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An Investigation of the Hydro-Power Potential of the Ojirami Dam in Nigeria

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Abstract

This research investigates the potentials inherent in the Ojirami dam as a source of hydro-electric energy. To achieve this, a physical observation of some physical features of the dam site and the rainfall catchment area of the dam was carried out, and a numerical evaluation of the catchment area evaluated. Data of monthly rainfall for a period of one year (January to December, 2021) was used to evaluate the run-off water using the khosla's formula $R = P - 4.811\,T$ *. From the data, a run off coefficient was determined for the catchment area, which was subsequently used to evaluate the run-offs. Hydrograph was plotted for the catchment area and from the hydrograph, a flow duration curve and a mass curve of the flow were plotted. From these graphs, it was possible to ascertain the average discharge at the mouth of the stream where the dam is located. Possible heads of water at the dam's location were also determined and potential power output calculated. The inference drawn was that the run-off water structure has main roles to play in sustainability of the hydro-electric power potentials inherent in the Ojirami dam to optimize its hydro-power capacity*

1. Introduction

The hydro-electric power potentials of the Ojirami dam meets present trends in addressing global and the current Nigeria national energy crises which include the need to refocus on the use of renewable energy sources, environmentally friendly energy schemes, evolution of independent power production and distribution schemes, as well as reduced operating cost of power production [1].

Hydro-electric power as the Ojirami dam portends is a renewable energy scheme. Energy from flowing water is ever present in the dam, even during the dry season. Energy production in hydro schemes does not require the use of nuclear fuels, or fossil fuel which constitute serious environmental pollution [2]. Apart from the huge initial capital investment for dam construction/reconstruction and equipment procurement, operating cost for running a hydro-power plant is low compared to other types of power plants. Additionally, the lifespan of a hydropower plants runs into several decades compared to steam plants.

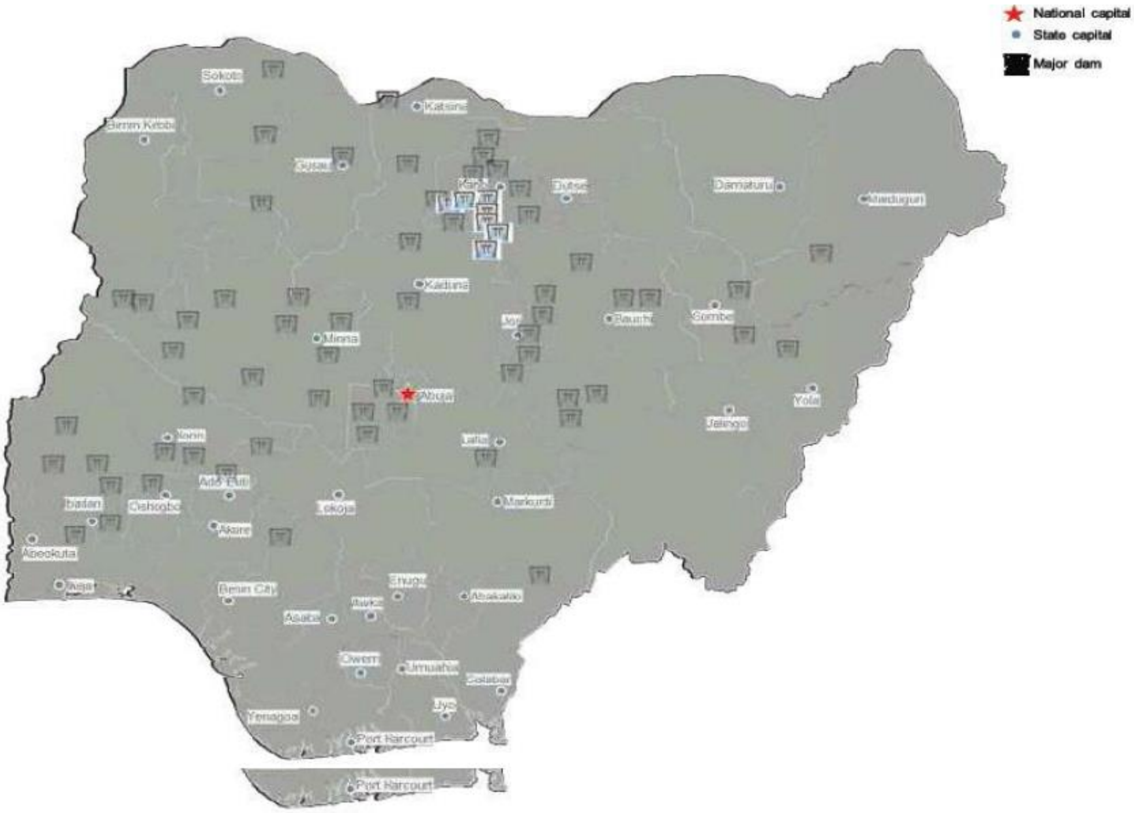

Figure 1: Dams in Nigeria
Source: *Natural Earth, African Development Bank*.

The trend in the Nigerian power sector is towards independent power production, transmission and distribution. This is because the national grid scheme that has been in use for decades has been unable to solve the Nigerian power problem. Natural features with potentials for power generation abound but are scattered all around the country. These resources, the potentials of most of which are currently being undermined, can consummately be put in place and use to generate power to feed their closest geographical areas which will sufficiently cater for the inefficient power supply experienced through the national grid. It is along these lines of reasoning that the Ojirami dam was conceived in Nigeria to cater for these needs to meet both the national and global trends.

The Ojirami dam shown in plate 1 is located in Ojirami-Dagbala village, 5 km east of Igarra town, the headquarter of Akoko-Edo Local Government area of Edo State, Southern Nigeria. According to Lukman et al., [3] Ojirami dam foundation stone was laid on the 26th of March 1971 and was commission on 20th of January 1974. The dam was constructed across River Onyami which flows into River Ose Akoko-Edo region. On 30th August 1980, the Ojirami dam failed and inundated the Akuku and Enwan communities.

Plate 1. Ojirami Dam

The dam lies within latitude 7˚17'52.41"N and longitude 6˚9'10.72"E. The western and eastern flank of the dam site is gently undulating along the traverses, with both sides sloping towards the river channel. The dam and spillway axes are oriented in West-southwest to East-northeast (WSW-ENE) while the river flows in the North –northwest to South – southwest (NNW-SSW) direction. The height of the dam is 3.9 m with a storage capacity of 45.3 million·m^3.

The dam was constructed to serve as a source of domestic and agricultural water supplies to sixteen adjoining communities in Akoko-Edo which include: Ojirami (Ojirami Petesi, Ojirami Afekunu), Dagbala, Uneme-Eturu, Akuku, Enwan, Igarra, Okpe, Ugboshi, Ibillo, Uneme-Osu, Ojah, Ayetoro, Makeke, Ososo, Uneme-Aruru, Uneme-Enekwa at an output capacity of 24 hours per day, at the construction of the dam. It is also intended to provide irrigation services to the adjoining farmland in dry seasons [4]. Today, with independent bore-holes providing domestic water supply to homes and beneficiary industries, and the near collapse of the government water supply scheme, the dam has been more or less abandoned. A close observation of the dam site reveals great potential for hydro-electric power production. With some redesign scheme, a considerable discharge large enough to power hydraulic turbines can be obtained from the dam. A reasonable head of water that will be suitable to operate reaction turbine can also be achieved. From appropriate investigations and design calculations, requisite number of turbines that can be installed to generate an amount of power supply that can justify capital investment input can be determined. Thus, potentials of the dam can be re-awakened to the benefit of all and sundry.

Several studies on dams have been carried out by researchers. These studies include that of Umaru *et al.* [5] who carried out a study on the structural failures of earth dams in Nigeria. The study investigated the reasons for failure of earth dams in Nigeria with emphasis on dams owned by the River Basin Development Authorities of the Federal Ministry of Agriculture and Water resources using Cham dam in Gombe State as case study. The general causes of earth dam failure were considered with emphasis on failures due to engineering factors. The result of the study show that Cham dam failed as a result of poor planning, inadequate study, inconsistent design, un-engineered construction and lack of dam safety monitoring team at site. There have been several cases of dam-related disasters in Nigeria with displacement of thousands of people, loss of livelihood and massive destruction of properties. These include the failures of Shiroro dam in 1999, Ojirami dam in August, 1980, Tiga dam in August 2001, Challawa dam in August, 2001, Shiroro second dam failure in September, 2003, Obudu dam in July, 2003, Igabi dam failure on river Kaduna and Cham dam in Gombe, September 1998 [6,7 and 8]. Arora [9] also showed that about 35% of failures of earth dams are due to hydraulic failures, about 30% are attributed to seepage failures and about 20% are as a result of structural failure. The remaining 7% of the failure are due to other miscellaneous causes such as accidents and natural disasters. Oyekanmi and Mbossoh [10] studied the role of dam in the realization of the sustainability agenda of the United Nations.

The seventeen (17) Sustainable Development Goals (SDGs) are linked to the proper functioning of dams as a source of municipal and rural water supply. Effect of climate change on dam, its failures and operational impact on agriculture, biotic and abiotic ecosystem were also considered. The inference drawn was that water structure such as dams has major roles to play in sustainability and many of the SDGs can be achieved by functional water system at all levels. Osimen and Elakhame [11] studied the physical and chemical hydrology of Ojirami reservoir **between** January 2009 and December 2010 to monitor the monthly and seasonal variations in the limnological variables (Variables associated with the scientific study of bodies of fresh water (such as lakes). Water samples were collected monthly from six stations (A, B, C, D, E and F) and analyzed following standard methods. The outcome of the study showed that the measured physical and chemical parameters were within the acceptable or permissible limits of Standards Organization of Nigeria (SON) and World Health Organization (WHO) guidelines. Ozegin et al [4] revealed the significance of electrical resistivity method on effect of geodynamic activities on an existing dam monitoring facility at Ojirami Dam, Edo State, Nigeria. The study considered the effect of geodynamic activities on Ojirami Dam. The research aimed at post construction monitoring of the Dam with a special focus on the status of the structural trends, setting in term of its integrity and to raise awareness towards environmental safety in the area of periodic monitoring of existing Dams. Geodynamic is a process that constantly and continuously taking place with time arising from stress and strains, temperature variations, internal and external pressure and gradual earth movement results from weathering, cracks, joining, fracturing and faulting [12]. According to Foster et al., [13] and Ikard e al., [14] early detection of seepage zones can help ensure that aging dams are properly maintained and that failures as a result of seepage are averted. Olasunkanmi et al., [15] noted that seepage is one of the major reasons for embankment dam failures and may constitute a significant potential social dislocation (displacement of people, loss of valuable life and properties) if not examined. Abdullateef and Ifabiyi [16] advocated that overall sustainability rests on the excellent relationship between the three dimensions of sustainability namely: social, economy and the environment. The authors noted that water is a factor for economic development at all levels and for all users and that global needs are not showing any sign of plummeting due to population growth.

The objective of this study is to investigates the potentials inherent in the Ojirami dam as a source of hydro-electric power generation. The number of advantages inherent in tapping the hydro-power potential of the dam were also considered.

2. Methodology

2.1 Research Method

The details of the Ojirami dam performance history was gotten by collecting and analyzing all available data on operational life, construction, design, and planning of the dam. Several official visit were paid to the dam site and assessments were carried out on different parts of the dam body. Photographs were also taken to highlight some landscapes in order to aid interpretation.

2.1.1 Survey of Dam's Catchment Area

The Ojirami dam is built at the mouth of a local stream which empties its water into an expanse of a lowland flood plain. Several smaller streams within and around the dam's catchment area empty their own run-off water into the main stream that feeds the dam's site. The dam's catchment area is essentially the hilly terrain of Igarra land and its environment which is associated with considerable amount of underground water. Consequently, the dam site is fed, not only with surface run-off water but a considerable amount of underground run-off water as well. This makes for an extended catchment area stretching across a length of about 10km and breadth of about 7km. This gives a catchment area of about 23km × 12km = 270 km^2.

2.1.2 Extraction and Analysis of Rainfall Data (For year 2021)

Table 1 depicts the monthly rainfall distribution for the month of January to December 2021.

Table 1: Rainfall distribution in 2021

S/N	MONTH	RAINFALL(CM)	AVERAGE MONTHLY TEMP.
1	January	2	20^{0}C
2	February	1	21^{0}C
3	March	12	21^{0}C
4	April	20	21^{0}C
5	May	25	21^{0}C
6	June	45	20^{0}C
7	July	60	21^{0}C
8	August	15	20^{0}C
9	September	60	20^{0}C
10	October	45	21^{0}C
11	November	15	22^{0}C
12	December	2	20^{0}C

The rainfall distribution as extracted from records of the rainfall pattern in the equatorial rainforest region of Igara in Edo state, which the dam's location happens to have two peaks of rainfall periods; June/July and September/October. These months furnish maximum run-off and hence, discharge around the dam. Generally, the rainfall pattern furnishes a considerable discharge that can guarantee decent power output from a hydro-plant between the months of April and November. Scanty rainfall and possible associated discharge in the months of December, January and February calls for special design at the dams site for a hydro-power plant powered by the dam to remain viable in these months.

2.2 Preliminary Evaluations

The preliminary evaluations carried out on the Dam's Catchment Area is Approximately 23km × 12km = 276km^2

2.2.2 Run-off Discharge and Run-off Coefficient

The run-off of a dam's site is the amount of water that finds its way to the pool at the dam site from within the catchment area of the dam. The run-off could be surface run-off as well as underground run-off. The design interest is the total run-off available as water power at the dam's pool. In hilly areas such as the case of catchment area of the Ojirami dam. The underground run-off contributes considerably to the total run-off of the dam. Run-off can be evaluated as yearly run-off, monthly run off, weekly run-off, daily run-off, hourly run-off or as run-off per second. Run-off per second constitutes the discharge of the dam. Thus, if R is yearly run-off in m^3/year and Q is discharge at dam's gate, in m^3/s, then

$$Q = \frac{R}{364.25 \times 24 \times 3600} \text{ (in m}^3\text{/s)} \quad (1)$$

Q can be similarly evaluated from run-off values expressed in other units.

Run-off is usually less than the total yearly precipitation or annual rainfall amount due to factors such as evaporation, seepage, local average, temperature, etc. The relationship between run-off and rainfall amount has been variously expressed by researchers. Notable among these is the Khosla's formula given by

$$R = P - 4.811T \quad (2)$$

where

R = run-off (mm)

P = rainfall amount (mm)

And T = temperature (^{0}C)

This formula is particularly very suitable for rocky areas like the Ojirami dam catchment area where permeability is low because of the rocky nature of the terrain and a relatively large percentage of the run-off is underground run-off.

This formula often gives negative values of run-off, for very small values of rainfall amount. Such negative values point toward backward flow of underground water from the dam's pool to nearby underground pools though this may not necessarily be the case: In this study, Khoslas formula was used to evaluate the values of monthly run-off from rainfall values of each month as shown. Table 2 show the run-off evaluation Table from rainfall measurements

Table 2: Run-off evaluation table from rainfall measurements

S/N	**Rainfall Amount (mm)**	**Temperature T (^{0}C)**	**Evaluation**	**Run-off R (mm)**
1	20	20	20– 4.811 × 20	- 76.22
2	10	21	10 - 4.811 × 21	-91.03
3	120	21	120 – 4.811 × 21	18.97
4	200	22	200 - 4.811 × 22	94. 16
5	250	21	250 – 4.811 × 21	148.97
6	450	20	450 – 4.811 × 20	353. 78
7	600	21	600 – 4.811 × 21	498.97
8	150	20	150 – 4.811 × 20	48. 97
9	600	21	600 – 4.811 × 21	503. 78
10	450	22	150 – 4.811 × 22	348. 97
11	150	22	150 – 4.811 × 22	44. 16
12	20	20	20 – 4 4.811 × 20	-76.22

In Table 2, a mathematical procedure entailing the evaluation of squares of values of run-off R^2 and of rainfall amount P^2, summing up each variable to obtain ΣR^2 and ΣP^2 and thereafter finding the square root of their ratio, i.e. $\sqrt{\frac{\sum R^2}{\sum P^2}}$ gives a value that approximates the run-off coefficient of the catchment area observed experimentally for rainfall measurements for heavy down pours or storms, vis -a-vis run-off measurements observed around the dam basin. Hence in this study, the run-off coefficient (ROC) for the catchments area of the dam is evaluated using

$$ROC = \frac{\sum R^2}{\sum P^2}$$

With rainfall amount and run-off values recorded in table 2, ΣR^2 and ΣR^2 were calculated thus: ΣR^2 = 805, 377 and ΣP^2 = 1,287, 800

Hence $ROC = \sqrt{\frac{805{,}377}{1{,}287{,}800}} = \sqrt{0.624}$

$$ROC = 0.79$$

2.3 Flow Duration Curve around Dam

The flow duration curve is a plot of available run-offs for a given percentage of time periods out of the twelve months of the year. The flow duration curve is obtained from the monthly run-offs arranged from the smallest to the largest with respect to the percentage of time (number of months out of twelve months) that the run-offs are available. The flow duration curve helps to obtaining a design that will guarantee a desired power output with available flow and to know modifications in dam construction that need to be made to alter flow, and consequently, power output. Table 4 shows the table used to evaluate flow duration parameters for plotting the flow duration curve.

3. Result and Discussion

The hydrograph of the catchment area, the run-off curve and the mass curse of water around the dam site are necessary in analyzing the hydropower potential of the dam.

3.1 Hydrograph of Catchment Area

A hydrograph is a plot of the volume of monthly run off over a period of time say a year. It is usually expressed in cubic metres per month. A hydrograph is plotted from the rainfall distribution of Table 1. The catchment area evaluated in section 2.2.1 and the run-off coefficient determined in section 2.2.2

Thus, monthly volume of run-off water V= (Monthly rainfall) × (Catchment area) × ROC

for example, run-off water for the month of January = $0.2 \times 27^6 \times 1060.79$

$$= 43608000\, m^3$$

$$= 43.61 \text{ million cubic metres}$$

Evaluation for other months is similarly carried out and the results depicted in Table 3.

Table 3: Result of Monthly Volume of run-off water

Month	**Rainfall amount (m)**	**Run-off (Millions m^3)**
Jan	0.02	4.4
Feb	0.01	2.2
March	0.12	26.2
April	0.20	41.5
May	0.25	49.7

June	0.45	89.4
July	0.60	32.7
Aug	0.15	89.4
Sept	0.60	130.8
Oct	0.45	89.4
Nov.	0.15	32.7
Dec.	0.02	4.4

Table 4 clearly depict the flow duration of the Ojirami Dam for year 2021while Figure 2 and Figure 3 show the flow duration curve and cumulative run-off chart respectively.

Table 4: Flow Duration of Ojirami Dam for year 2021

Run-off per month (millions) of cubic metre	**Total number of months during which flow is available**	**Percentage time during which flow is available**
2.2	12	100.0
4.4	11	91.7
26.2	9	75.0
32.7	8	66.7
41.5	6	50.0
49.7	5	41.7
89.4	4	33.3
130.8	2	16.7

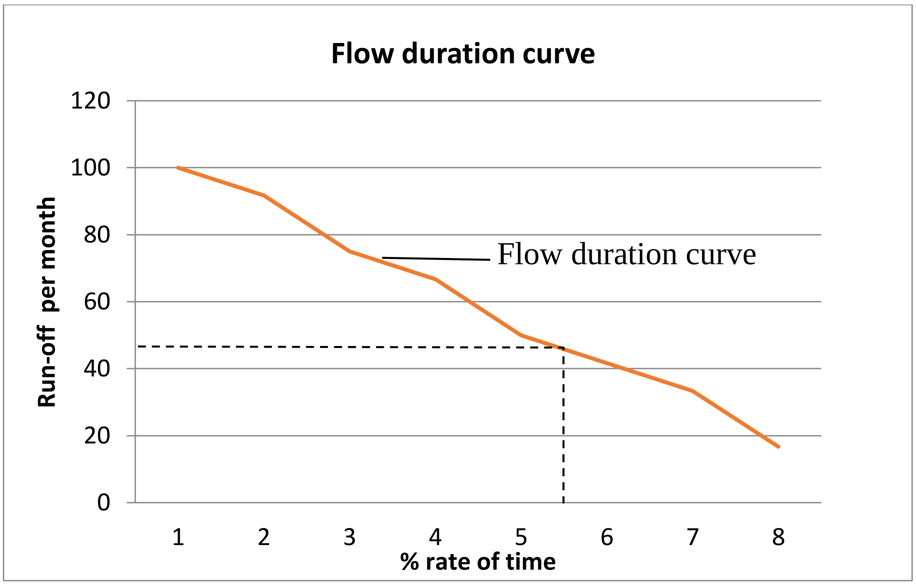

Figure 2: Flow duration curve

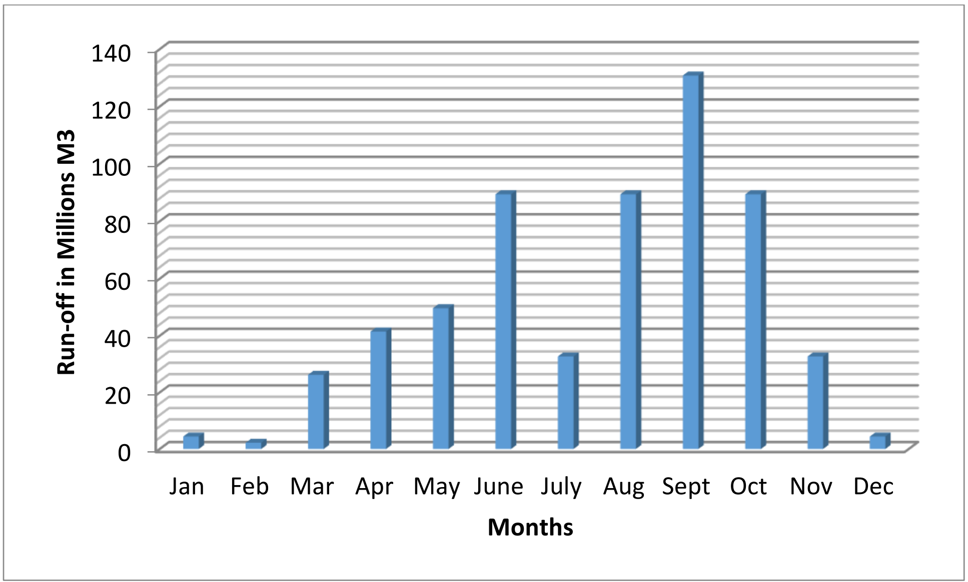

Figure 3: Cumulative run-off chart

3.2 Mass Curve

A mass curve is a plot of the cumulative mass of water (run-off) with time as collected in a dam's storage pool. The mass curve enables the designer determine the required capacity of the dam's reservoirs for an intended uniform flow of water per month throughout the year. It also enables the determination of the spill-way capacity for the dam.

To plot the mass curve, a cumulative run-off table for the various months of the year needs to be obtained as shown in Table 5. From the Table, the cumulative values of quantity of water in millions of cubic metre were plotted against the corresponding months.

Table 5: Cumulative Volume of run-off

Months	**Run-off In (x 10 km^2)**	**Cumulative Volume of run-off x 10 m^3**
1	20	20
2	10	30
3	120	150
4	200	350
6	450	1050
7	600	1650
8	150	1800
9	600	2400
10	450	2850
11	150	3000
12	20	3020

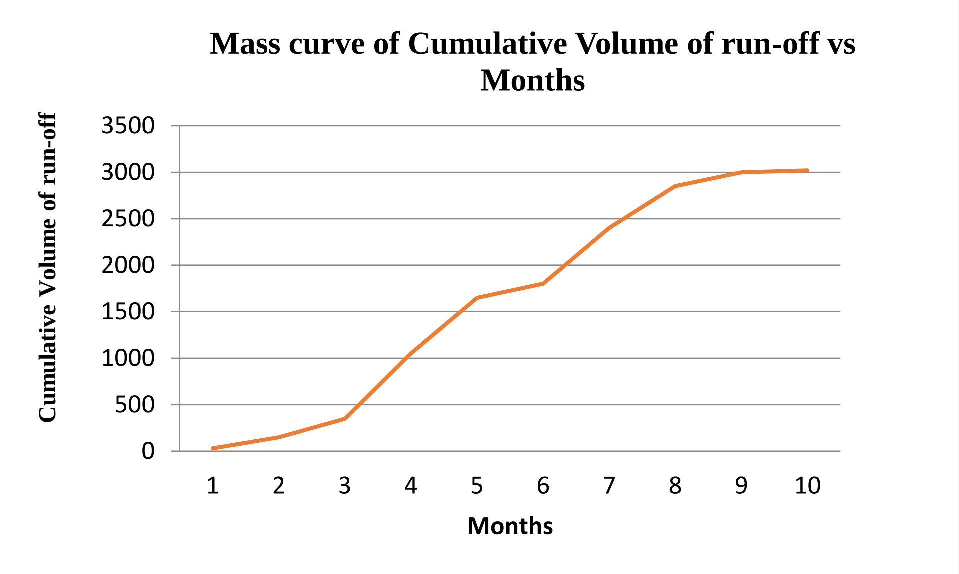

Figure 4: Mass Curve of the Ojirami dam for year 2021

Figure 4 displays the correlation of result obtained from the cumulative run-off for the various months of the year 2021.

From the mass curve, the capacity of the dam for any interval of months of interest, particularly the peak months can be easily determined and the dam designed accommodate this capacity. Bearing in mind the discharge from the dam within the time interval of interest. The dam capacity for the months of peak run-off from the mass curve plotted above can be evaluated as being approximately equal to (2850 –1800), less discharge of September = 1050 x 106 m^3 less discharge of September. It can also be evaluated as (1050 – 350), less discharge of June = 700 x 106 m^3 less discharge of September which is a more realistic value of dam capacity to use for design.

4. Conclusion

This study has been able to unravel the various potentials inherent in the Ojirami dam as a source of hydro-electric power plant. The Ojirami dam was discovered to have a great potential to serve as a site for hydro - electric power plant. From its catchment area, a discharge is realizable and with this, a potential for generating appropriate Mega Watt of electricity is inherent. With a redesign that will involve erection of an embankment and a reservoir and with the installation of appropriate turbines and pumps, the calculated water power potential of appropriate Mega Watt or even more is realizable. To this end, a dam of capacity 1050 x 10^6 m^3 which is able to take the peak rainfall season's run-off will be appropriate.

5. Conflict of Interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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