Proceedings of IOE Graduate Conference, 2019-Winter
Peer Reviewed
Year: 2019 Month: December Volume: 7
ISSN: 2350-8914 (Online), 2350-8906 (Print)

Impact of Reservoir Sedimentation on Hydroelectric Power Generation: Case Study of Kulekhani First Hydropower Station

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Abstract

Reservoir Hydropower Plants are more reliable than the Run-off Plants. Kulekhani First Hydropower Station (KL1HPS) is the reservoir type Hydropower Station. It is 60 MW plant and is very reliable power plant of Nepal. Sediment data from the primary and secondary sources were taken for analysis. Trend lines and bar charts were used for analysis and forecasting purpose. The reservoir is being filled by sediment after its commissioning in 1982 and annual siltation rate in active volume is found to be 0.65 Mm^3. It is estimated that active volume will be filled in 2100 AD which means the estimated life is about 80 years from now. With the decrease of the active volume, the energy generation capacity of KL1HPS is also decreasing and after about 80 years the KL1HPS plant will be run off river plant. Also the revenue generation of KL1HPS is decreasing and after 80 years the revenue generation from the active volume will be almost zero.

Keywords

Sediment–Reservoir–Hydropower–Active Volume

1. Introduction

Access to energy is a key pillar for human wellbeing, economic development and poverty alleviation. Ensuring everyone has sufficient access is an ongoing and pressing challenge for global development. Electricity continues to position itself as the "fuel" of the future, with global electricity demand growing by 4% in 2018 to more than 23,000 TWh [1]. In the context of Nepal, the electricity consumption and the number of consumers are increasing per year and total energy consumption in FY 2018/19 was 6,394.38 GWh, an increase by 13.89 % over the corresponding figure of 5,614.59 in the FY 2017/18 [2]. Among the different means of electricity generation, hydropower is one of the convenient and most widely used technique in electricity generation. Electricity generation from hydropower projects achieved a record 4,200 terawatt hours (TWh) in 2018, the highest ever contribution from a renewable energy source, as worldwide installed hydropower capacity climbed to 1,292 GW [3]. On the other hand, Nepal has huge potential for hydropower development. The rough estimate of the potential is more than 80,000 MW. However, the installed hydro capacity as of 2018 is less than 1,000 MW [4].

Nepal is blessed with huge capacity of hydropower. Reservoir hydro is more reliable than ROR hydro project. Reservoir sedimentation is a global challenge. The current estimate of total reservoir storage worldwide is about 7,000 km^3 with estimated loss of approximately 45 km^3 per year [5]. It has become one of the obstacles in the development and operation of hydroelectric power plant. It interferes the operation of hydropower, because the operation of hydropower depends on the availability of sufficient water for hydroelectric power to operate. A study by [6] is one of the most important on reservoir sedimentation. According to the author, the average useful life of reservoirs in the world has decreased from 100 to 22 years and the average annual loss of volume of the reservoirs caused by silting is 1%, which ranges from one region to another.

The main aim of this research is to find out the impact of reservoir sedimentation on hydroelectric power generation of Kulekhani First Hydropower Station.

2. Methodology

Following methodologies were adopted for the study. The research methodology includes Literature Review, Data Collection, Result and Discussion and

Conclusion and Recommendation which are described below in detail.

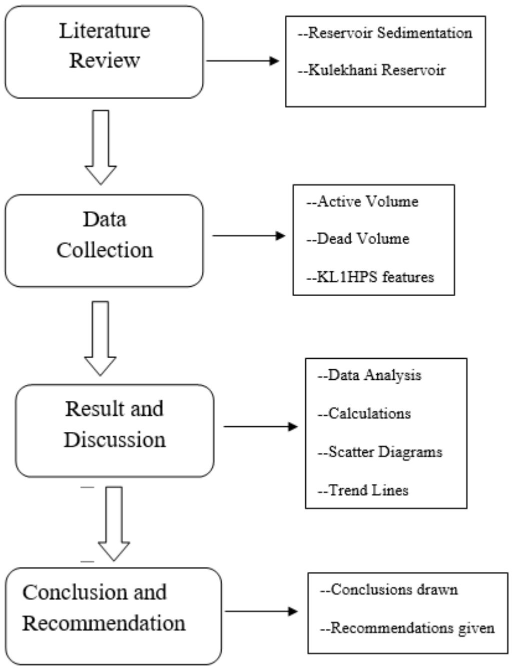

Figure 1: Research Methodology Chart

Literature Review

Reviewing of the literature gives insight and knowledge of the subject matter. Different literatures relating to the reservoir sedimentation was studied in detail. Related journals and papers are to be studied in detail and necessary data were referred from them. Mainly the literatures related to reservoir sedimentation and Kulekhani Reservoir were studied.

Data Collection

Different reservoir sedimentation data were taken. Also the features of power station were taken. The data collection was mix of primary and secondary data. Primary data were collected from the bathymetric survey by NEA. Secondary data of sedimentation was collected from different research articles. The data related to Total, Active and Dead volume of the reservoir in different time periods were collected. Also data were collected of the salient features of KL1HPS.

Result and Discussion

Active Volume, Energy Generation and Revenue Generation

At first, the data taken from different sources were sorted out in the table. Data were of the total, active and dead volume of the reservoir in millions cubic meter. Then after calculation was done to find out the electricity produced in KL1HPS from each m^3 of reservoir water.

Formula used to calculate overall efficiency is

$$P = \rho g H Q \eta$$

Here,

P = Output power (W),

ρ = Density of water (kg/m^3),

g = Acceleration due to gravity (m/s^2),

H = Rated Head (m),

Q = Flow rate (m^3/s) &

η = Overall Efficiency

Formula used to calculate electricity produced from each m^3 of reservoir water is

$$E = \frac{H \rho g \eta}{3600}$$

Where,

E = Electrical Energy produced from each m^3 of reservoir water (Wh/m^3),

ρ = Density of water (kg/m^3),

g = Acceleration due to gravity (m/s^2),

H = Rated Head (m) &

η = Overall Efficiency

Table was generated to find out the energy generation in different time periods. It was assumed that the annual energy generated is the energy that is produced if whole reservoir water capacity was used in energy generation.

Scatter diagram was plotted for active volume vs. year and energy generation vs. year. Trend line was added to the scatter diagram to obtain trend line equation and R^2 value. With the help of equations obtained from the trend lines, the forecasting of the active volume and energy generation was done for the year 2020, 2050, 2070, 2099 and 2100 AD. Values were also plotted on the bar chart. Taking PPA rate for reservoir hydropower for dry season, revenue generation was also estimated and forecasted for 2020, 2050, 2070, 2099 and 2100 AD. Revenue generation with forecasting was plotted on the bar chart.

Conclusion and Recommendation

Based on the results obtained from the analysis, conclusions were drawn. Recommendations were given for the techniques of the sediment removal process and managing the sediment.

3. Result and Discussion

The actual survey data for the sedimentation of Kulekhani Reservoir was taken from the different sources and following analysis were done. Here, it is assumed that the annual energy generation is generated energy if all the active volume is used in electricity generation.

Table 1: Volume of Kulekhani Reservoir in different time periods [7, 8]

Year	Storage of Reservoir		
	Total volume Mm^3	Active Volume Mm^3	Dead volume Mm^3
1982	85.30	73.30	12.00
1993	75.11	69.00	6.11
1994	72.41	69.66	2.75
1995	70.83	67.78	3.05
2017	58.64	51.61	7.03

Calculation of Electricity produced from each m^3 of reservoir water (Data were taken from standard brochures)

$$P = \rho g H Q \eta$$

Here,

P = Output power = 60 MW,

ρ = Density of water = 1000 kg/m^3,

g = Acceleration due to gravity = 9.8 m/s^2,

H = Rated Head = 550 m,

Q = Flow rate = 13.1 m^3/s &

η = Overall Efficiency

From the above equation the overall efficiency is calculated as 85%.

Again,

$$E = \frac{H\rho g\eta}{3600} Wh$$

Where,

E = Electrical Energy produced from each m^3 of reservoir water,

ρ = Density of water = 1000 kg/m^3,

g = Acceleration due to gravity = 9.8 m/s^2,

H = Rated Head = 550 m &

η = Overall Efficiency = 85%

Thus Electricity produced from each m^3 of reservoir water is calculated as 1.27 kWh. Thus assuming 1m^3 volume of reservoir water produces 1.27 kWh, below table can be generated.

Table 2: Active Volume of Kulekhani Reservoir and Theoretical Energy Generation of Kulekhani First HPS in different time period

Year	Active volume Mm^3	Energy Generation MWh
1982	73.3	93257.00
1993	69.00	87786.26
1994	69.66	88625.95
1995	67.78	86234.10
2017	51.61	65661.58

Scatter diagram was plotted with year vs active volume. Trend line was added on the scatter diagram so the equation of the line with R^2 value was found. Also scatter diagram was plotted with Year vs Energy Generation. Trend line was added on the scatter diagram so the equation of the line with R^2 value was found.

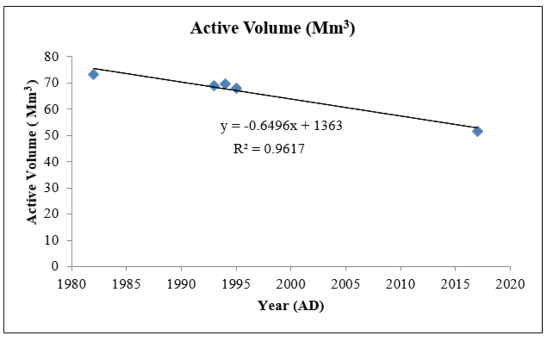

Figure 2: Change in Active Volume of Kulekhani Reservoir with time

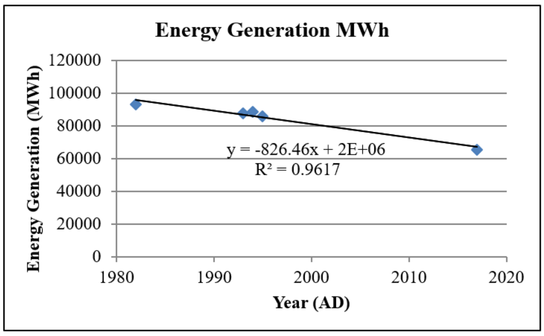

Figure 3: Change in Theoretical Energy Generation from KL1HPS with time

Figures 2 and 3 show that the active volume of Kulekhani Reservoir is decreasing at the rate of 0.65 Mm^3 per year and energy generation of KL1HPS is decreasing at the rate of 826.46 MWh per year.

With the help of equations obtained from the trend lines, the forecasting of the active volume and energy generation was done for the year 2020, 2050, 2070, 2099 and 2100 AD. The values were plotted on the Bar Chart.

Table 3: Active Volume of Kulekhani Reservoir and Theoretical Energy Generation of Kulekhani First HPS in different time period with forecasting

Year	Active volume Mm^3	Energy Generation MWh
1982	73.3	93257.00
1993	69.00	87786.26
1994	69.66	88625.95
1995	67.78	86234.10
2017	51.61	65661.58
2020	52.02	66183.21
2050	32.55	41412.21
2070	19.57	24898.22
2099	0.749	952.93
2100	0.100	127.23

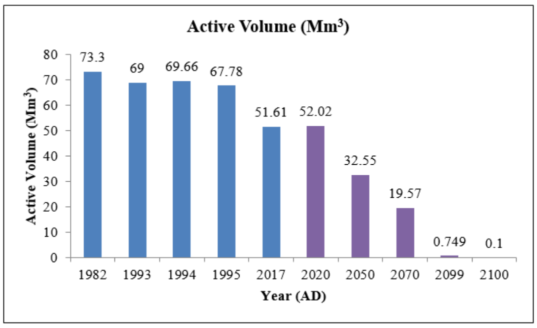

Figure 4: Change in Active Volume of Kulekhani Reservoir with time with forecasting

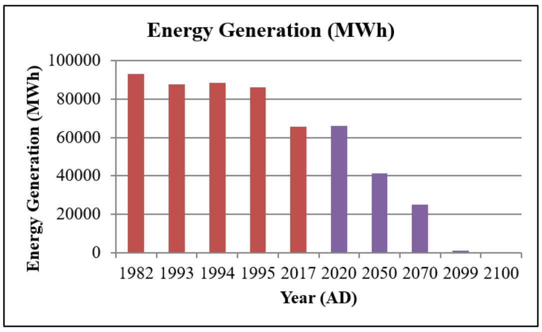

Figure 5: Change in Theoretical Energy Generation from KL1HPS with time with forecasting

Figures 4 and 5 show that the active volume of Kulekhani Reservoir and energy generation of KL1HPS is decreasing and will be about zero on 2100 AD. Then after KL1HPS will be Run-off River Plant.

Taking the PPA rate of NRs 12.40 per kWh [4] for reservoir hydropower plant for dry season, the revenue was calculated as follows. Also it was shown in bar chart.

Table 4: Active Volume of Kulekhani Reservoir and Theoretical Energy Generation with estimated revenue generation of Kulekhani First HPS in different time periods with forecasting

Year	Active Volume Mm^3	Energy Generation MWh	Revenue (in Million NRs.)
1982	73.30	93257.00	1156.39
1993	69.00	87786.26	1088.55
1994	69.66	88625.95	1098.96
1995	67.78	86234.10	1069.30
2017	51.61	65661.58	814.20
2020	52.02	66183.21	820.67
2050	32.55	41412.21	513.51
2070	19.57	24898.22	308.74
2099	0.749	952.93	11.82
2100	0.100	127.23	1.58

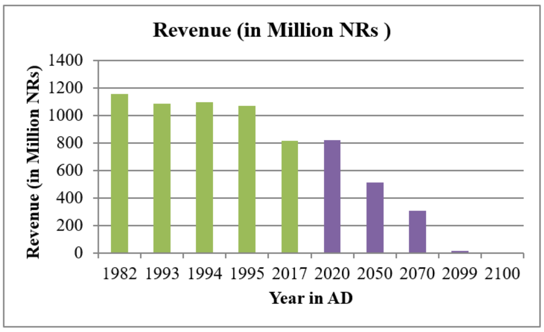

Figure 6: Change in Revenue Generation from KL1HPS with time with forecasting

Figure 6 shows that revenue generation from KL1HPS is decreasing and revenue generation from active volume of KL1HPS will be about zero in 2100 AD.

4. Conclusions

i. The annual siltation rate in active volume in Kulekhani Reservoir is found to be 0.65 Mm^3.

ii. The annual siltation rate of Kulekhani reservoir is high and it is estimated that active volume will be filled in 2100 AD which means the estimated life is about 80 years from now.

iii. With the decrease of the active volume, the energy generation capacity of KL1HPS is also decreasing at the rate of 826.46 MWh per year and after about 80 years the KL1HPS plant will be run off river plant.

iv. Analysis shows that NEA is getting huge financial loss due to deposition of sediment and if proper action is not taken, loss will increase.

5. Recommendations

i. Proper sediment removal techniques such as Dredging, Dry Excavation or Hydrosuction Sediment Removal System (HSRS) technology should be implemented so as to flush out the sediments deposited in the Kulekhani Reservoir.

ii. The intakes of the reservoir shall be monitored and measures should be taken to stop the sediment before the intake.

iii. Yearly bathymetric survey of the reservoir is necessary for proper understanding of sediment condition in the reservoir.

iv. Proper techniques should be used to avoid the landslides and erosion from the sides of the reservoir.

References

[1] IEA. Global energy demand rose by 2.3% in 2018, its fastest pace in the last decade, 2019.

[2] NEA. Nea, a year in review 2018/19. Technical report, NEA, 2019.

[3] IHA. 2019 hydropower status report—international hydropower association, 2019.

[4] Prakash Kaini and George Annandale. Hydro review: The way forward for nepal's hydropower development, 2019.

[5] Alessandro Palmieri, Farhed Shah, George W. Annandale, and Ariel Dinal. Reservoir conservation volume i the rescon approach economic and engineering evaluation of alternative strategies for managing sedimentation in storage reservoirs. Technical report, The World Bank, 2003.

[6] K. Mahmood. Reservoir sedimentation- impact, extent, and mitigation. Technical report, The World Bank, 1987.

[7] Dambar Bdr Shrestha and Niroj Karmacharya. Report on kulekhani reservoir sedimentation study. Technical report, NEA, 2017.

[8] Keshar Man Sthapit. Sedimentation monitoring of kulekhani reservoir. In *The International Conference on Reservoir Sedimentation*, Fort Collins, Colorado, USA, 1996.