International Journal of Research and Review
Vol. 11; Issue: 1; January 2024
Website: www.ijrrjournal.com
Research Paper
E-ISSN: 2349-9788; P-ISSN: 2454-2237

Assessment of the Hydroenergy Potential of the Gueeni Village Waterfall on the Kokoulo River in Pita, Guinea

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DOI: https://doi.org/10.52403/ijrr.20240117

ABSTRACT

Background and Aim : In Guinea, the supply of electrical energy still remains a major challenge, especially in rural areas. However, Guinea's hydroelectric energy potential is enormous, more than 6000 MW, with a very dense hydrographic network of 1165 rivers, which finds its origin mainly in the Fouta-Djallon. To date, only 5% of this potential has been developed and only benefits nearly 10% of the Guinean population. This study is part of this aspect, for the improvement of electricity supply in isolated areas of the country. Its objective is to evaluate the hydroenergetic potential of the waterfall in the Gueeni village on the Kokoulo river in Pita.
Method : This study is based on field measurements, the use of physical formulas and sizing software to determine the energy characteristics of the site.
Results: The main results obtained are: equipment flow (9.781m3/s), gross head (31 m), net head (28.264 mm), hydraulic power (3000 kW) and power net of falling water (2700 kW).
Conclusion: The results obtained represent important basic data for the construction of the small power plant on the Gueeni site.

Keywords: Hydroenergy potential, waterfall, Gueeni village, Electric power

INTRODUCTION

Hydroelectricity is one of the oldest techniques for producing electricity. It is a reliable and profitable technology in the long term. Hydroelectric energy exploits the potential energy of water flows (rivers, rivers, waterfalls, sea currents, etc.). The kinetic energy of the water current is transformed into mechanical energy by a turbine, then into electrical energy by an alternator [1].

Hydroelectric power plants are classified according to several hydro-energetic parameters (installed power, head of head and filling time of the reservoir). According to the International Union of Electric Power Producers and Distributors, hydroelectric plants are classified according to installed power and head [2].

Depending on the power, they are classified as follows: Pico central from 1 kW to 100 kW; Micropower plant from 1 MW to 10 MW; Mini-power plant from 10 MW to 100 MW; Medium power plant from 100 MW to 1000 MW and Large power plant from 1000 MW and more. Depending on the head (H), there are three types of hydroelectric development, namely: high head ($H > 200$ m); medium fall ($30 \text{ m} < H < 200$ m); low head ($H < 30$ m) [3].

There are two important types of work for the construction of a hydroelectric dam: civil engineering works, electrical and hydraulic equipment [4].

In the Republic of Guinea, the electricity system is essentially based on hydroelectric energy, which represents 58% of the total

installed power, and on thermal energy. Based on the standard needs of rural households and socio-collective facilities per village, the annual energy needs of rural areas of Guinea are estimated in the year 2025 at: 65000 toe/year of electrical energy; 98900 toe/year of cooking and heating energy and a total of 163900 toe/year [1].
This study is part of this perspective, the development of developable waterfalls in Guinea with a view to improving the energy shortage in rural areas. Its general objective is to evaluate the hydroenergetic potential of the waterfall at the Gueeni site.

MATERIALS AND METHODS

Presentation of the study area

Located in the central part of Fouta Djallon, the prefecture of Pita has an area of 2087 km^2 for a population of more than 300000 inhabitants, 92% of whom are in rural areas, 85% engaged in agriculture and 55.7% women. The prefecture is subdivided into 11 Rural Communities. It is between 11°03′32″ North latitude, 12°23′58″ West longitude.
Of a tropical type, particularly mild at altitudes and hot in the lowlands, the climate is characterized by nocturnal cooling in all seasons, the rigor of the harmattan in December. With the alternation of two seasons (dry and rainy) of relatively equal duration. The average (minimum and maximum) annual temperatures are 14.2°C and 29.5°C respectively. The average annual precipitation is 1771.2 mm. The relief of the prefecture consists of high plateaus whose altitude varies between 900 and 1264 m. The wooded and wooded savannah is the essential characteristic of its vegetation [5].
The main economic activities of the prefecture are agriculture, livestock, trade and crafts. Pita Prefecture is home to the Kinkon hydroelectric dam, built by the Chinese from 1963 to 1966 on the Kokoulo River as a seasonally regulated reservoir water diversion plant [6]. The waterfall on the Kokoulo River on which this study relates, is located 4 km from the village of Gueeni and 15 km from the prefecture of Pita.

Work equipment

During this study, we used the following materials: the level meter, a graduated ruler, a GPS, a decameter, calculation charts and rainfall data from the Pita weather station.

Method

As part of this report, we carried out a field visit on March 2, 2022. This period coincided with the low water period. Thus, during this investigation, we did:

- The topographical survey for the determination of the gross fall height;
- The choice of installation points for the structures (dam, penstock and technical room);
- Waterfall flow measurements;
- Measurements of the water flow velocity by the float method;
- Calculations of the hydro-energy parameters of the plant.

Equipment Flows

The equipment flow (Qeq) is the maximum flow likely to be turbined by the plant when all the turbines are operating together at full power. It is the difference between the average available flow (Qdi) and the reserved flow (Qré) (Emmanuel Ighodalo Okhueleigbe and Ofualagba Godswill, 2017). It is determined by formula 1.

$$Q_{éq} = Q_{di} - Q_{ré} \quad (1)$$

Average throughput available

The average flow available (Qdi) is a function of the wetted section (Sm) and the average velocity (Vm) of the watercourse. It is determined by formula 2. For its calculation, a margin of error of +20% is taken into account [7].

$$Q_{di} = S_m \times V_m \quad (2)$$

Reserved flow

The reserved flow of a river is the minimum flow maintained to safeguard its physical and chemical characteristics and the life of the species that live there to guarantee their migration. The reserved flow (Qré) is the product between the reserved rate (tr = 10%) and the available flow. It is determined by formula 3.

$$Q_{re} = t_r \times Q_{di} \qquad (3)$$

With :
Q_{eq}: equipment flow in (m^3/s); Q_{di}: average flow available in (m3/s); Q_{re}: reserved flow in (m3/s); Sm = lm × Pm: Wetted section in (m^2);
Vm = L_m/t_m: Average speed in (m^2/s); l_m = 30 m: average width of the watercourse; P_m = 1.1 m: average depth of the watercourse; L_m = 7m: average travel distance of the float;
t_m = 21seconds: Average time taken by the float;
tr = 10%: reserved water rate.
Thus, the various calculations give:
S_m = 30 ×1.1 = 33 m^2; V_m = 7/21 = 0.33 m/s;
Q_{di} = 33×0.33 = 10.89 m_3/s.
Taking into account the margin of error (+20%) and the reserved rate (10%) we have:
Q_{di} = (10.89 + 0.2)×0.1 = 1.109 m^3/s;
Q_{re} = 0.1×11.09 = 1.109 m^3/s.
Hence the plant equipment flow rate is:
Q_{eq} = 10.89 - 1.109 = 9.781 m^3/s.

Gross drop height

There are several techniques for measuring gross head (H_b), namely: pressure gauge, barometer/altimeter, clinometer, GPS and lead string techniques. As part of this study, given the relief of the site, we used the GPS method. It consists of determining the altitude upstream of the waterfall (water intake), and the altitude downstream (technical room) then making the difference between these two altitudes upstream and downstream. It is determined by relation 4.

$$H_b = H_{am} - H_{av} \qquad (4)$$

With :
H_b: Gross drop height in (m); H_{am} = 465 m: altitude upstream; H_{av} = 434 m: altitude downstream. Hence the gross drop height is:
H_b = 465 – 434 = 31 m.

Civil engineering works

The main civil engineering works of the plant are: the water intake, the entrance gate and the intake channel [8].

Hydrant

The water intake has a lateral and rectangular shape. The height of this water intake (hpr) is calculated by formula 5.

$$h_{pr} = \sqrt{S_m/2} \qquad (5)$$

With : $S_m = \frac{Q_e}{V_{ml}}$, $V_{ml} \leq 0.75$m/s: maximum speed limited at the water intake; Sm: wetted section at the water intake in (m^2). The length (L_{pr}) is equal to twice the height of the water intake ($L_{pr} = 2 \times h_{pr}$). We thus have:

$$S_m = \frac{9.781}{0{,}75} = 13\ m^2$$

$$h_{pr} = \sqrt{13/2} = 2.55 \text{ m}$$

$$L_{pr} = \sqrt{13/2} = 2.55 \text{ m}$$

L_{pri} = 2 × 2,55= 5.1 m

Surface of entrance gates

Grids are tools made from parallel metal bars. They are placed at the level of the water intake upstream in order to prevent the penetration of solid particles and debris entering the development. Thus, the grids protect the turbines. They can be in several other places at the level of the layout, thus preventing debris from passing through. Their surface (Sgr) is calculated by relationship 6.

$$S_{gr} = \frac{1}{F_b} \times \frac{a+d}{d} \times \frac{Q_{éq}}{V_0} \times \frac{1}{\sin\delta} \qquad (6)$$

Where: F_b = 1: form factor of the bars for steel; a = 12mm: aperture; d = 70mm: thickness of the bars; V_0 = 0.75m/s: speed of water flow; δ = 60°: slope relative to the horizontal.
So :

$$S_{gr} = 1 \times \left(\frac{12+70}{70}\right) \times \frac{9.781}{0{,}75} \times \frac{1}{0{,}86} = 17.76\ m^2$$

Geometric and hydraulic parameters of the headrace

The geometrical and hydraulic parameters of the headrace are: the fruit of the bank, the slope of the bank, the draft, the critical depth, the width of the invert, the height of freeboard, the height of the channel, the wetted section , mirror width, hydraulic depth, wetted perimeter, hydraulic radius, hydraulic diameter, channel flow velocity, center of gravity depth, pipe wall diameter and thickness pressure, the outside diameter of the pipe and the loading chamber. These geometric and hydraulic parameters are calculated as follows (Jahidul Islam Razan, 2012).

Bank slope
The bank slope is the inclination with respect to the vertical giving an angle to the slope (m), it is: m = cotg60° = 0.57.

Draught
Draft (y) is the depth of free surface flow. It is calculated by relation 7.

$$y = \left[\frac{2^{2/3} \times Q_{équi}}{\lambda \times k_s \times \sqrt{I}}\right]^{3/8} \quad (7)$$

With: $\lambda = 2\sqrt{1+m^2} - m$

Where: n = 0.009: Manning's coefficient; λ: Dimensionless quantity that depends on the slope of the banks; I = 0.001 to 0.002: Longitudinal slope; Ks = 111.11: Specific coefficient for smooth concrete.

So :

$$\lambda = 2\sqrt{1+\frac{1}{3}} - \frac{1}{\sqrt{3}} = 1{,}73$$

$$y = \left[\frac{2^{2/3} \times 9{,}781}{1{,}73 \times 111{,}11 \times \sqrt{0{,}002}}\right]^{3/8} = 1.25\ m$$

Critical depth (yc)
The critical depth (yc) of a channel is the low water depth. When the water level reaches this depth, mining becomes impossible. It is equal to two thirds of the draft (yc=2/3×y). Thus: yc=2/3×1.25 = 1m.

Invert width (b)
The width of the invert (b) represents the bottom of the channel. It is obtained as follows: b = y (λ - m). Thus: b = 1.25 × (1.73 - 0.57) = 1.45 m.

Height of revenge
The height of freeboard (Hrev) is the difference in altitude between the crest of the structure and the body of water. It is equal to 3/7 of the draft (3×y/7). Thus, we have: Hrev = (3×1.25/7) = 0.54 m.

The height of freeboard is characterized by: the raising of the water level during the passage of the maximum flood; the maximum height of the waves caused by the extreme wind considered; the breaking of the waves on the surface of the upstream face; the safety supplement (waves caused by landslides, glacier ruptures, earthquakes) [9].

Channel height (Hc)
The height of the channel (Hc) is the sum between the draft and the freeboard height. We have: $H_c = H_{rev} + y$. So : Hc = 0.54 +1.25 = 1.79.

Wetted section (Sm)
The wetted section of a channel is the portion of the channel section bounded by the walls of the channel and the free surface. It is expressed by relation 8.

$$S_m = \lambda \times y^2 \quad (8)$$

Thus, we have:

$$S_m = 1{,}73 \times (1{,}25)^2 = 2.7\ m^2$$

Mirror width (lm)
The mirror width in a free surface flow section is the contact length between water and air. It is calculated by relation 9.

$$l_m = b + 2 \times m \times y = 1{,}45 + 2 \times 0{,}57 \times 1.25 = 4.88\ m \quad (9)$$

Hydraulic depth
The hydraulic depth (ym) is the ratio between the flow area (Sm) and the width of the surface (lm) free of water. Let: ym = Sm/Im. Thus we have: ym = 2.7/4.88 =0.55 m

Wet perimeter
The wetted perimeter is the perimeter of the surface of the cross-section of a pipe through which a liquid flows, which is in contact with said liquid. It is determined by relation 10.

$$P_m = 2 \times y \times \sqrt{1+m^2} = 2 \times 1.25 \times \sqrt{1+(0{,}57)^2} = 2.88\ m \quad (10)$$

Hydraulic radius
The hydraulic radius is used in particular for free surface flows (in non-full pipes). It is the ratio between the wetted section and the

wetted perimeter (Muhammadu M. M. and Usman J., 2020). (R_h = Sm/Pm). We have: R_h = 2.7/2,88 = 0.94.

Hydraulic diameter

The hydraulic diameter (Dh) is determined by relation 11.

$$D_h = \frac{4 \times S_m}{P_m} = \frac{4 \times 2{,}7}{2.88} = 3.75 \text{ m} \qquad (11)$$

Flow velocity in the channel (Vc)

The channel flow velocity (Vc) is the speed of passage of a fluid along a pipeline. It is calculated by relation 12.

$$V_c = \frac{1}{n} \times \frac{y^{2/3} \times \sqrt{1}}{2^{2/3}} \qquad (12)$$

With: n = 0.009 the Manning coefficient. We thus have:

$$V_c = \frac{1}{0{,}009} \times \frac{(1.25)^{\frac{2}{3}} \times \sqrt{0.002}}{2^{\frac{2}{3}}} = 3.71 m/s$$

Center of Gravity Depth (YG)

The center of gravity called G is the point of application of the resultant of the forces of gravity or gravity. It can be calculated by the relation (13) through the diagram of figure 1.

$$Y_G = \frac{y}{6} \times \frac{(3b + 2 \times m \times y)}{(b + m \times y)} = 0.56 \text{ m} \qquad (13)$$

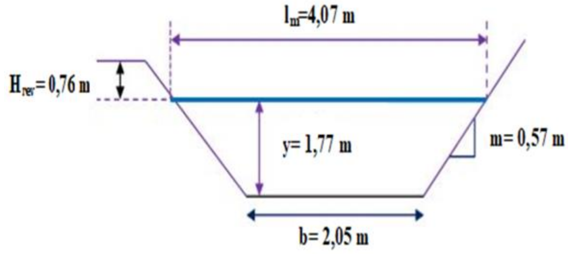

Figure 1. Schematic of channel cross-section

Penstock Diameter

It is determined by relation (14).

$$D = 2{,}83 \left(\frac{n^2 \times Q_{equi}^2 \times l_c}{H_b} \right)^{0{,}1875} \qquad (14)$$

Where: n- Manning coefficient (see appendix); LC- length of pipes (33m); Hb- Gross drop height (31m); Qequ- Equipment flow.

$$= 2{,}83 \left(\frac{(0.012)^2 \times (9.781)^2 \times 33}{31} \right)^{0.1875} = 1.28 \text{ m}$$

Wall thickness

$$e = \frac{P_h \times D}{2б_f \times K_f} + e_s \qquad (15)$$

Where: e - pipe wall thickness (m); P_h- hydrostatic pressure at sea level (N/m^2); $б_f$- admissible stress (140N/mm^2); K_f- for stabilized welds (0.9); e_s- thickness beg to take corrosion into account (0.001m).

$P_h = \rho \times g \times H_b + P_0$ = 1000 x 9,81 x31+1013= 0.31N/mm^2:

$e = \frac{0{,}31 \times 1{,}28}{2 \times 140 \times 0.9} + 0{,}001 = 0.00257$m = 2,57 mm

Outer pipe diameter

The external diameter of a pipe varies according to the thickness of the material that composes it. It is determined by relation (16).

Da = D+ e = 1.28 + 0.00257 = 1.3m (16)

Loading room

It is a small pond that supplies water to the penstock at all times. The pressure chamber must guarantee a satisfactory hydraulic transition between the headrace and the penstocks. It is used to create a "decompression" zone during a sudden closing of a valve in the plant. It is sized according to the diameter of the penstock.

The width is equal to 5 times the diameter of the penstock : l=5×D=5×1.28=6.4m

The length is equal to 8 times the diameter of the penstock : L=8×D = 8 × 1.28 = 10.24m

The height is equal to 3 times the diameter of the penstock : H= 3×D = 3 × 1.28 = 3.84m

Evaluation of pressure drops

Head losses or pressure losses represent the reduction in gross head as it flows through pipes. They are expressed in pascals or column meters of the liquid. These head losses depend on the flow velocity, the diameter, the length of the pipes and the Reynolds number [10].

Singular head losses

It is determined by relation (17).

$$\Delta H_s = K_s \frac{V_0^2}{2g} \quad (17)$$

With: K_s - coefficient which depends on the type of material; V_0- speed of water flow in the material; g - gravitational constant (9.81N/kg).

Linear pressure drops

It is determined by relation (18).

$$\Delta H_g = K_l \left(\frac{a}{d}\right)^{4/3} \times \left(\frac{V_0^2}{2g}\right) \times \sin\beta \quad (18)$$

Pressure losses induced in the grids

The pressure drop in the grilles is due to the friction of the air flow during its passage through the blades of the grilles. It is determined by relation (19).

$$\Delta H_g = K_l \left(\frac{a}{d}\right)^{4/3} \times \left(\frac{V_0^2}{2g}\right) \times \sin\beta \quad (19)$$

Where: K_r- kirchner's coefficient (0.2); a - thickness of the bars; d- spacing between bars; β - inclination of the grid with respect to the horizontal; V_0- speed at gate re-entry (0.75m/s).

$$\Delta H_g = 0{,}2\left(\frac{12}{70}\right)^{4/3} \times \left(\frac{0{,}75^2}{2 \times 9.81}\right) \times \sin 60° = 0{,}00046 \text{ mcl}$$

Head loss when the penstock retracts

$$\Delta h_c = k_c \times \frac{V_a^2}{2g} \quad (20)$$

With: V_a - flow velocity in the penstock (V_a=4 Q_{eq}/3.14xD2= 9.73m/s); k_C – head loss coefficient (0.04).

$$\Delta h_c = 0{,}04 \times \frac{(9{,}73)^2}{2 \times 9{,}81} = 0.193 \text{ mcl}$$

Pressure drop at the valves

$$\Delta h_v = k_v \times \frac{V_c^2}{2g} \quad (21)$$

With: k_v- pressure drop coefficient of the spherical valves (0.04); V_c - water velocity in the penstock; D - internal diameter of penstock (m).

So : Δh_v= 0.04 × $(9.73)^2$/(2×9.81) = 0.193 mcl

Pressure losses in the penstock

They are determined by relation (22).

$$\Delta h_c = 10{,}33 \times \frac{n^2 \times Q_{équi}^2 \times l_c}{D^{5{,}33}} \quad (22)$$

Where: Δh_l- linear pressure drop in the pipe (m); n- manning's coefficient; Q_{eq} - equipment flow (m^3/s); l_c- length of pipe (33m); D - pipe diameter (m).

$$\Delta h_v = 0{,}04 \times \frac{(9.73)^2}{2 \times 9.81} = 0{,}193 \text{ mcl}$$

Elbow head losses

At the level of the penstock, two (2) elbows are considered:

- *First elbow*

It is closer to the grid whose water flow velocity at the inlet is equal to that in the bend. It is determined by relation (23).

$$\Delta h_{cd1} = K_1 \frac{V_a^2}{2g} \quad (23)$$

K_1- pressure loss coefficient in the elbow (0.085).

$$\Delta h_{cd1} = 0{,}085 \times \frac{(9.73)^2}{2 \times 9{,}81} = 0{,}41 \text{ mcl}$$

- *Second elbow*

It is located at the outlet of the penstock to the turbine. It is determined by relation (24).

$$\Delta h_{cd2} = K_2 \frac{V_c^2}{2g} \quad (24)$$

With: K_2 - head loss coefficient in the elbow (0.14).

$$\Delta h_{cd2} = 0.14 \times \frac{(9.73)^2}{2 \times 9.81} = 0.68 \text{ mcl}$$

The total head losses are thus calculated using the formula (25).

$$\Sigma\Delta h = \Delta h_g + \Delta h_c + \Delta h_c + \Delta h_v + \Sigma\Delta h_{cd1} + \Sigma\Delta h_{cd2} \quad (25)$$

$$\Sigma\Delta h = 0{,}00046 + 0{,}193 + 1{,}26 + 0{,}193 + 0{,}41 + 0{,}68 = 2{,}736 \text{ mcl}$$

Net drop height

It is the difference between the gross drop height and the total sum of the head losses.

$$H_n = H_b - \Sigma\Delta h = 31 - 2.736 = 28.264 \text{ m} \quad (26)$$

Hydraulic power or raw power

Hydraulic power is the power supplied to the turbine by the water that feeds it.

$$P_h = \rho \times g \times Q_{eq} \times H_b \quad (27)$$

Where: P_h- hydraulic power in W; Q_{eq}- average flow in m^3/s; H_b- gross drop height in m; g - gravitational acceleration in N/kg.
So : P_h= 1000 × 9.81 × 9.781 × 31=3MW

Net power

It is calculated by relation (28).

$$P_{net} = \rho \times g \times Q_{equi} \times H_n \qquad (28)$$

$$P_{net} = 1000 \times 9.81 \times 9{,}781 \times 28{,}264 = 2.7 \text{ MW}$$

RESULTS AND DISCUSSION

The results obtained during this study are shown in Table 1.

Table 1. Hydroenergetic characteristics of the Gueeni site on the Kokoulo River in Pita

Designation	Symbol	Value	Unit
Equipment Flows	Q_{ep}	9.781	m^3/s
Average throughput available	Q_{di}	10.89	m^3/s
Reserved flow	Q_{re}	1.109	m^3/s
Gross fall height	H_b	31	m
Water intake height	h_{pr}	2.55	m
Maximum speed at water intake	V_{ml}	≤ 0.75m/s	m/s
Wet section at water intake	S_m	13	m^2
Surface of entrance gates	S_{gr}	17.76	m^2
Bank slope	m	0.57	-
Draught	y	1.25	m
Critical Depth	y_c	0.83	m^3/s
Invert width	b	1.45	m
Height of revenge	H_{rev}	0.54	m
Channel height	H_c	1.79	m
wWet section	S_m	2.7	m^2
Mirror width in flow section	L_m	4.88	m
Hydraulic depth	y_m	0.55	m
Wet perimeter	P_m	2.88	m
Hydraulic radius	R_h	0.94.	m
Hydraulic diameter	D_h	3.75	m
Flow velocity in the channel	V_c	3.71	m/s
Center of Gravity Depth	Y_G	0.56	m
Penstock Diameter	D_{CF}	1.22	m
Penstock Wall Thickness	e_{CF}	0.00257	m
External diameter of a penstock	Dex_{CF}	1.3	m
Weighting chamber width	l_{cmc}	6.4	m
Weight bearing chamber length	L_{cmc}	10,24	m
Weight chamber height	H_{cmc}	3,84	m
Linear pressure drops	Δh	2.736	mcl
Net fall height	H_n	28.264	m
Hydraulic power	P_h	3000	kW
Net power	P_n	2700	kW

The Gueeni waterfall on the Kokoulo River in Pita is one of the important sites of small hydroelectric power stations in Guinea. The main hydraulic parameters and the main hydroenergetic characteristics of the site are: equipment flow rates (9.781 m^3/s), gross head (31 m), net head (28.264 m), hydraulic power (3000 kW) and the net power (2700 kW). The hydroenergetic parameters determined are average values; they were evaluated during the dry season of the year (February, March and April 2022).

CONCLUSION

This study is a continuation of our research work in the field of valorization of Guinea's renewable energy resources. It made it possible to assess the hydroenergetic potential of the Gueeni waterfall on the Kokoulo river in Pita. Likewise, the electromechanical equipment of the power plant was sized.
The completion of this small hydroelectric power plant project would improve the supply of electrical energy in the country and especially in isolated rural areas, which will reduce the abusive use of firewood and charcoal.

Declaration by Authors

Acknowledgement: None
Source of Funding: None

Conflict of Interest: The authors declare no conflict of interest.

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How to cite this article: Ansoumane SAKOUVOGUI, Elhadj Ousmane CAMARA, Saidou BARRY, Mamby KEITA. Assessment of the Hydroenergy potential of the Gueeni Village Waterfall on the Kokoulo River in Pita, Guinea. *International Journal of Research and Review*. 2024; 11(1): 154-161. DOI: *https://doi.org/10.52403/ijrr.20240117*

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