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ASSESSMENT OF THE HYDROPOWER POTENTIAL OF KANGIMI RESERVOIR IN KADUNA STATE NIGERIA

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Abstract

This study evaluated the hydropower potentials of the Kangimi reservoir (KR) and found that the Kangimi reservoir can potentially generate 1.109MW and 0.692 MW if the KR dam axis is respectively placed at 612m and 604m above mean sea level. These levels represent the upper and the lower limits at which the proposed hydropower scheme can sufficiently release water from Kangimi reservoir to conjunctively meet the water demands for the newly proposed hydropower and designed water supply and irrigation purposes. This hydro electric power potential of the reservoir can sufficiently meet the 872.566 KW total estimated energy needs of the communities surrounding the KR. The study further assessed and highlighted all the possible impacts, implications and requirements for developing this proposed Kangimi small hydro power scheme to improve the socio-economic development of the neighboring communities around KR.

Keywords: hydropower potentials, Kangimi reservoir, small hydropower plant, rural development, energy needs

1. Introduction

In Nigeria as in most developing nations, the demands for sustainable energy are increasing due to population and developmental growth [1]. But the available infrastructures for providing and extending these required energy especially to rural areas have continued to diminish and have become grossly inadequate in recent times [2,3,4]. The realization of this fact have necessitated the need for the nation to identify and promote the development and utilization of other renewable energy sources such as wind, small or mini hydropower sources to augment the existing ones for the socio-economic development of the unreached rural areas of Nigeria [2,5].

The development of energy from small, mini and micro hydropower projects are being encouraged and supported worldwide because of its relative advantage of being a safe and clean renewable source of energy that can be developed and managed by local communities [6,7,8]. The frameworks for sustainable development and utilization of SHP across the globe that are well documented in different literatures [9–12] present some information that are useful for guidelines and adaptation in implementing this SHP project at Kangimi.

Although SHP is still experiencing slow growth in its development in Nigeria, yet recent reviews have shown that Nigeria is blessed with huge hydropower potentials [2, 6, 13, 14]. With the difficulty of starting new small hydropower scheme from the scratch, this study desires to look into the feasibility of incorporating hydropower schemes in existing reservoirs with other supplementary functions. The inclusion of hydropower schemes into any technically viable existing reservoirs is without doubt a welcoming solution to the critical power crises in most rural communities living within the vicinities of these water infrastructures.

It is in view of the above mentioned reasons that this study have selected an existing Kangimi reservoir (KR) in Kaduna state, Nigeria, with the intent of evaluating its hydropower potential under its existing as-built conditions and to evaluate the feasibility of raising the dam axis to accommodate a small hydropower plant (SHP) that can be operated at optimal hydropower capacity to meet the electricity demand of its neighboring communities as well as fulfilling its other primary use and purpose. Furthermore, the study is also expected to review some socio-environmental impacts and requirements for bringing about the utilization of the full hydropower potentials of this reservoir without jeopardizing the primary objectives for constructing this reservoir. KR has been specifically selected because of its notable features which can allow the conjunctive utilization of this reservoir for hydropower, irrigation and water supply if its available water resources and some socio-environmental and engineering considerations and provisions permit.

At this preliminary stage, the study intends to carry out the feasibility of this Kangimi SHP from the hydrological and civil engineering context only and leaving other consideration for the next engineering design stage. It is expected that the outcome of this study would help to address the issue of the lack of SHP feasibility studies that was opined by [13] as one of the major barriers for SHP sector development in Nigeria.

1.1. The study area

The Kangimi Reservoir is located in Kaduna state. It lies within the sub basin of the Kaduna river system in Northern Nigeria. Its Grid Reference is 241000N, 1875000E (i.e. 10°39′36.87″N, 7°36′02.22″E). It can be reached through a feeder road that is 13 kilometers south-east from Katabu and about 1.6 kilometer from Maraban-Jos (along Kaduna-Jos road) [3,10]. The prominent villages surrounding the reservoir are Rihogi, Burkornu and Maje . Figures 1 and 2 respectively shows the schematic and Google Earth satellite imagery maps of the Kangimi reservoir.

KR was designed to augment the raw water supplied to Kaduna treatment plant during the periods of low flow in River Kaduna and to irrigate about 16.2 km^2 strip of land on the north bank of River Kaduna upstream of Kaduna town [3]. Obtaining stream flow data of Kangimi river like most river in Nigeria is difficult [15].

2. Assessment of the Hydropower Potentials of the Kangimi Reservoir

This study primarily intends to undertake only a rapid technical assessment (RTA) that provides some basic information that essentially helps in making unbiased technical decision on the viability of the proposed energy production from this existing dam which had not been planned or designed with the inclusion of an hydropower scheme. RTA is only concerned with the evaluation of the hydropower potential of the KR and as well to investigate the socio-environmental impacts of energy production from this existing dam without endangering life and properties within the environment of this proposed hydropower scheme [9, 10].

The broad aspects of RTA undertaken for this study are briefly discussed as follows:

A. Evaluating technical viability of proposed Kangimi SHP within hydrological context

(a) **Estimating the hydropower potential of the SHP.** Concisely and within hydrological context, it involves the determination of the technologically feasible limits of the gross hydropower potential (GHP) of the studied river basin. By definition, GHP is the theoretical optimum limits of hydroelectricity production (HEP) of any river basin which represents the potential that possible feasible fall and flow within the basin constitutes. Conceptually, GHP is proportional to the product of gross head and discharge which can be determined from equation (1) [17, 18].

$$P = e\rho g Q H \tag{1}$$

where GHP or P is power (Watts), e is the overall efficiency (%), ρ is the density of water (1,000 kg/m^3), g is the acceleration due to gravity (9.81 m/s^2), Q is the water discharge expected to pass through the turbine (m^3/s), and H is the gross head (m). The most technically feasible head (H) is the optimum head attainable from the reservoir pool of water when the current dam axis is raised to its optimum and technically feasible height. This information which is required to determine GHP and to evaluate the most technologically feasible and optimum hydroelectricity production of the river basin under study is made possible through a detailed reservoir hydrological analysis described below

(b) **Undertaking Reservoir Hydrologic Analysis.** The procedural details of undertaking this analysis involve the following:

(i) *Reservoir Surface Elevation Data Processing:* This involves extracting some preliminary design data on the reservoir under study, i.e. the elevations for the reservoir outlet, the maximum pool level, the spillway level and the crest level of the dam. In the absence of a detail Topo-map for the study area, the available Google Earth satellite image map of November 23rd, 2003 and February 14th 2009 was collected and used to extract respective coordinates and reservoir surface elevations on a pre-defined grid size. These extracted data were further processed to develop the digital elevation models across the entire surface area of the reservoir under study. A grid size of 400 x 400 pixel was selected for the Kringing method to give a fair interpolation of the whole elevation values across the entire surface area of the KR. The Surfer 8 software was used to generated and produced the contour plot of the surface elevations across the Kangimi basin.

(ii) *Reservoir Area Computation:* Using the contour lines at various elevations, the reservoir area was determined for each contour elevation closing at a defined dam axis level. The Area-computing Module of the Surfer 8 software software reservoir

Figure 1: Schematic map and satellite imagery of the study area in Kaduna state.

area at various contour elevation, the contour plot was exported to the Autocad 2009.

(iii) *Reservoir Capacity Determination:* The reservoir capacity was computed using the Simpson rule equation using Equation (2)

$$V = \frac{1}{2}\left[h_2 - h_1\right]\left[A_2 - A_1\right] \tag{2}$$

V is the average volume between two elevation contour interval, h_1 and h_2 are the respective contour level / height of each reservoir at point 1 and 2, A_1 and A_2 are the area covered by respective contour lines. The reservoir capacity is the cumulative volume computed over the whole contour lines across the entire reservoir. The amount of energy that can be generated depends on the quantity of water available and the variability of flow throughout the year. The technical viability of a potential small hydro project is made possible through several data obtained from some of the following functional reservoir relationships that are very site specific: i. Reservoir surface elevation versus reservoir storage volume and ii. Reservoir surface elevation versus reservoir surface area.

(c) Estimating Electricity Power Demand of Neighboring Communities The electrical power demand of all neighboring communities around the Kangimi reservoir will be estimated by using the energy demand derived for basic electrical appliances used at rural households to obtain the average energy demand per household and multiplying it with the average number of households within each of the villages around the study area. The average energy for estimated to number of small scale industries around these villages will also be added to get the total estimated energy demands for these villages will be compared with the optimum hydroelectricity that can be generated by the proposed Kangimi SHP.

B. Assessing of possible impacts and cost implications of developing the Kangimi SHPs This aspect of the evaluation work covers investigating all possible positive and negative impacts scenarios in order to ascertain the viability of developing this SHP without much harm to the environment, lives and properties located around the vicinity of the existing reservoir. It will also involve assessing cost implication, environmental impacts of the proposed SHP at optimum feasible conditions.

3. Results

Some basic reservoir data in Table 1 were extracted from the reservoir design report by [14]. The generated reservoir surface elevation data obtained from preliminary data analysis was used to generate the contour map shown in Figure 3. By using a contour interval of 1m, the contour map was trimmed at proposed dam axis to obtain the reservoir area and volume at various elevations shown in Table 2. The reservoir capacity was computed using the Simpson rule computational approach in Equation (2) and the resulting reservoir elevation storage capacity for various existing design elevations and proposed (raised) elevations are respectively presented in Tables 2 and 3. It should be noted that at other contour elevations above 612m above mean sea level, the KR water will spill to other basin and areas around the dam will become inundated.

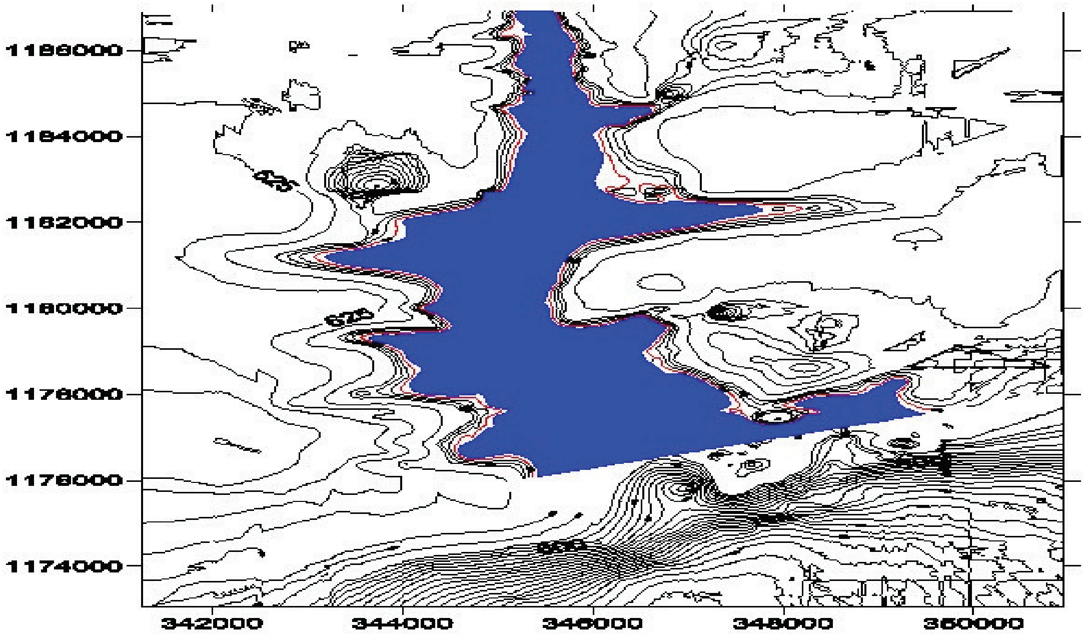

Figure 2: Generated surface elevation contour of Kangimi reservoir.

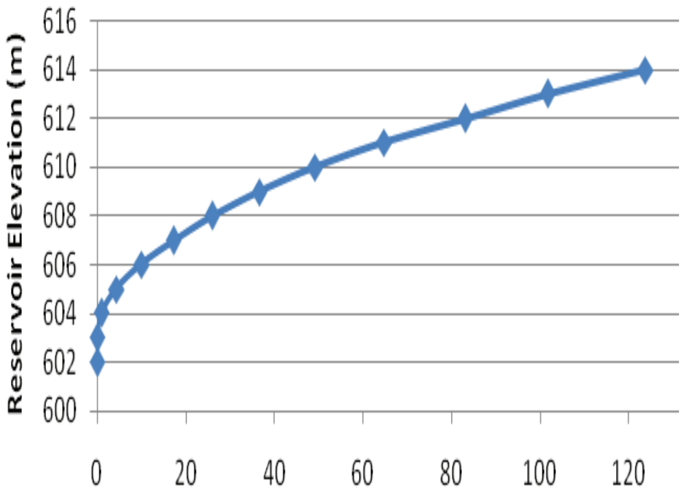

Figure 3: Capacity-Elevation curve for Kangimi Reservoir.

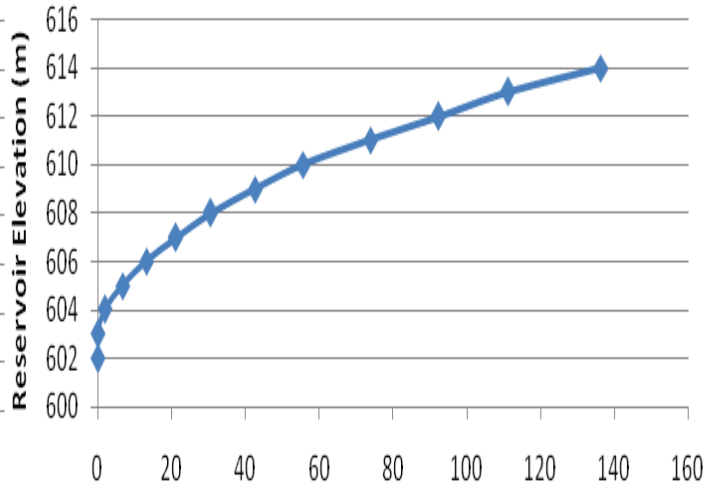

Figure 4: Area-Elevation curve for Kangimi Reservoir.

By assuming that the flow into the proposed hydropower plant be at the initial designed flow rate of 202,000 m^3/day, the hydropower potentials of the Kangimi reservoir was derived using equation (1) and the results is as given in Table 4 while the corresponding reservoir elevation-capacity and elevation-area curves are shown in Figures 4 and 5.

As shown on Tables 3, 4 and 5, the hydro-electric power potentials (HEPP) of this proposed reservoir-type of hydropower scheme at Kangimi heavily depends on the proposed elevation to which the axis of the existing dam can be raised. It is therefore important that the structural adequacy of sustaining this hydropower scheme at the proposed elevation be considered during the design stage of the dam axis. Another critical factor that could decrease the available head of water which will also consequently affect the HEPP of this proposed hydropower scheme at Kangimi is the level of siltation within the confines of the reservoir area. The study therefore carried out a preliminary evaluation of the silt level within the KR.

3.1. *Siltation study for Kangimi reservoir*

It should be noted that no detail siltation study on the Kangimi reservoir has been carried out since it was constructed. Hence an attempt was made to estimate the current silt capacity in the reservoir by obtaining the difference between the design capacity of the reservoir and the current capacity estimated from this study. The differences between the two capacities shown in Table 5 possibly represent the current volume of reservoir that has been silted.

3.2. Electricity power demand of neighboring communities

Based on basic electric power demand data collected from Power Holding Company of Nigeria and focal group discussions with some members of the communities at Kangimi, Katabu, Rihogi, Burkornu and Maje, the total maximum electrical power demand for all the neighboring communities around the Kagimi reservoir was estimated as 872.566kW.

4. Discussion of Results

4.1. Hydropower Potential of Kangimi Reservoir

From the plot of the generated contour, 612m above mean sea level (amsl) is the optimum level possible for the reservoir axis to be raised. Raising the reservoir axis beyond 612m will result in water spilling to other basins and leading to environmental degradation and farmland inundation. At this raised elevation of 612m amsl, the proposed KR hydropower scheme can generate 1.109MW and can generate 0.692MW at 604m amsl. These represent the upper and the lower limits at which water can be released from Kangimi reservoir for energy purpose while still performing the functions of providing water for water supply and irrigation use.

The available potential power from the proposed KR hydropower scheme at 612m if completely dedicated as off-grid supply can meet the electric energy requirements of the neighbouring villages. 1.109 Megawatt of electricity on a steady basis can do a lot to change the style of living of the surrounding communities and generate revenue for the owners of the reservoir. Revenue generated can be used for the maintenance of the entire KR hydropower scheme and its ancillaries.

4.2. Implications of the proposed hydropower development

It is obvious from the result of the study that the Kangimi reservoir if raised to a higher elevations (with optimum at 610m amsl) can generate over 1 Megawatts which at the best can meet the electric energy demands of the rural communities at downstream of the reservoir.

One major issue to be considered is the cost implication of implementing this proposed project. The guides provided by [19, 20, 21, 22] have been used to identify the major components of this proposed KR hydropower scheme project that need to be considered for funding. A detail costing of these itemized project items in Table 6 will need to be further investigated during the project design stage. The required fund can be sourced through a public private partnership arrangement to take advantage of the positive implications of creating an industrial revolution in these communities [3, 23].

Some other implications and impacts of developing this proposed Kangimi hydropower scheme under the technical conditions proposed by this study are given in Table 7.

4.3. Additional requirements for realizing the optimum hydropower potentials of KR.

4.3.1. Additional structural and geotechnical works

Certainly for the full development of the proposed KR hydropower scheme, is need to carry out detail structural and geotechnical evaluations on the existing dam to ascertain the additional structural and geotechnical works that will be required to strengthen the existing dam and spillway structures before raising the elevation of dam axis to the optimum dam axis level proposed in this study.

4.3.2. Dredging of the reservoir

The preliminary estimated siltation capacity in Table 5 shows that KR is stilted and will require dredging to restore the KR to its design capacity. This will allow deeper water levels and additional heads that can further increase the hydropower generation potential of KR considerably. A substantial fund can also be generated from the sales of the dredged silted materials that can supplement the overall project cost of this proposed KR hydropower scheme.

However, during the proposed dredging process, aquatic life within the KR will be disturbed and the water being released to Kaduna Water treatment plant will also be turbid and will require treatment at higher cost.

4.3.3. Reconstruction and relocation of Kaduna-Jos road

Since inundation of some portions of the neighbouring Kaduna-Jos road is inevitable if the dam axis is raised to the 612m amsl, it is required that this section of the road be relocated and reconstructed with a new bridge at higher elevations.

The outcome of the preliminary rapid assessment further showed that the potential positive impacts of developing this Kangimi SHP outweigh its negative impacts. This implies that within some reasonable assumptions, it is still feasible to incorporate the proposed SHP under the existing as-built conditions of the Kangimi reservoir. However, this will certainly

Table 1: Available Design Data on Kangimi Reservoir [14].

Reservoir design Data	Unit	Quantity
Release for water supply	m^3/d	182,000
Daily projected requirement	m^3/d	50,227,500
Total storage volume	m^3	59,208,000
Kaduna river supply at low flow	m^3/d	45,500
Average annual rainfall	mm annum	121,9.2
Catchment area	Km^2	365.19
Average annual discharge	m^3	74,010,000
Water available for water supply and irrigation	m^3	43,172,500
Water supply	m^3	16,035,500
Irrigation	m^3	19,736,000
Distribution losses/surplus yield	m^3	7,401,000

require some technical, financial, social and organizational intermediations.

5. Conclusions

Within the hydrological context that this study assessed the technical viability of incorporating a SHP at Kangimi, it was ascertained that the optimal hydropower potential of the KR, evaluated at 1.1 MW, can be fully utilized for power generation to meet the gross domestic energy demands of the neighboring communities as well as those demanded by all potential small scale industries expected to bring about a rapid rural transformation of the neighboring villages within the study area.

The realization of utilizing this renewable energy source to bring about the desired sustainable developments in the rural communities around this study area is however the alternative costs to other forgone costs of intermediations to reduce or eliminate the negative impacts of this proposed Kangimi SHP project.

In addition, the preliminary findings of this study will be useful for consideration in the next engineering design phase of preparing a detailed bankable project document with detailed designs, cost estimates, construction schedule and financial analysis on this proposed Kangimi SHP project.

6. Acknowledgement

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Table 3: The reservoir elevation-area-capacity at various proposed raised elevations.

	Area		Volume*	
Elevation	m^2	Change in Area	m^3	MCM
602	0	0	0	0.00
603	8,523.99	4,261.99	4,261.99	0.0043
604	1,940,272.95	974,398.47	978,660.46	0.9787
605	4,771,302.73	3,355,787.84	4,334,448.30	4.3344
606	6,558,676.63	5,664,989.68	9,999,437.99	9.9994
607	7,997,632.49	7,278,154.56	17,277,592.55	17.2776
608	9,354,012.21	8,675,822.35	25,953,414.90	25.9534
609	12,011,365.72	10,682,688.96	36,636,103.86	36.6361
610	13,148,252.72	12,579,809.22	49,215,913.08	49.2159
611	18,141,711.91	15,644,982.32	64,860,895.40	64.8609
612	18,433,125.78	18,287,418.85	83,148,314.25	83.1483
613	18,874,242.20	18,653,683.99	101,801,998.24	101.8020
614	25,133,513.73	22,003,877.96	123,805,876.20	123.8059

* Computed using equation 2.

Table 4: Available hydropower power potential at various proposed elevations at study area.

Elevation (m)	Reservoir capacity (MCM)	Available head (m)	Power available** (kW)
602	0.00	11.298	588.341
603	0.0043	12.298	640.415
604	0.9787	13.298	692.490
605	4.3344	14.298	744.565
606	9.9994	15.298	796.640
607	17.2776	16.298	848.714
608	25.9534	17.298	900.789
609	36.6361	18.298	952.864
610	49.2159	19.298	1,004.939
611	64.8609	20.298	1,057.013
612	83.1483	21.298	1,109.088
613	101.8020	22.298	1,161.163
614	123.8059	23.298	1,213.238

** Estimated using equation (1).

Table 5: Preliminary estimated siltation capacity at various reservoir elevations.

Elevation (m)	Design capacity (m^3)	Estimated Capacity from this Study (m^3)	Estimated Silt Capacity (m^3)
604	16,436,202.48	978,660.46	15,457,542.02
605	23,494,906.23	4,334,448.30	19,160,457.93
606	34,263,361.33	9,999,437.99	24,263,923.34
607	51,008,247.08	17,277,592.55	33,730,654.53
608	57,585,885.85	25,953,414.90	31,632,470.95
609	64,730,934.58	36,636,103.86	28,094,830.72

Note: The design capacity values were not available for elevations higher than 609m.

Table 2: The reservoir elevation-area-capacity at various existing design elevations.

Elevation	**Area** m^2	**Mean Area** m^2	**Contour difference** m	**Capacity** m^3	**Mean Capacity** m^3	**Mean Capacity** (MCM)
590.7024	0					
591.312	14163.89		0.6096	4,317.25		
592.836	109264.3	60702.38	1.524	94054.38	4,317.25	0.00
594.36	445150.8	277207.5	1.524	422473.8	98,371.63	0.10
595.884	781037.2	815435.2	1.524	1242751	520,845.38	0.52
598.932	2185286	1810954	1.524	2760080	3,453,491.63	3.45
600.456	3273881	2324901	1.524	4159979	6,213,571.23	6.21
601.98	4682177	3613815	1.524	6062653	10,373,549.98	10.37
605.028	7931777	7065756	1.524	10768455	23,494,906.23	23.49
606.552	9975424	8953600	1.524	13645717	34,263,361.23	34.26
607.1616	10380106	10572330	0.3048	3222519	51,008,247.08	51.01
608.076	12180943	11938134	0.3048	3651160	61079774.58	61.08
609.6	14649507	13415225	1.524	19211763	64730934.58	64.73
					83942697.08	83.94

Table 7: Outcomes of rapid environmental impact assessments.

Positive Impacts of Developing KR and Comments	**Negative Impacts of Developing KR and Comments**
(a) Cleaner Source of Renewable Energy: Developing KR hydropower scheme will reduce the current level of green house emissions from alternative energy sources used in these communities around Kangimi. i.e the use of fossil fuel for generators will reduce drastically.	**(a) Inundation of some arable lands and roads:** Some arable lands for crop and animal farming will be inundated if the Kangimi reservoir axis is raised to 612m amsl. These effects can be minimized by planning and paying compensation as alternative cost to the more promising benefits offered if KR is developed.
(b) Reduced risk of flooding and other environmental degradation: It is expected that the improved controlled releases from the proposed hydropower scheme will moderate the effects of the usual flooding and environmental degradation experienced at the downstream of the Kangimi river and the adjoining Kaduna river.	**(b) Biological diversity:** During construction stage of this proposed project, It is expected that some fauna and flora around Kagimi reservoir will be displaced or destroyed. However, new wetlands can be created to support fauna and flora resettlement, migration and breeding purposes; Species of fishes in the reservoir that may be destroyed during the construction stage may also be re-stocked after construction.
(c) Improved sources of livelihood and Industrialization: Developing Kangimi SHP will create more diversified job opportunities as neighborhood communities get electricity supply and more rural industries take advantage of this renewable energy source.	**(c) Conflicts:** Several conflicts that may arise can be resolved by effective communication between concerned parties. They include conflicts due to land ownership, settlements and compensations etc.
(d) Recreation and tourism: The increase storage volume in the proposed Kangimi reservoir may encourage the use of the watercourse for fishing, canoeing etc.	**(d) High Investment Cost:** Without doubt, there is a cost implication to implementing this proposed Kangimi small hydropower plant at the raised elevations. This will include cost of paying compensations, settling conflicts, constructing the required SHP equipment and facilities at the Kangimi Dam site.
(e) Optimizing Available water: Regular water releases through the tail water of the proposed KR hydropower scheme will always keep water in the main channel that can be optimized for irrigation throughout the year.	**(e) Noise and Water Pollution:** High noise and turbid water level that may arise during the construction stage that may cause problems in the neighboring rural communities. Noise sediment reduction facilities should be installed during construction stages of the project.

Table 6: Outcomes of rapid environmental impact assessments.

S/No	Project Item Description	% Total Estimated Cost
1	Engineering Studies and Project Administration	7.1
2	Dam Re-Construction Works (Raising the dam axis)	26.2
3	Spill Re-construction works	17.2
4	Power House Civil Works Construction	8.4
5	Power House Equipments	7.5
6	Tailrace Construction	5.1
7	Power Transmission Facilities (Flow valve, Governor, Turbine, Generator rotor, Transformer, Control panel & Switch board)	3.5
8	Compensation for land and properties	4.5
9	Reconstruction works on inundated road	20.5
	TOTAL	100

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