team. (Figure 6 is drawn from ref. [18] numbered as Figure 1). Symbol ALT means altitude.

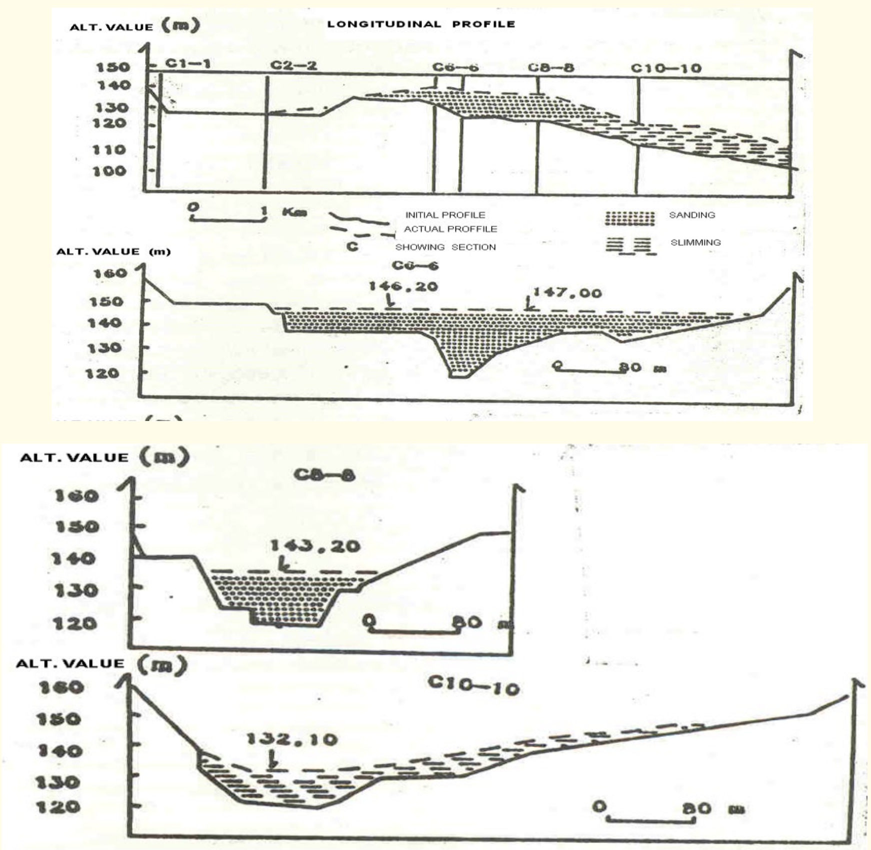

Figure 7: Figure 7 shows four successive maps that represent respectively the localization of JTD3 monitorings, bathymetric maps and types of deposits obtained by the Cren-K team. (Figures drawn from ref. [18]).

The above table is based on data obtained from samples taken on the Congo River and in the Inga channel CGEA/DRC-C.R.E.N.-K. (1988, 1986, and 1987) the following mean sediment concentrations are reported:

Figure 8: Figure 8 shows the on-site calibration of the gauge dens-X by IAEA and CREN-K experts

- During the July-August low water period: 35mg/l;
- At the rising waters from September to October: 60mg/l;
- During the flood from November to January: 90mg/l.

Apart from CREN-K nucleonic gauge JTD3, the Congolese national society of electricity (SNEL) intends to use the CREN-K x-rays micro-tube dens-X to asses sediment transport in the two channels of Inga I and Inga II. A comparison between JTD3 and dens-X can then be done.

Since 1990, the Congolese National Electricity Company (SNEL) has become aware of the situation on the supply channel and decided to acquire 3 dredges to evacuate the sediments deposited on the bed of the Inga supply channel by means of a discharge piping attached to these dredges and return to appropriate locations for storage of sand to meet a potential local demand.

Problem concerning stagnant water on some plots in inga dams I and II

In this section, we would like to present the problem of the origin of stagnant water, even after being evacuated, on plots of Inga I and II dams. If it is originated by the upstream flux, that means the concrete structure of the two dams has lost its mechanical properties. If it is originated from a resurgence, the normal hydrostatic pressure must have as result to diminish the dams weight. In both cases, there is a problem to be solved. For that, we propose to use classical and radioactive tracers.

Specifically, since about 2010, maintenance engineers of Inga I and II dams noticed stagnant water at a fixed height h (given in figure 9) on the dams plots. The phenomenon was recurrent after many evacuations of those masses of water. The question of their origin arises then.

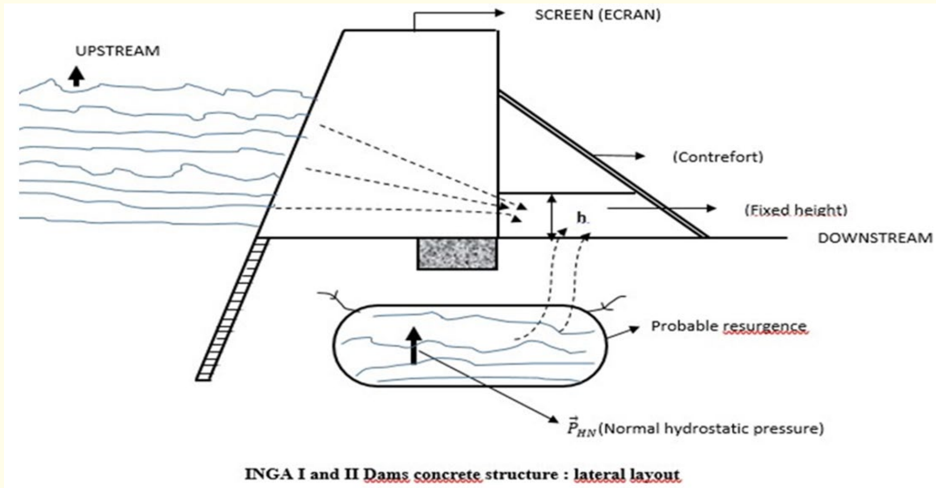

Figure 9: Figure 9 shows the lateral layout of Inga I and II structural problems.

Structural problems

If the stagnant water is originated by the upstream flux, that means the concrete structure of the two dams are seeping and then has lost its mechanical and physical properties. If it is originated from a resurgence, the normal hydrostatic pressure must have as result to diminish the dam weight. In both cases, there is a problem to be solved.

Figure 10: Figure 10 shows views of 4 plots of Shongo dam with stagnant water on the plot foot.

As the stagnant water reaches a fixed height, the upstream flux has less probability to be its cause. A continue seepage does not generally correspond to a fixed height. However to be sure, investigation must be done. To conduct investigations, geological investigations achieved in 2006 by Giancarlo in 2006 must be taken into account. Indeed, he reported that from the hydrogeological point of view, in the rock mass in question, the underground circulation of seeping water in the foundations of the structures is quite facilitated by the presence of joints and shear zones systems that strongly affect the original natural water tightness (or low permeability) that, in general, is peculiar to a very compact rock body characterized by a compact and tight rhyolites-schists metamorphic "package". Furthermore, if the geological sections along the Dam and Power Plant axis, both oriented N70°E (W20°S), are compared with the attitude (strike and dip) of the rock mass that characterized the rest of the project area (inclination of 50° along the dip toward SW), it results evident that the Dam and Power Plant axis are almost perpendicular to the schistosity planes [20].

However, to explain stagnant water in plots, the Stucky Design Office rejected the hypothesis of the important circulation of water through the entire Inga 1 and 2 dams foundation, which explains not only the presence of stagnant water at the foot of dams but also disorders noted on these structures after conducting detailed geological investigations on site from 2016 to 2017 [21].

Foreseen solutions

Water leakage at the dams is a very complex problem, especially since it generates considerable losses and threatens the stability of these structures. The study of this kind of problems is very important. To find adequate solutions, it is necessary to determine the pathways of these water leaks and defective locations. Tracer method is indicated as the case in the Algerian dams [22].

We propose for the above problem the use of classical tracers in the upstream flux side and radioactive tracers to be chosen according to the time of the recharge of water stagnant after evacuation, for the research of possible resurgence. For this case we can analyze also environmental isotopes (H, O, and C).

Conclusion

The first bathymetry carried out by the DR Congo Atomic Energy Commission through CRENK in the Inga channel in 1988 using the JDT3 gauge constitutes a basic matrix that has made it possible not only to locate the roofs of the sediments on the channel, but also to provide qualitative information on the sediments deposited therein.

This precision allowed a good deployment and orientation of the dredging groups during the works with an optimal yield because a dredge with cutter is appropriate for the argillaceous and silty sediments by against that with Jet is more effective than for the fine sand.

The upcoming use on the Inga supply channel of the Dens-X gauge, which gives vertical profiles with good precision, will contribute to a better management of the sedimentation problem in the Inga supply channel and see even in the restraint of the future great the big Inga project. Moreover, the use of radioactive tracers to determine the origin of the stagnant water in some dams plots render strengthen the partnership between the Congolese Company of Electricity (SNEL) and the Congolese Atomic Energy Commission. Note that all internal reports of references [8,9,13,14,16,17,19-21] are available in SNEL archives.

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