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Environmental Impact Assessment of a Small Hydropower Plant: A Case Study of Orle River Auchi

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Abstract: *An Environmental Impact Assessment (EIA) that identifies both the positive and negative environmental impacts of some significant development at the planning stage of the project is required statutorily in Nigeria in line with the provision of the Environmental Impact Assessment bill of 2017. The study carried out an environmental impact assessment on a Small Hydropower (SHP) in the Orle Valley, Auchi, Edo State. Screening and scoping processes were carried out to interact with the competent authorities, stakeholders in the community, and members of the public on the likely impacts of the project. A field survey was used to enumerate the facilities and assets in the study area. The consequence of the hydropower plant construction, operation, flooding and failure on humans, assets, use of water, and economic activities associated with the river were analyzed. The safety by design approach was used to enhance the design and operation of the reservoir to minimize the risk of its failure and disruption of economic and social activities in the affected area. The result of the study indicates a low-level risk and impact of the dam construction and operation on humans, assets, and ecosystems in the vicinity of the reservoir and downstream of the river. It was observed that the economic benefits of the dam will largely offset the aggregate cost of assets that will be consumed by the plant construction and operation. The research work established a template for the determination of EIA for small hydropower plant in developing countries.*

Keywords: *Environmental, Impact, Assessment, Small, Hydropower, Orle, Auchi*

INTRODUCTION

Environmental Impact Assessment (EIA) is a process that assesses and establishes the positive and adverse environmental effects of proposed projects before permission for implementation is considered (Pawar and Gaikand, 2020). It seeks to prevent and minimize any identified significant adverse environmental impacts of proposed projects (Parsons Creek Aggregates, 2008). The EIA brings to notice the environmental impacts of the proposed project to guide planning decisions for project implementation with the involvement of local interest groups, regulatory bodies, and the general public. Increase in population, technological advancement, and rising energy demand has created a serious strain on the environment. The effluents from manufacturing industries are discharged into the environment with negative impacts that threaten human existence and ecosystems. Also, the operations and failure of some production entities constitute a threat to humans in the immediate vicinity and the biodiversity of the entire environment. The threat of the operation of some production firms may be apparent or unnoticed with the consequence that the harm is not noticed until it reaches some dangerous proportions. The wellbeing of man and other animals on the planet is governed by the quality of the environment giving justification to the need to address environmental challenges during project planning. The EIA is a standard instrument to carry out sustainable development with the minimization of the degradation of the environment (Yusuf *et al.*, Durojaiye, 2007). In Nigeria, the environmental management structure is guided by the Environmental Impact Assessment (EIA) Bill of 2017 of the Federal Government of Nigeria (Office of Environmental Assessment Department, 2017). The Federal Ministry of Environment through its Department of Environmental Assessment and the Department of Petroleum Resources regulates the EIA processes in Nigeria. Under this law, all planned industrial projects and developmental activities that are present in the Federal Environmental Protection Agency's mandatory project list must be subjected to an EIA before approval. Ogunba (2004). The construction of hydropower stations falls within this purview.

The rapid increase in the Nigerian population and its economic progression requires electricity generation and availability (Cepin, 2011). The thermal power plants that constitute the main power supply base are plagued with low-capacity utilization as a result of numerous challenges. It has been established that in order to diversify the electrical power generation base of Nigeria for improved and sustainable power availability, the assessment and development of potential hydroelectric power sources is imperative (Olaoye *et al.*, 2016). Nigeria is endowed with several potential hydroelectric power sources that can generate substantial quantity of electricity to power industrial processes in the economy (Abdulkadir *et al.*, 2013). The main focus of research and development efforts in hydropower generation is currently on the development of small hydro technology because of the low environmental impact (Vasiliev *et al.*, 2013). Small hydropower plants have capacities between 1 – 30 MW (Directorate of Energy, 2018).

The physical environment is affected rather significantly by the development and operation of a hydropower station especially large hydropower (Bobat, 2017). The diversion of the river and associated construction work during reservoir construction negatively impact the quality of water downstream and causes a severe restriction in flow volume. This disrupts quality water availability downstream and affects the life pattern and structure of the aquatic ecosystem. The physical, geo-morphological, and chemical properties of the river may be transformed. The sudden release of water from reservoirs may cause heavy erosion that may wash away farmlands, changes erosion patterns and the quantity and nature of sediments carried downstream. All these may have far reaching effects in a particular environment (Bobat, 2017). It is essential that an Environmental Impact Assessment be carried out for every proposed hydropower project to determine the feasibility of the project from an environmental perspective. The aim of this study is to carry out an environmental impact assessment of a small hydropower plant on River Orle, Auchi, to determine the impact of the project in the immediate and extended environment. The specific objectives are to;

i. Assess the environment of the River Orle and determine the effects of the construction of a dam in the Orle valley, Warrake Road, Auchi.
ii. Assess the economic features and the damage that will accrue as a result of the dam operation and failure.
iii. Determine appropriate measures and technology to mitigate the observed impact of the project construction.

The environmental impact assessment will enable the establishment of possible damage to the environment of the plant in the future and propose appropriate remedial action to mitigate the effects. The study is concerned with technical issues of the impact on the environment of the construction of the SHP at the Orle valley.

MATERIALS AND METHODS

2.1 The Study Area

The study area is the Orle River valley located at Kilometer three Auchi -Sabogadia Ora road. The valley has a vertical height elevation of about 80.56m, longitudinal width of 2050m, and a length of 4150m. The area consists mostly of forest and sparse cultivated land. There is an abattoir which is the critical structure in the area, some few residential buildings, undeveloped buildings, and plots. It is bothered by Oshiomole village in the South-West and East, Warrake in the South, and Ayuele village in the East.

2.2 Project Design and Description

A feasibility assessment of the hydrological and hydroelectric properties of River Orle produced the result shown in Table-1.

Table-1 Hydrological and Hydro Power Characteristics of River Orle (Audu *et al.,* 2020)

	Minimum	Maximum	Average
Velocity (m/s)	0.462	0.564	0.513
Flow rate (m^3/s)	6.64	58.55	19.243
Power (MW)	3.957	33.374	9.703
Head (m)	-	50	-

The project consists of a small reservoir with an area 1000m x 4392m integrated into the Orle valley. The effective head of the dam is 50m, the average power production is 10 MW and peak power production is 18.5671MW. The project consists of 4 units of Francis turbines. The dam is equipped with spillways to evacuate excess floods. A water level sensor is provided to monitor the water level rise in case of excessive discharge. The sensor is automated to control the spillway gates to initiate the evacuation of fluid in volumes commensurate with the rate of rising of water above a benchmark level. The design is to avoid the accumulation of water in the reservoir to a level that will cause downstream flooding and excessive erosion.

2.3 Justification for the Project

The Small Hydro project is required for the generation of electric power to Auchi and other parts of Edo North. The Nigeria power generation base is plagued by low-capacity factor utilization with the generation of recent peak power of 5300 MW out of an installed capacity of 12,500 MW (Audu and Chukwuyem, 2020), which is grossly inadequate for a population of about 220 million people.

The hydropower system is nourished by rainfall and does not require expensive arrangements to obtain fuel, environmentally friendly, modular in nature, and flexible in operation with high efficiency of energy conversion and economy of operation (Meng *et al.*, 2020). Development in the field of hydro power is currently focused on SHP technology because of its minimal environmental impact. SHP is particularly suitable for Distributive Power Systems (DPR) that supply power close to the point of consumption without the requirement of an extensive power grid. The Nigeria Power Grid (NPG) is faced with myriads of problems which include high transmission and distribution losses, power lines vandalism, low level maintenance, poor monitoring and protection equipments and frequent grid failure. The SHP can supply surplus power to the NPG, and provide the spinning reserve and the grid inertia to stabilize its operation (Audu and Chukwuyem, 2020).

2.4 Methodology of Environmental Impact Assessment

The EIA was carried out in line with the basic requirements of the Environmental Impact Assessment (EIA) Bill of 2017 by the Federal Government of Nigeria (Office of Environmental Assessment Department, 2017). A summary of the basic requirements is given below;

i. Determine the scope of the environmental impact assessment (EIA) through a process of screening.
ii. Identify the key issues to be examined in more detail during the assessment including the impacts to be assessed.
iii. Provide an Environmental Statement on the EIA describing the proposed development
iv. Consider the alternatives to the proposed development that may be more environmentally acceptable.
v. Study the state of the potentially affected environment in the absence of the project to provide a baseline against which the possible effects of the project can be measured.
vi. Predict the likely significant environmental effects of the proposed development depending on the type of industry.
vii. Describe the measures designed to avoid, reduce and if possible, remedy significant environmental effects of the project.

2.5 Environmental Impact Assessment of SHP at Orle Valley

A. Determine the Scope of the Environmental Impact Assessment (EIA) through a Process of Screening.

Scope of Assessment

The scope of the project for the purposes of the EIA involved the impact of site preparation, construction and hydropower generation of the project. These include material movement, provision of access roads, water and electricity provision.

Site Clearing and Civil Work Construction

The clearing and construction-related impacts such as equipment emission, vibration and noise impacts are short-term in duration, but their impact is not significant (Huawei Technologies Nigeria Limited, 2015**)**. Also, there is no significant human habitation in the project area. The quality of surface water will largely be affected during the construction stage in the project area (Zelanakova, 2018), but the effect will be largely mitigated by the diversion of the river before major construction work

Access Road
The project site is accessed by a functional standard road, the Auchi – Sabongida road. There is no need to construct an access road through difficult terrain for personnel, material and equipment movement.

Construction, Equipment and Material Site

The location of the abattoir which is 200m by 200m is large enough for equipment and material storage. Minimum expansion may be done to increase the space with minimum effect on the environment.

Excavation Work and Waste

Excavation work for the dam will produce earth materials that need to be disposed of without nuisance to the environment. Since the dam will be located in the Orle River valley basin, minimum excavation will be required. The river basin has a vertical height of 80.56m and a longitudinal length of 2015m. Materials excavated from the basin could be arranged to be sold to the citizen of Auchi for the filling of numerous gullies within Auchi town and its surroundings which are ravaged by gulley erosion. Filling sand for building construction and repair of roads ravaged by gulley erosion is almost always in short supply in Auchi town.

Electricity and Water Access

The project site is accessed directly by high tension cables from the NPG from which power could be derived for equipment and utility consumption.

B. Identify the Key Issues to be Examined in more Detail during the Assessment including the Impacts to be Assessed and Alternatives to be Examined

The following issues are fundamental in the assessment of the effects of hydroelectric power systems on the environment.

Impact of Size, Type and Operation of Small Hydropower Plant

Plants with smaller reservoirs are generally considered to be less environmentally damaging than those with larger dams (Zelanakova *et al*., 2018). The hydro plant reservoir size was determined from the average annual flow rate determined by previous studies (Audu *et al*., 2020). The hydrological and hydroelectric characteristics of the river are shown in Table-1. The proposed Orle dam by all consideration is a small hydro dam. Some safety measures were undertaken in the design of the location of the dam. The location of the hydropower plants is at the formation of the Orle River valley to create a basin to accommodate the total reservoir volume within the depth of the valley. The gross head was determined from the longitudinal height elevation within the valley. This will create a dam that is safe from spillover across the edges even in the worst scenario of flooding.

Impact of River Diversion

An open channel of 6000m by 10m was constructed to divert the river round the project site. The construction activity was initiated during the dry periods around December when the river has very low volume flow as indicated in Fig. 1. The diversion was carried out to avoid the disruption of the flow of the river during the construction phase to minimize the impact on water use the downstream, the river ecosystem, and biodiversity.

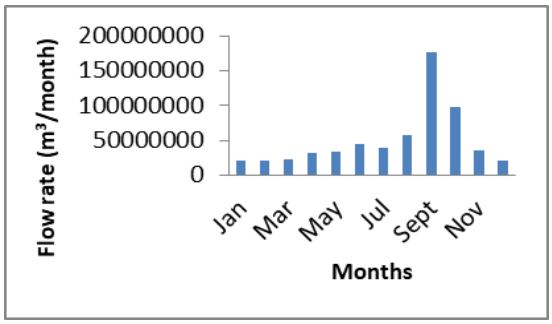

Fig. 1 Hydrograph of River Orle (Audu *et al.*, 2020)

Impact of the Reservoir

Dams have major impacts on the physical, chemical and geomorphological properties of a river. Environmental impacts of dams have largely been negative, instigating opposition to the construction of large hydropower dams (Bobat, 2018). This has shifted the focus of dam construction to SHP such as the River Orle project. The impact of the physical, chemical and geomorphological properties of the project dam were considered. The estimated area covers approximately 4500 x 1500 m^2. This land will become unusable and unavailable immediately after the barrier for the reservoir is put in place. The area was observed for the presence of endangered species. The critical infrastructure in the area is the abattoir which can be relocated. The area of the Orle valley is largely nonresidential. Farmlands are not common in the vicinity of the project sites because of the flooding characteristics of river Orle between September and October annually. The same flooding plane is to contain the dam. The major difference is that while the annual flooding water recedes from mid-October the dam storage will remain.

Sedimentation of Hydro Projects

Large dams with reservoirs significantly alter the timing, amount and pattern of river flow. (Marcinkowski and Grygoruk, 2017). This changes erosion patterns and the quantity and type of sediments transported by the river. The sedimentation in the reservoir will affect the amount and pattern of river flow which can change the erosion pattern in the area. Mud and other sediments will cover the flooded area and may alter the area ecosystem. Since removal of sediments is a normal practice in hydro dam operation, this effect is going to be minimized. The creation of the dam storage is likely to boost the area's ecosystem diversity and water use which will include a boost in irrigation activities.

Downstream Erosion

Trapping of sediments at the dam has downstream impacts by reducing the flux of sediments downstream which can lead to the gradual loss of soil fertility in flood plain soils. Clean water stripped of its sediment load flows faster downstream of dams (U.S. Environmental Protection Agency, 1981). This clean water has more force and velocity than water carrying high sediment loads and the risk of erosion of the riverbed and banks becomes higher (Marcinkowski and Grygoruk, 2017). This unnatural and forced flow occurs at a much faster rate than natural river process erosion. Consequently, the erosion of the river bed and banks may be more severe. The regulated release of high volumes of water due to heavy rains could cause more severe erosion downstream.

Impact on Fisheries

River diversion can cause freshwater challenges and negatively impact marine fisheries. Migratory fish are especially affected by the impacts of reservoir construction. Dams are barriers that could prevent migrating fishes from reaching spawning grounds. The dam is a small dam covering a length of about 4500m only compared to large dams of close to a hundred kilometers long. There will be no significant impact on fisheries in the Orle valley and downstream of it. Large populations of fish have not been observed according to interviews with people around the river. The creation of the dam will create a large volume of water for the breeding of fish which was not available with the normal flow of the river. The fishes in the river can easily migrate away from the short length of the dam.

Use of Natural Resources

The operation of the dam has no direct impact on the use of natural resources in the area. The working fluid is water which will flow naturally downstream of the dam. The water does not carry any major contaminants.

Production of Waste

There is no direct production of any waste material, pollution and nuisance by the plant. There is also no associated pollution activity of the reservoir.

Impact of Dam Failure

The impact of dam failure will release large floods of water downstream that will affect the community downstream. The communities downstream are mostly farmers. The communities are listed below.

i. Part of Auchi
ii. Ayuele kingdom
iii. Anegbete
iv. Odame
v. Ifueku

Farmlands in the above communities may be washed away. There is no direct human settlement on the part of the course of River Orle.

Loss of Lives

The assessment indicates that the loss of lives will be low because the flood is likely to occupy mostly farmland far from villages from the observed navigational course of the river and its proximity to human settlements. The loss of lives will however be circumstantial concerning people trapped in floods.

C. The State of the Affected Environment was Studied in the Absence of the Project, which provided a Baseline against which the Possible Effects of the Project were Measured

The project area was found to contain the following infrastructure in the designated area for the hydro reservoir as indicated in Table-2.

Table-2 Enumeration of facilities in the Orle Valley

Structure/Facilities	Quantity	Purpose	Remark
Public utility building	5	Assembly for religious and social functions	Most are not fully operational
Residential buildings	12	Low density area residential areas	Situated at the outskirt of the project site
Abattoir	1	Slaughtering of animals for sale to the Auchi Community	Fully operational but can be relocated
Farmlands	Sparse	Cultivation of crops	The flooding of the river limited farming activities in the valley

D. Consider the Alternatives to the Proposed Development that may be more Environmentally Acceptable

The alternatives to the project are solar photovoltaic (PV) modules and thermal power plants. The solar PV modules occupy large spaces with low level power output and high capital costs. Solar systems are suited for small power appliances. They are also affected by low solar insolation and variation in weather. Thermal power plants have problems of inadequate gas supply, low-level maintenance, and vandalism of gas supply lines. Gas is piped from locations in the Niger Delta Region which is about 300 km from Auchi. The cost of installation of the lines that are further prone to supply disruption is enormous. Thermal plants also contribute largely to the production of greenhouse gases responsible for global warming.

2.6 Technological Enhancement of Reservoirs to Mitigate Failure

The following design features have been integrated into the design of the reservoir to prevent the dam failure;

i. Spillway over top.
ii. Maximum water level sensor.
iii. Twin side spillways
iv. Enhanced structural stabilization.

A. Spill Over Top

The dam is incorporated with a spillway over the top. This is to ensure that when the maximum water level is reached, water is released across the top instead of accumulating in the reservoir. In this way, the hydraulic pressure of the water is regulated.

B. Maximum Water Level Sensor

This sensor sounds an alarm when the maximum water level of the dam is approached. This alarm will activate the spillways depending on the surge in the volume of water.

C. Twin Side Spillways

The twin spillways are incorporated into the reservoir design. The spillway which is sensored to the maximum water level will be activated to gradually spill the contents of the dam at regulated volumes to avoid flooding downstream of the reservoir.

D. Enhanced structural Stabilization

Enhanced structural stabilization for the dam is targeted at containing the maximum lateral hydraulic stress from the reservoir. Stabilization is done with concrete and boulder material well positioned around the storage area.

RESULTS AND DISCUSSION

An EIA study of the Orle River valley at KM 3 Auchi - Sabongida road was carried out in respect of the construction of an SHP dam at the valley. The anticipated level of damage to assets in the project area from the EIA is shown in Table-3.

Table-3 Anticipated level of Damage

Assets	Location of Address	Approximate Distance (Meter)	Anticipated level of damage for scenario (High, Medium and Low)
Abattoir	Beside dam	500	High
Family homes	No family home in the dam area. Occupied houses are far beyond the valley	2,500	Low
Business	Club house	200	High
Industry	No established industry in the area	Nil	Low
Fishing site	No form of fishing activity	Nil	Low
Farm land	Sparse around the area	Sparse	Low

Assessment of the Social and Economic Lives of the Communit

Assessment of the social and economic lives of the community revealed the effects summarized in Table-4.

Table-4 Occupancy of inundation Area

Asset	Anticipated level of flood severity	Typical occupancy	Estimated occupancy for the dam failure scenario
Abattoir	High	0	0
Family home	Low	300	50
Business premises	High	5	Nil
Industry	Low	Nil	Nil
Farmland	Low	67	43
Fishing site	Low	Nil	Nil

Environmental Impact on the use of Resources in the Study Area

The assessment of the anticipated level of damage shown in Table-3 indicates that the anticipated level of damage to the infrastructures in the study is generally low considering that the only eventual functional infrastructure in the area is the abattoir (meat industry). However, the entire infrastructure can easily be relocated to another side beyond the Orle Valley.

Impact on the consequence of the Dam Failure

The probability of the dam failure is very low based on the modern safety by design features that were considered in the dam design. The safety by features incorporates sensors into the dam system that will activate the opening of the spill gates to allow the passage of excess water downstream. The function is supplemented by the spillover top of the sluice gate. Dams with these features have high level of safety against failure. Adequate structural stabilization was considered in the dam construction to further eliminate the possibility of dam failure.

Impact on the Ecosystem and Biodiversity

The Orle valley witness low existence of other animal habitats due to the activity of humans around the area which also affected the biodiversity around the valley. The persistent flooding of the valley by the river is also a strong factor why the valley witnessed the low animals' presence. Other animals have migrated from the vicinity with the exception of those associated with water. More availability of water in the reservoir will enhance the lives and activity of other animals and water-related animals in the area. The presence of the dam will enhance the ecosystem and multiply the biodiversity in the area.

Impact on the use of Economic Resources in the Area and Downstream

The dam being a small dam is designed not to retain water to significantly affect the river discharge downstream. With the adoption of a uniform discharge of 19.243 m^3/s adequate flow of water will be available downstream for water usage and other utilities. Water retained in the period of surplus rain between June and October will be used to power the dam during the dry season. Consequently, there is no significant effect of the dam downstream in the retention of water. The dam will bring about increased regulated flow that will enhance both fishing and irrigation activities downstream.

Impact on Economic Activities on the Study Area

The reservoir construction will significantly boost economic activities in the area. There will be the production of electricity that will enhance economic activities in the area; water will be available for irrigation purposes and processing for pipe-borne water supply.

CONTRIBUTION TO KNOWLEDGE

The research work established a template for the determination of EIA for small hydropower plant in developing countries. Safety by design features to regulate the release of excess water from reservoirs was integrated into the design of the project to prevent flooding of rivers downstream in case of excess rainfall.

CONCLUSION

The Environmental Impact Assessment of the Construction of a hydropower Plant on Orle valley was carried out. The major findings indicate that with good safety by design features the probability of the dam failure is low. The dam is equipped with sensor-enhanced spillways that can monitor the rise in coming flood levels and release water in time to avoid dangerous levels of accumulation of flood in the dam. The impact of the disruption of economic and social activities by the construction of the dam is still low because of the low level of economic activities in the area and downstream, the only critical economic feature is the abattoir which can be relocated. The hydroelectric power plant will boost economic activity in the area by bringing stable power supply to the area; enhance farming, fishing, and irrigation activities. It will also multiply the biodervisity and bring about a stable water-related

ecosystems in the area. The economic benefits of the dam will largely offset the aggregate cost of assets that will be consumed by the dam construction.

CONFLICT OF INTEREST

There is no conflict of interest for this research work.

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