FEASIBILITY STUDY REPORT FOR OFU HYDROPOWER PROJECT , KOGI STATE

PART – I: EXECUTIVE SUMMARY

Bureau of Public Private Partnerships, Kogi State Government requested UNIDO Regional Centre for Small Hydro Power in Africa, Abuja to assess the power potential on using the existing dams at Osara, Okura and Omi which were primarily built for irrigation and other industries and a project on Ofu river for hydro-power generation. The UNIDO team visited the state from 13th March to 16th March 2017 to do a pre-feasibility study. Since the potential in these sites is attractive, UNIDO decided to conduct a detailed study for these sites.

Ofu Dam Micro hydro project will bring sufficient electricity to uplift the economic activities of the region. Many villages near the proposed scheme will get connected to the power plant. The following villages will be connected: Ofokopi, Adikafane, Ugwolawo, Akpagidigbo and Odogbagada, All the communities have expressed their desire to have this project and their unconditional support to the implementation.

Figure 1 : Community members at Ofokopi

		UNIT/DETAIL
Project Name	Ofokopi Micro hydro Project	
Location (Village, district , region)	Ofokopi village in Ofu LGA and Idah, Kogi State, Nigeria	

Developer (Physical address and contact details including telephone contacts)	Farmers co-operatives (Unyogba, Achenyo and Ojokochobi)
Position/project layout including GPS coordinates in accordance to the datum and coordinate system : Dam Forebay Surge Tank Power house Switch Yard Interconnection arrangement /delivery point	 7°16'36.59"N, 6°58'38.93"E 7°16'26.32"N 6°58'35.41"E 7°16'22.31"N 6°58'29.15"E Power has to be evacuated to the villages of Ofokopi, Adikafane, Ugwolawo, Akpagidigbo and Odogbagada.
Purpose, objective and scope of the project	To build a micro hydro scheme to generate 300 kW to meet the requirement of the villages and to supply power to the thriving cashew nut industry..

Hydrological Features at the Diversion Weir site		
Catchment Area	790 km^2	
Mean Annual Flow	9.5m^3/s	
Normal Average Flow – Wet season	15.8m^3/s	
Normal Average Flow – Dry season	5.33 m^3/s	
Design Flow	6 m^3/s	
Flow (1,000y flood event)		
Flow (100y flood event)		
Present Use of Water		
Water used for irrigation	Less than 1 m^3/s	
Water used for drinking purposes	Less than 1 m^3/s	
Water used for other settlement/industry purposes (please specify activities)	None now. But once the power plant is implemented, cashew nut processing industries will grow.	m^3/s
Diversion Weir		
Weir Construction	Concrete	
Type	RCC	
Slope	1:2	m/m
Crest elevation	124	m
Crest length	25	m
Diversion facilities (please specify) Side intake		
Length	25	m
Diameter/cross-section	1 x 1	m
Diversion flow	6.5	m^3/s
Spill way		
Type		
Crest Elevation		m
Maximum flood level		m
Width		m
Discharge		m^3/s
Canal system		
Length	350	m
Discharge	6.5	m^3/s
Fore-bay/Surge tank		
Design water level	123	mAD
Static water level	123	mAD

Penstock		
Penstock construction	Mild steel	
Total length	225	m
Horizontal length		m
Diameter	2.0 (12mm wall thickness)	m
Power facilities		
Power House type		
Type of turbine	Francis, Horizontal axis	
Gross head surge bay-power house Design discharge	10 6	m m^3/s
Length of tailrace channel	3	m

Installed capacity	400	kW
Distribution / Transmission facilities		
Transformer type	A hermetically sealed step up transformer	
Transformer rating	600 kVA	
Transmission line type	HV, three phase	
Line voltage	33	kV
Line length	10	km
Line capacity Proposed conductor size	0.75 10	MVA mm^2
Proposed conductor material	ACSR	
Technical Loss factor along the line	8.1	Percentage
Power Production		
Total Efficient Capacity	400	kW
Average generation during wet season	400	kW
Average generation during dry season	300	kW
Mean Annual Power Production during Peak Periods	3.141	GWh
Mean Annual Power Production during Shoulder Periods		GWh
Mean Annual Power Production during off-peak Periods		GWh
Mean Annual Total Power Production	3.141	GWh
Capacity factor	60	%
Plant factor *(The ratio of the average power load of the plant to its rated capacity)*	90	%
Average Generation for own use	NA	MW
Annual Power Production for own use	NA	GWh
Economics and Financials		

Investment Costs based on detailed underlying assumptions		USD
Annual Operational costs based on detailed underlying assumptions		USD/year
Annual Revenue from Operation		USD/year
Net Present Value (NPV)		USD
Internal Rate of Return (IRR)		%
Pay-Back Period (PBP)		Years
Environmental and Social Indicators		
Distance to nearest residential zone	1000	m
Distance to nearest protected area	N.A	km (or “inside”)
Access roads through protected areas		km total
Labour requirement for construction		Average number
Labour camp accommodation needed		Number of persons
Personnel requirement for operations Environmental Flow		Number of persons m^3/s
Fish species diversity Land acquisition required		No. of fish species m^2
Required resettlement		Number of persons
Compensation for land access/use		Number of persons
Cultural heritage sites within project affected area		Number of sites

PART II- MAIN REPORT

1 INTRODUCTION

1.1 Background

With a population of over 190 million[1], Nigeria is the most populous country in Africa and the eighth most populous country in the world. According to the United Nations, one in six Africans is Nigerian. It is a regional power, listed among the "Next Eleven" economies, and a member of the Commonwealth of Nations.[i] But sadly, on the economic front, the country seems to be stagnant at the best. The main factor that hinders the development as perceived by many is the power sector. Nigeria is ranked 172 out of 187 countries by world Bank on the " ease of getting electricity"[2].

The Energy Commission of Nigeria (ECN) together with the International Atomic Energy Agency (IAEA) projected a demand of 15,730 MW for 2010 and 119,200 MW for 2030 under the reference scenario (7% yearly economic growth)[3]. Many studies indicate that the current gap between supply and demand is already very high (1:3) and that, it will become worse if the same reliance on fossil fuels is continued.

In order to bring a solution to these problems, the Federal Government of Nigeria (FGN), in its Power Sector Reform Roadmap (2013), set ambitious targets to increase installed hydro to 5,690 MW, thermal to over 20,000 MW and renewable 1000 MW capacities by 2020[4] . The targets also aim at diversifying Nigeria's energy mix to reduce its natural gas dependence.

Federal Government of Nigeria through the Federal Ministry of Power and Federal Ministry of Water Resources (FMWR) are undertaking studies of irrigation dams in the country to identify their potential for SHP integration and development.

Bureau of Public Private Partnerships, Kogi State Government requested UNIDO Regional Centre for Small Hydro Power in Africa, Abuja to assess the power potential on using the existing dams at Osara, Okura and Omi which were primarily built for irrigation and other industries and a project on Ofu river for hydro-power generation. The UNIDO team visited the state from 13th March to 16th March 2017 to do a pre-feasibility study. Since the potential in these sites is attractive, UNIDO decided to conduct a detailed study for these sites.

1.2 Project Objective

Ofu micro hydro power project proposes to use the Ofu river water, a perennial river in the state to generate electricity to meet the energy demands of the five rural communities in the region. Kogi state is, as the rest of the country, facing a severe shortage of power supply options and this project will take care of these few communities and thereby improving the local economy through small agricultural processing industries.

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[1] Based on the latest United Nations estimates. www.data.un.org/en/iso/ng.html

[2] www.doingbusiness.org/data/exploretopics/getting-electricity

[3] A. S. Sambo, 2008, Matching Electricity Supply with Demand in Nigeria, Fourth Quarter, International Association for Energy Economic, p. 33

[4] The Presidency of the Federal Republic of Nigeria, August 2013, Roadmap for Power Sector Reform, Revision1, p. 24-25

The proposed mini-grid project aims at providing reliable, clean and affordable electricity access to communities in Ofu Local Government Area of Kogi state. The overall objective of this project is to improve the quality of life of rural communities through provision of electricity services to households, enterprises and institutions. The project outcomes will include the following:

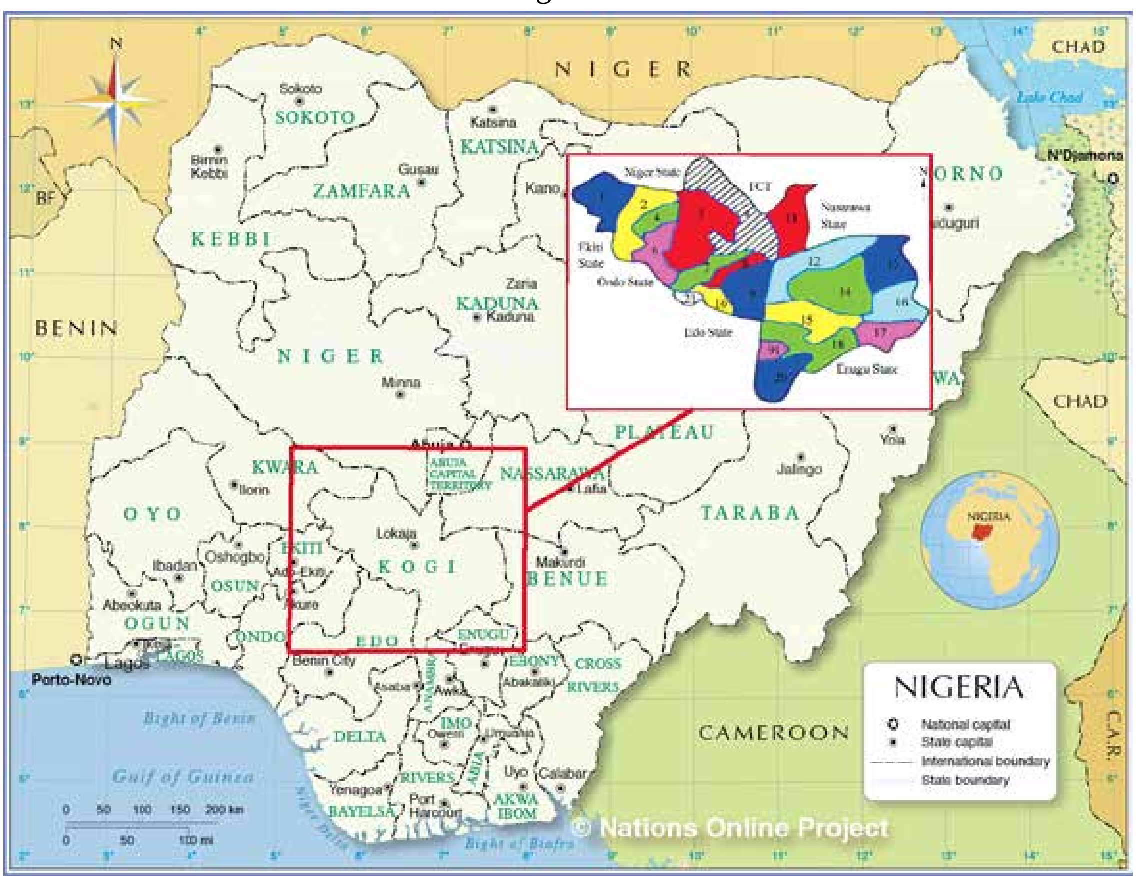
- Supply of reliable, affordable electricity
- Increased Value addition and other small industries for the rural areas
- Reduced pollution – both indoor and outdoor
- Increased facilities to health services

1.3 Feasibility Study Objective

UNIDO sent a technical team to assess the potential and to provide broad guidelines to design and implement the hydro-power project in the Ofu river. The objective is also to ascertain the technical and economical viability of the proposed project. The FS will provide topographical data, hydrological data, analysis of historical rainfall data using flow duration curve, as well as assess the environmental and social impact that might arise from developing these sites.

2 DESCRIPTION OF PROJECT AREA

Kogi is a state in the central region of Nigeria. It is also popularly called as the Confluence State because the confluence of River Niger and River Benue is at its capital, Lokoja. The State has twenty one (21) local government areas and is located in the middle belt or what is historically referred to as the North Central area of Nigeria.



The state experiences two major seasons, dry and wet seasons which favours the growth of varieties of food and cash crops. The major economic activities of the people are farming, fishing, services and government employees. The major crops grown are yam, cassava, and rice while the cash crops include cashew, oil palm, and Neem tree. Kogi State is also abundantly endowed with Iron Ore, Limestone and coal.

2.1 Project location with coordinates and relevant site maps

The proposed project site is in the vicinity of *Ofokopi* village of Ofu Local Government Area.

There is a small concrete bridge, about one km from the main road. A diversion weir will be built here and the water diverted through a 350m long canal to the forebay. A penstock of 225m length will connect this to the powerhouse. It is estimated that a potential of 400 kW is possible at this site.

2.1.1 Physical & Salient features of the project site

Ofu River originates from Ojofu in Dekina Local Government Area of Kogi State Nigeria and empties into the Anambra River falls within the Lower Benue River Basin Development Authority. The river is of perennial flow. Records of Stream flow for the river exist from 1955 to 1973 after which no measurement was done again. Some private researchers have collected flow data from 2008 to 2011. The flow ranges from 5.33 m^3/s in Mar to 15.8 m^3/s in September. During the visit in December 2018, it was measured to be 8.59 m^3/s.

The catchment area is approximately 790 km^2. Catchment area is shown below:

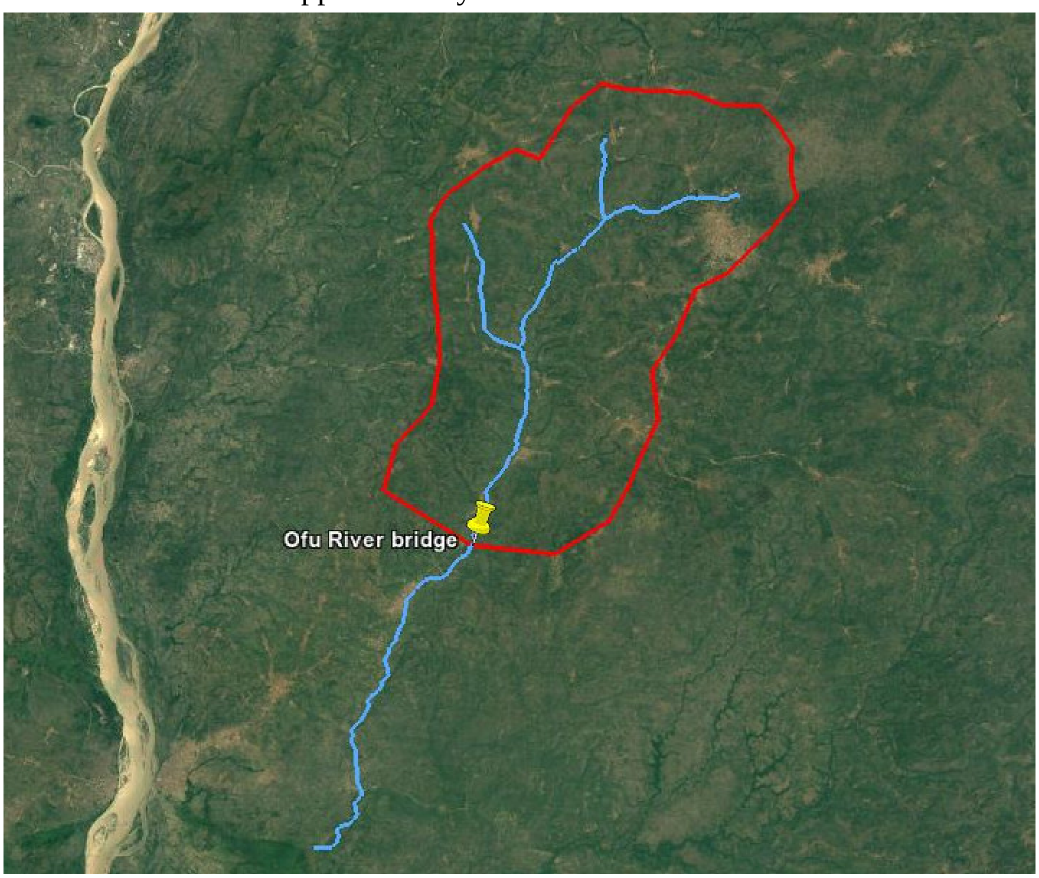


Figure 2 Ofu project catchemnt area

2.1.2 Load profile and electricity demand

This project will bring enormous benefits to the five communities near the project area. The details are given in the following table.

	Name of community	Distance from power house in km	Number of house-holds [ii]	Connected domestic load[5]
1	Ofokopi	1	400	80 kW
2	Adikafane	4	No data	30 kW
3	Ugwolawo	4	No data	80kW
4	Akpagidigbo	3	No data	40 kW
5	Odogbagada	2	No data	30 kW

Figure 3 Government official at Ofu LGA

All these communities grow a lot of cashew nuts. This has become the main source of income and the communities are relatively better off than most of the rural communities in the region. They are willing to contribute to the project to make it happen quickly. The government officials at Ugwolawo met the team and assured that they will also extend the full support.

2.1.2.1 Communities profile

Ugwolawo is the capital of this LGA. It is a large town but population and number of households figure has not yet been provided to us.

The project falls within the community of Ofokopi. It has 400 households. The community has one primary school , one nursery school and one hospital. Village has 10 small diesel generators (the number is suspected to be much higher) and about 200 TVs. There are 15 mills for grinding corn and casava.

Grid transmission is present in the village but there has been no power on these lines since six months. The main transformer burnt out and no replacement happened.

As the whole area is under cashew nut cultivation, this community produces/sells about 17500T of unprocessed cashew nuts. 80 kg bag usually sells at 30 to 50,000 Naira. Taking the lower price, the annual income from the cashew nut is 6.56 billion Naira (16.4 million USD). The additional income from the possible value addition with the micro hydro power availability is discussed under a separate topic.

2.1.2.2 Future projections

No data is available for the population and its growth rate. This project assumes the cashew nut processing unit as a sole end-use.

2.1.3 Demographic and Socio-economic parameters

A detailed survey was conducted by visiting the nearby communities to assess the energy requirements. Based on the survey, it was found out that there are five different types of load centers i.e. households, Churches/mosques, future small enterprises, street lights, and schools. Large commercial entity, business centers, high rise buildings or any other medium enterprises

[5] 200 watts per household

are not present near the project site.

During the last Census carried out in 2006, the population of Ofu LGA was 192,169 and it was projected to have a population of 258,500 in 2016[6].

There are three main ethnic groups in Kogi state: Igala, Ebira and Okun with the Igalas being the largest group.

The main occupation of the area is agriculture. 90% of the population is engaged in agriculture though mostly it is subsistence farming. They produce crops for their immediate family needs and sell only when in excess. Farmers use mostly local hand made tools for farming. The region has arable land supporting cultivation of Yam, sorghum, maize, cassava and vegetables. Coffee, Cashew and cocoa are the cash crops that are grown here.

A few Fulani nomadic are found in the region and they are involved mainly in cattle grazing.

2.2 Cashew Industry

The cashew industry focuses on low-end raw nut production, losing substantial income to countries like India and Vietnam by not focusing on value added products like the cashew kernel.

The total quantity of cashew nut kernel production in this project area is estimated to be in the range of 17500 to 20000 MT per year. The average selling price per tonne is USD 800. The total income is 14 million USD.

The true fruit of the tree is a small kidney shaped nut that hangs below a much larger false fruit (see Figure 2). The edible false fruit, called cashew apple, is pear-shaped, with a waxy appearance, and turns yellow when ripe. The unripe cashew apple is astringent and slightly acidic. When ripe, it has a characteristic apple flavor and can be eaten fresh or dried or processed into juices, jellies and wines. The nut consists of a smooth tough shell surrounding an edible kernel. This kernel is what the tree is primarily valued for. The cashew shell contains a corrosive phenol, cashew nut shell liquid (CNSL), which must be extracted before the shell can be removed to yield the kernel. CNSL has found many applications in the polymer-based industries -the most important use is in the manufacture of brake linings and clutch facings in the automotive industry. Covering the kernel is a thin tannin rich skin, the testa, which must also be peeled away before the kernel can be consumed. The following table gives the various uses of the different parts of the fruit.

[6] www.citypopulation.de

Input	Products	Description and Uses
Nuts	Kernels:	Raw nuts are processed into kernels by boiling, cracking, decorticating and roasting.
Apple	Prunes:	Cashew prunes, produced by boiling the cashew apple in molasses, is very similar to dehydrated prunes or dates.
Apple	Juice:	Cashew fruit is pulped by grating or pounding and the juice is pressed out and strained. Cashew juice has five times more citric acid than orange juice and is thus a good source of preservation acid medium when mixed with other fruit juices or vegetables.
Apple	Wine:	The juice from the cashew fruit can be processed into wine using the conventional method of producing fruit wines. The alcoholic content averages 18%.
Apple	Pulp:	The fibrous pulp obtained after extracting juice from the cashew apple can be used as animal feed or dried and processed into diet fiber biscuits.
Shell	CNSL:	Extracted from the cashew shell, Cashew Nut Shell Liquid (CNSL) is used in the manufacturing of paints, varnishes, resins and brake linings.
Shell	Fuel Wood	After extraction of the shell liquid, the spent shells are used as a processing fuel.

Table 1: Cashew Products

The Nigerian Cashew nut has a yield ratio of 25% - meaning for a tonne of raw cashew nuts 250 kgs of kernel is produced. The retail price of roasted kernels ranges from 14000 to 25000 USD per tonne. It can be seen that a little value addition can bring in substantial additional income to the cashew growing regions.

The processing steps include

1. drying of raw nuts,
2. steaming the raw nuts,
3. cooling,
4. cutting to separate shell from kernel,
5. drying the kernel,
6. peeling,
7. grading and packing.

An average of 8 to 10 kWh of electricity is required for producing one kg of cashew kernel. Considering the hydro potential of 400 kW and annual generation of 3.16 GWh, about 1250 MT could be processed to cashew kernels. The additional income by processing part of the produce (3500 MT of raw cashew) will be 3.73 million USD per year.

A few of the fruits are consumed locally and a vast quantity is left just to rot. The fruit pulp can be used to make juice and wine; the leftover after this process is a good animal feed.

3 TOPOGRAPHICAL SURVEYS

A team led by Engineer Rufai prepared the topographic maps for the site. A maximum head of 10m is available at the site.

Topographic maps were prepared for the downstream and upstream areas of the weir site.

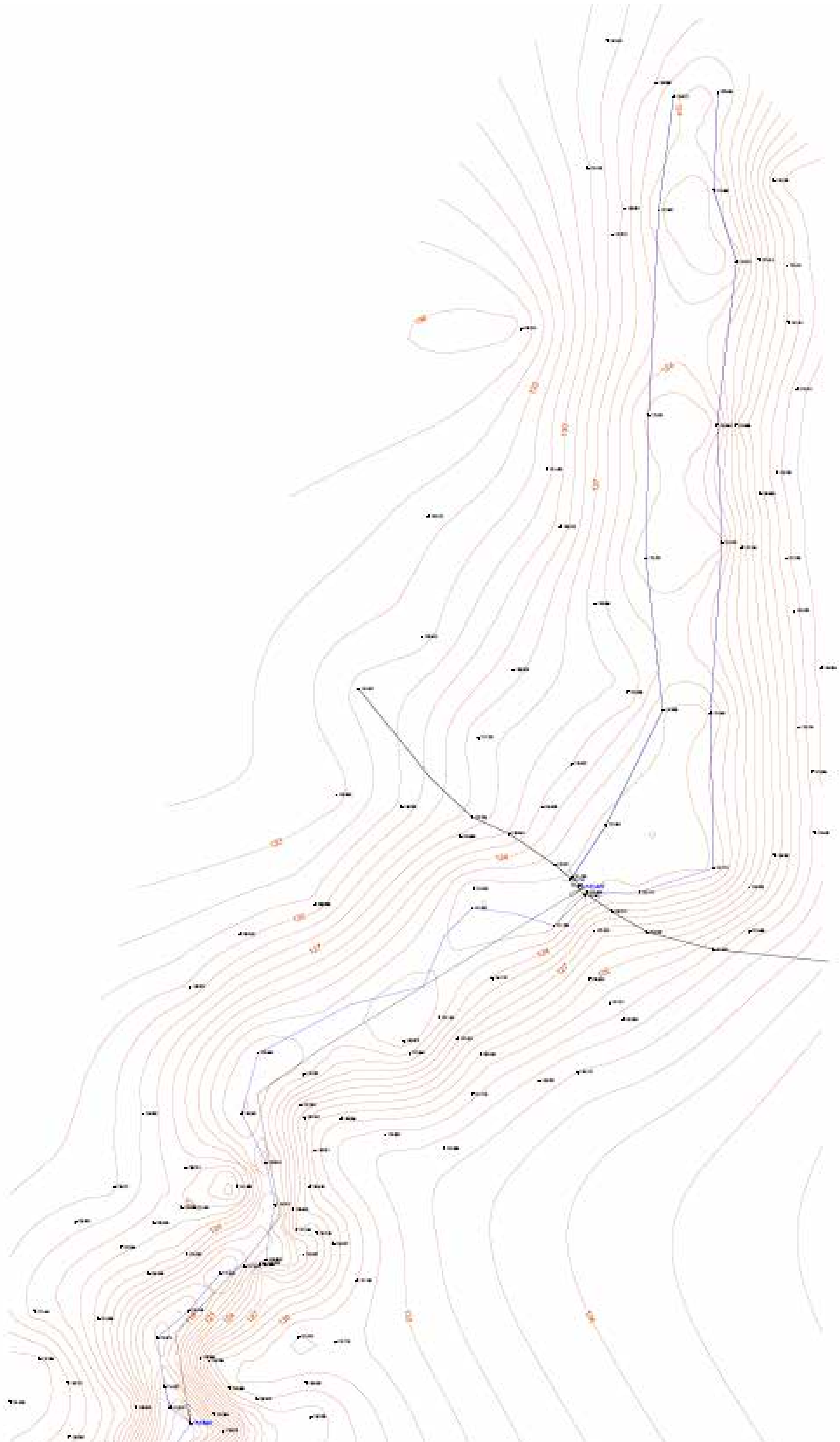


Figure 4 Topographic survey map the project area

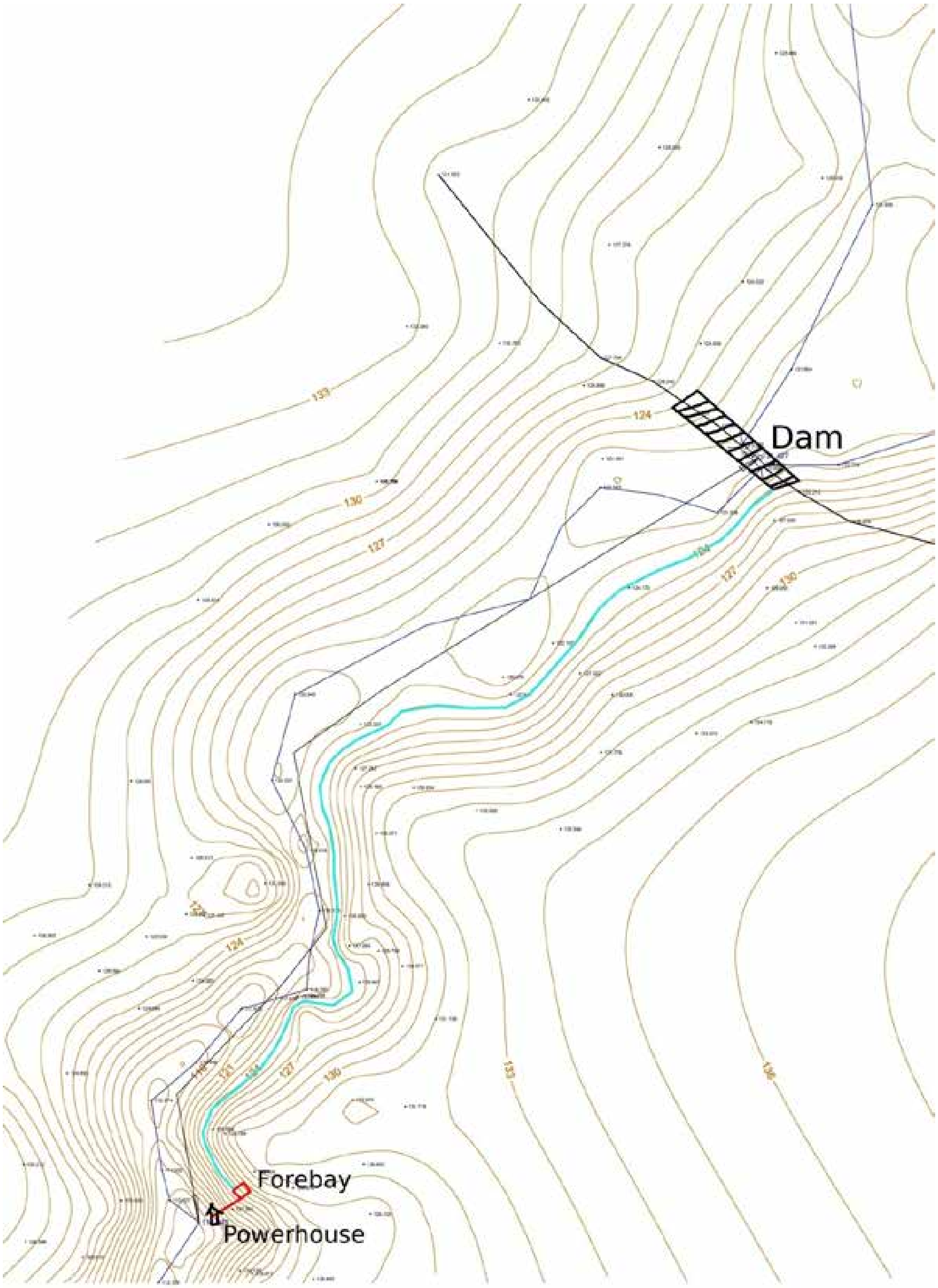


Figure 5 Okura topographic map with components details

The height of the weir has to be 3.5 m which will give a gross head of 10m for the power generation.

A detailed survey of the reservoir area which will be upto the level of the 124 m contour line has to be carried out.

The reservoir area, after the increased height, is calculated using the google earth application. The following picture shows the proposed reservoir area. It is clear from the picture that few farmers may have to compensated for the submerged land.

4 HYDROLOGICAL AND SEDIMENTATION STUDIES

Sedimentation studies need to be conducted for the increase of the height of the dam. This is not covered in this assignment.

4.1 Catchment characteristics

Ofu River is the main source of water for people within its catchment area. The catchment area consists of humid tropical rain forest of Nigeria and hence the river is perennial. The mean annual rainfall for the Kogi state is about 1200mm. The vegetation of the area is typical of the derived savannah and consists of short to tall trees. However, the toposequence is covered with grasses and scattered shrubs. The topography of this land is strongly undulating. The land is used for the cultivation of the following crops; yam, cassava, groundnut, maize and vegetables.

4.2 Rainfall, climate and precipitation data analysis

Rainfall data recorded in Lokoja Kogi state station is used in this analysis. Data from 1995 to 2016 is obtained and the average monthy rainfall is presented below.

Month	Average rainfall in mm
Jan	1.1
Feb	8.3
Mar	29.0
Apr	120.1
May	174.4
Jun	142.5
Jul	215.4
Aug	213.5
Sep	191.8
Oct	151.9
Nov	5.3
Dec	0.5
Total	1253.8

As it can be seen, April to October is the wet season with peak rainfalls in July and August. The catchment area above the existing dam is shown in Figure 4. The total area is about 790 km^2. The run-off characteristics for the region is not well-established. As the catchment area is said to be full of tropical rain forests, run-off can be assumed to be high. We have taken 30% for this DPR to arrive at the component sizing for the scheme.

The total run-off in a year = $1.253 \times 790 \times 10^6 = 989{,}870{,}000\ m^3$

The average flow rate = 31.4 m^3/s

4.3 Flow Duration Curve

With limited available data, a FDC was prepared. Q57 (6 m^3/s) is selected as design flow. This flow will be available for nearly 7 months.

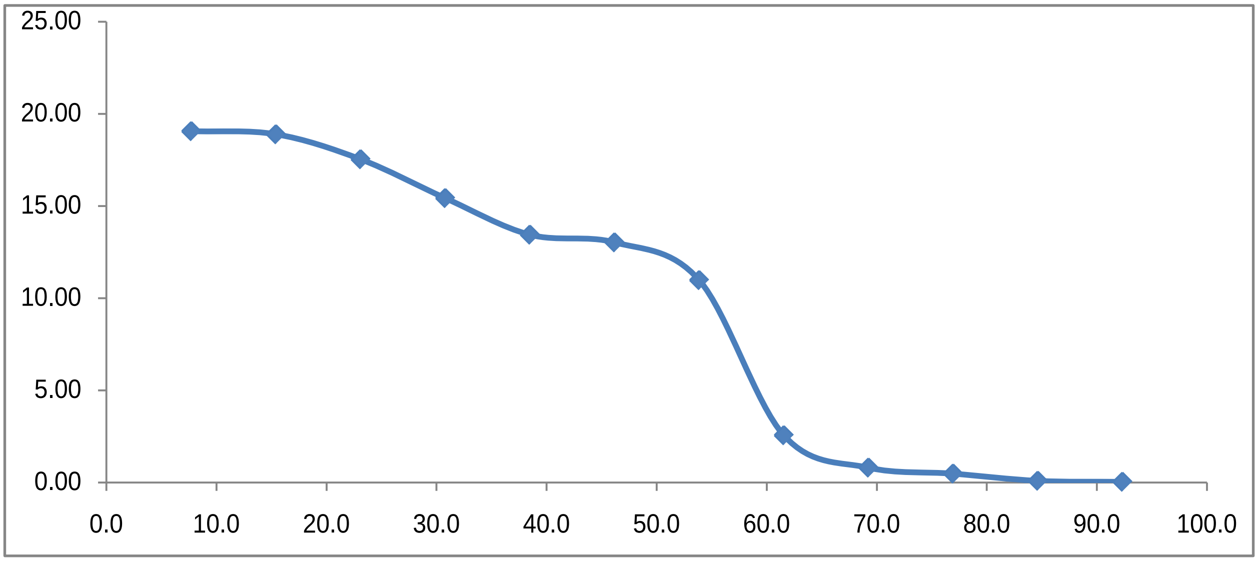


Figure 6 FDC for Okura River

5 GEO-TECHNICAL STUDIES

A detailed geo-technical study was not within the scope of this visit. The major rock types that occur in this state are migmatites, augen gneiss and biotite gneiss while there are minor occurrences of rock types like pegmatites, and quartzo-feldspathic veins.

Water-table in the region is quite high as indicated by a few open wells. The people of the area are predominantly subsistence farmers who use the available land for farming and the river water for washing, drinking and other domestic needs.

The flood plains of the Niger and Benue river valleys in Kogi State have the hydromorphic soils which contain a mixture of coarse alluvial and colluvial deposits . The alluvial soils along the valleys of the rivers are sandy, while the adjoining laterite soils are deeply weathered and grey or reddish in colour, sticky and permeable. The soils are mostly coarse textured, ranging from loamy to sandy loam in the surface horizons and from sandy loam to clay in the subsurface horizon.

These conditions don’t pose any major issue for civil construction.

6 SUMMARY OF ENVIRONMENT AND SOCIAL IMPACT ASSESSMENT (ESIA)

6.1 Environmental Impacts

The ecological problems in the state are not necessarily peculiar to it. Some of these include leaching, erosion and general impoverishment of the soil. These problems are compounded by the annual bush burning of the savannah that further exposes the top soil to more erosion. Floods pose a problem on the flood plains during the rainy season.

Detailed flow reading are necessary to calculate the flood conditions – data not available.

6.2 Social Impacts

To the extent that over 90% of the people of the project area depend on agriculture and land based resources for livelihood, significant acquisition of land for this project without proper mitigation measures will expose some social groups to economic vulnerability.

6.2.1 Local Dispute Resolution Procedure

Information about the traditional administrative structure within these communities is similar and shows that the governance structure is hierarchical formed around the traditional leadership. For example, community governance hierarchy follows a systematic order of household head, ward head, districts or clan chief and the Obaru as the head of the community. The Obaru in each community reports to Olubunu or the apex King in the LGA.

The communities build their administrative structure around this chain of command which is based on the size of the population or domain that each leader has within his constituent/community.

There exists a traditional mechanism for dispute resolution in the communities structured after the order of the administrative command described above. An aggrieved person is required to lodge his/her complaint to the head of the ward or clan. A matter that is not adjudicated satisfactorily at this level is taken to the Obaru Council.

6.3 Assessment of significance of environmental and social impacts

An in-depth study was not carried out at this stage. When the project moves onto the next stage of detailed technical design, this study could be taken up.

7 DETAILED DESIGN

7.1 Site Data

Power out put (P_o) = Efficiency x g x Gross head x flow

= η x g x H x Q

The flow required to produce the required power (Q) = Po / η x g x H where

H	= Static Head	= 10 m
h	= Overall efficiency	= 70%
g	= Gravitational force	= 9.81 m/sec^2

Required power P_o = 400 KW

Q = Flow in m^3/sec

= 400 / (0.7x 9.81x 10) = 5.8 m^3/s

Hence the entire civil works should be designed to carry the required flow (6 m^3/s).

7.2 Design of intake

Considering entrance losses and trash rack losses, the intake should be designed to carry a flow of 6.3 m3.

Cd - Co-efficient of discharge of the Orifice (rough edge-0.6 and well-finished 0.8) 0.8

The effective head from the centre line of intake	0.6	m
Velocity of water flow through intake V	2.74	m/s
(Where cd is the co-efficient of velocity.)		

Flow through the intake, Qi (design flow+ losses 5%)	6.30	m3/s
Area of cross section of the intake	2.30	m2
Width of intake, assume	2.0	m
Therefore, height of the intake	1.15	m

The quantity of water flowing through the intake can be regulated by a sluice gate.

7.3 Design of weir

The forces acting on a weir built on an impervious foundation may be static or dynamic.

Static forces

- Normal water pressure on the upstream face of the weir.
- Normal water pressure on the downstream face of the weir. It is not applicable in this site as the downstream of the weir there is a big fall.
- The weight of the water supported by the crest and the weight of the weir.

Dynamic forces

- Erosive or the scouring forces on the downstream side of the weir produced either by high velocity or by the impact of water pouring over the weir.
- The force of impact of floating matter against the crest on the upstream side of the weir.

Conditions for stability of weirs

- There must be no tension in the masonry or in the contact plane between weir and the foundation.
- There must be no overturning.
- There must be no tendency to slide on the joint with the foundation or any horizontal plane above the base.
- The maximum toe and heel pressures in foundations should not exceed the prescribed safe limits.

Failure by crushing is not considered here, as it generally does not occur, being a low structure.

A concrete weir with dimensions - 25m long, 2 m bottom width, 1 m top width and 1.2 m high can safely withstand the water pressure acting on the weir. As there is no bridge across the river, this weir could also be designed as a bridge. But this is beyond the scope of this assignment.

7.4 Design of Channel

Design discharge of the channel, Q	6.30	m3/s
Length of the channel, L	350	m
Freeboard allowance (normally 1.3)	1.3	
V = selected velocity through the Concrete channel	1.5	m/s

Cross sectional area of the channel, A	5.46	m2
Cross-sectional dimensions of the channel		
Selected Section	Rectangular	
Depth, H	1.65	m
Bottom Width, B	3.30	m
Top Width	3.30	m
Side slope	0	
Hydraulic Radius R	0.83	
Channel Bed Slope, S	0.00065	
Head loss = Channel bed slope x Length of the channel	0.229	m

7.5 Design of settling tank

Width (select 3 to 10 times the width of channel)	10	m
particle size to be settled = 0.3mm and thus its settling velocity =	0.03	m/s
Length of the settling	21.00	m/s
Length of entry	10	m
Length of exit	10	m
Assuming river's silt carrying load, S	0.5	kg/m^3
Emptying frequency, T	12	Hours
Total Silt load	136,080	kg
Density of Sand	2,600	kg/m^3
Assuming a packing density of 50%, volume of silt	104.68	m^3
So depth of collection =	0.50	m

7.6 Collection tank capacity

The Flood spillway can be sized on the basis of the headrace water depth of 1.27 m at normal flows. The height of the spill crest ($h_{spillway}$) should be aligned to the normal flow surface level or water depth.

$$h_{spillway} = h_{h\ (normal)} = 1.27\ m$$

The spillway length ($L_{spill\ way}$) is found from the standard weir equation. It must be long enough to pass the spill flow (Q_{spill}) with the available excess head of water behind it. The spillway length is not found from worst flood conditions but from minor floods when the headrace flow has only risen by 15 % above its normal value.(This is because a loner spill length is needed when there is a smaller head driving water over the spill crest.)

Standard weir equation $Q = c_w \times L_{weir} (h_{over\ top})^{1.5}$

In this case

$$Q_{spill} = Q_{minorflood} - Q_{gross}$$
$$= c_w \times L_{spillway} \times (h_{minor\ flood} - h_{spillway})^{1.5}$$

Adopt a value for weir coefficient for spillway of ($c_w = 1.6$)

$L_{spillway} = (Q_{minor\ flood} - Q_{gross}) / 1.6 (h_{minor\ flood} - h_{spillway})^{1.5}$

For a minor flood flow of 15% above normal flow, $Q_{minor\ flow}$ = 7.25 m^3/s

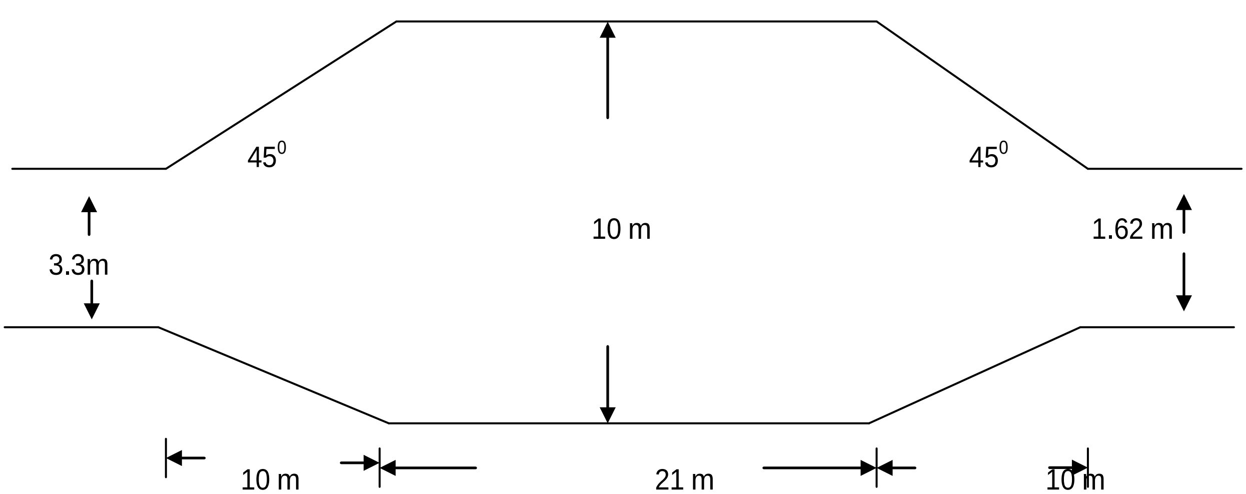
$h_{spillway}$ = $h_{h\ (normal)}$ = 1.27 m

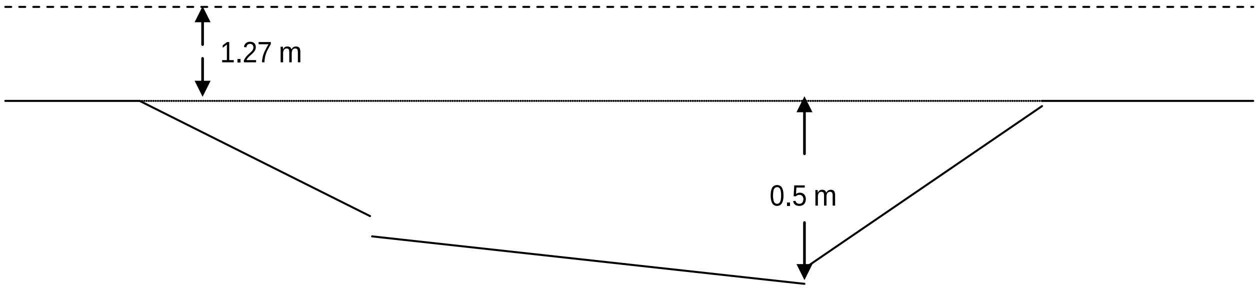
So,$h_{minor\ flood}$ = 1.46 m

and $L_{spillway}$ = 7.10 m

The calculation is very approximate as the water level behind the spillway will vary. So it is better to use a safety factor of 1.5.

Final $L_{spillway}$ = 10.66 m





7.7 Design of penstock

7.7.1 Material of the penstock – Mild Steel

Length of penstock	L_p	=	225 m
Flow through the penstock pipe	Q_p	=	6.0 m^3/s
Gross head	H_g	=	10 m
Pipe inner diameter	D_i	=	2000 mm
Thickness of the Pipe	t	=	15 mm
Equivalent sand grain roughness	K_s	=	0.02 mm
Young's modulus of elasticity	E	=	200 kN/mm^2
Bulk modulus of elasticity of water	K	=	2.15 x 10^9 N/m2
No. of bends		=	2
Angle of bends		=	30º

7.7.2 Hydraulic Design

Area of cross section of the pipe A_p = $(p/4)\, D_i^2$

= $(p / 4) \times (2.0)^2$

= $3.142\ m^2$

Velocity of the flow through the pipe V_p = Q_p / A_p

= 6.0 / 3.142

= 1.91 m / sec

Reynolds number R_e = $V_p\, D_i \times 10^6$

= $1.91 \times 2.0 \times 10^6$

= 3.82×10^6

Relative roughness K_r = K_s / D_i

$= 0.02 / 2000 = 0.000010$

Friction factor from moody's chart $f = 0.013$

Head loss due to friction $H_f = \dfrac{fL\ 0.083\ Q^2}{D_i^{\ 5}}$

$= \dfrac{0.013 \times 225 \times 0.083 \times (6.0)^2}{(2.0)^5}$

$= 0.273$ m

Considering 2 bend of 30°, entrance losses and valve losses

$H_{turbulence} = K V^2 / 2g$

$H_{turbulence} = \dfrac{(\{0.23X2\} + 0.2 + 0.1)\ 1.91^2}{2 \times 9.81}$

$= 0.099$ m

Total head loss $H_{loss} = H_f + H_{turbulence}$

$= 0.273 + 0.099 = 0.372$ m

Net head $H_{net} = H_g - H_{loss} = 10 – 0.372 = 9.628$ m

7.7.3 Structural design

Wave velocity in Penstock	837	m/s
Penstock Critical Time	0.538	s
Surge head	26.3	m
Total head at surge	36.3	m
Required penstock thickness	5	mm

SUMMARY

MATERIAL OF PENSTOCK = MS

INTERNAL DIAMETER = 2000 mm

WALL THICKNESS = 15 mm

OUTSIDE PIPE DIAMETER = 2030 mm

7.8 Forebay

The forebay size suggested is 3500m^3 volume. The dimensions could be 50m X 20 m X 3.5m.

7.9 Powerhouse

The suggested size is 10m X 5m floor area and wall height of 5m. The roof should be of RCC to support winch pulleys during installation and maintenance.

8 PROJECT OPTIMIZATION

8.1 Estimation of Power and Energy Production

8.1.1 Plant capacity

The proposed capacity of the power plant is 400 kW. The available head is 10m. The design flow is 6 m^3/s.

8.1.2 Plant factor

The plant factor 0.88 for this project will be quite high as the stream is perennial and the design flow is Q57 as per FDC.

8.1.2.1 Annual energy

The generation profile is given in the table below:

	Power kW	**Energy kWh**
Jan	400	297600
Feb	400	268800
Mar	400	297600
Apr	400	288000
May	400	297600
Jun	400	288000
Jul	400	297600
Aug	400	297600
Sep	400	144000
Oct	400	148800
Nov	400	144000
Dec	400	297600
	Total	3,067,200
Installed capacity		3,504,000

The plant factor is 0.88. A period of 45 days downtime for maintenance is considered in the calculations.

8.2 Cost Estimates

The total project cost is estimated to be 7.5 million USD. Approximate Break-up of civil costs are given below:

	Item	**Quantity**	**Units**	**Rate, USD**	**Total, USD**
1	2000mm ID MS pipe (740 kg/m)	225	m	3700	832,500
2	Cement	11000	bags	10	110,000
3	Sand	1600	m3	10	16,000
4	Gravel 25mm	2000	m3	35	70,000
5	Rubble stones for foundations	2250	m3	9	20,250
6	16mm and 8 mm steel	21000	kgs	9	189,000
7	Power house site	10m X	area		

		8m			
8	Bricks	16000		0.3	4,800
9	Skilled labour (masons)	4150	man days	15	62,250
10	Semi-skilled labour	16500	man days	5	82,500
	Sub total				1,387,300
	Contingency	10%			138,730
	Total cost of civil works				1,526,030

The electro-mechanical equipment cost is estimated to be 0.6 million USD(@ 1500 USD per kW) and the total transmission cost is estimated to be 50,000 USD (5000 USD per km). The total cost of the project is about 2.176 million USD.

Initially the entire power could be supplied to a cashew nut processing industry to minimize the transmission costs and losses.

8.3 Economic Analysis

With the total project cost of 2.176 million USD, the benefits are enormous both in short term and long term. As discussed in the earlier section, the area is one of best cashew-nut growing regions of the country. But there is not a single processing unit adding value to the produce. By providing a reliable power supply and access to processing facilities can bring in an additional income of 3.7 million USD per year to the region's farming communities. Indirect benefits are innumerable: with increased incomes, health, education, common infrastructure will all become better.

The tariff charged in Nigeria is in different slabs: taking an average of 40 Naira/ kWh (10 cents), the IRR of the project is 19%

9 PROJECT DESCRIPTION AND BASIC DESIGN

The proposed dam will be of concrete type dam with 3.5m height providing a total head of 10m.

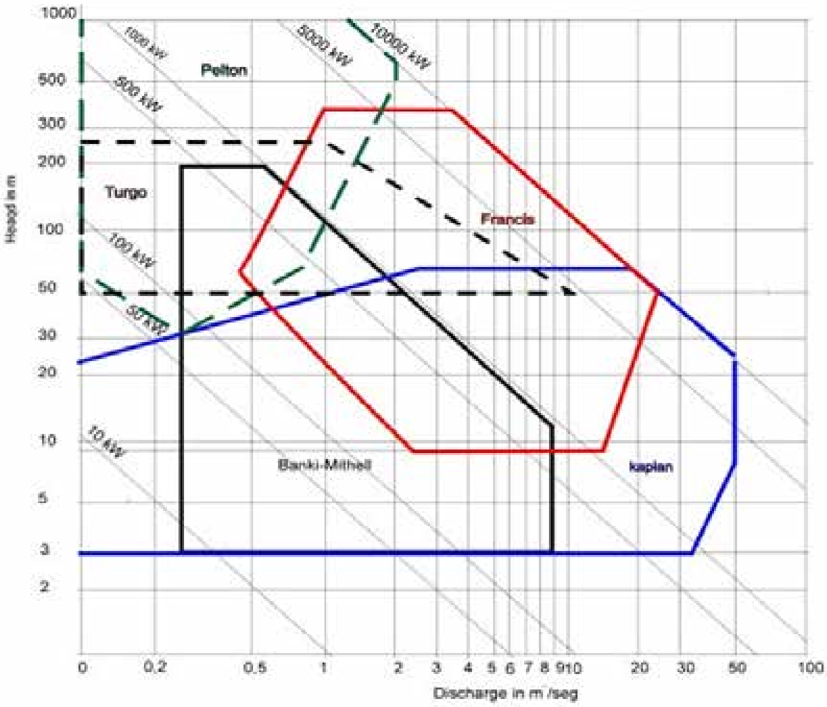
The powerhouse location is at about 500m from the dam site. It will have a single turbine unit to handle the flow variations effectively. The turbine will be of Francis type reaction turbines.

The tail race will be 5m long and leads the water back to the stream.

Penstock will be of mild steel and will be of 2m diameter and 15mm thick wall.

Four villages will be connected to this power plant. The total transmission line distance is over 10 km. The generated voltage will be stepped up to 33 kV by a transformer.

9.1 Turbine choice



The Francis water turbine, named after its inventor James Francis, is a radial flow reaction type of water turbine design in which the entire turbine wheel assembly is immersed in water and surrounded by a pressurized spiral casing. The water enters the casing under pressure and is guided through a set of fixed or adjustable slots called guide vanes around the casing which direct the flow of water to the turbines blades at the correct angle.

The turbine is of horizontal axis type for this site.

9.2 Generator

A three phase AC synchronous generator with horizontal arrangement and air cooled as per the IEC regulations is considered for this project. Two sets of generators will be installed which can also be synched with each other through a power electronics panel.

Each unit has a synchronization microcomputer automation device to perform synchronism connecting to the grid. Switchyard is also equipped with a set of microcomputer automation synchronization device and a set of manual synchronization device, mainly used to finish synchronism connecting to net of main transformer and 33 kV line.

10 DISTRIBUTION / TRANSMISSION LINE AND CONNECTION TO THE GRID

The following figure gives the transmission arrangement.

The total length of the transmission is 10 km. The main feeder line will be of 33 kV and step down transformers will be used at load centers. Existing transmission network can be used. Poles are already there. cable is missing in between some points.

11 OPERATION AND MAINTENANCE REQUIREMENTS

Most of the operation will be automatically controlled with SCADA. A team of 5 operators will manage the power plant to monitor the proper functioning of components. The plant will have two turbines to enable continuous power generation even during breakdowns / maintenance shut-downs.

The maintenance requirements are mainly desilting the dam once in a year, checking the seepage losses in the dam, fixing penstock leaks, transmission line issues, etc. For the T&D management, a team of five line-men will be needed.

12 PROJECT RISK ASSESSMENT AND MITIGATION

The private developer has already invested a large amount of money to buy the land needed and to build the dam. He has also obtained the necessary license for generating power at this site. He is willing to take it to the completion.

13 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are made:

1. ofu hydro project is technically and financially feasible.
2. Installed capacity and energy: The installed capacity of the plant is 400 KW with a design discharge of 6 m^3/s and gross head of 10 m. The gross energy production is 3.14 GWh
3. About 10 km long, 33 kV transmission line will be required from the project powerhouse to the five village communities.
4. A construction period of 18 months has been considered.

Based on the findings of this study, the project is financially attractive. It is recommended the detailed design for the dam & reservoir, penstock alignment, powerhouse and transmission& distribution design be initiated immediately.

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[i] Energy Sector Study – GIZ NESP 2015-16 report

[ii] Data awaited from Mr. Donald Adgidzi. The figures given are rough estimates based on the visits to the village.