TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

Thesis No: M-109-MSESPM-2015/2019

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

by

Ramesh Shrestha

A THESIS

SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE IN

ENERGY SYSTEMS PLANNING AND MANAGEMENT

DEPARTMENT OF MECHANICAL ENGINEERING

LALITPUR, NEPAL

NOVEMBER, 2019

COPYRIGHT

TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

DEPARTMENT OF MECHANICAL ENGINEERING

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"Impact of Reservoir Sedimentation on Hydroelectric Power Generation : Case Study of Kulekhani First Hydropower Station"** submitted by Ramesh Shrestha, in partial fulfilment of the requirements for the degree of Master of Science in Energy Systems Planning and Management.

____

Supervisor, Dr. Rajendra Shrestha
Professor
Department of Mechanical Engineering

____

External Examiner, Er. Sandeep Joshi
Assistant Manager
Nepal Electricity Authority

____

Committee Chairperson, Dr. Nawraj Bhattarai
Head
Department of Mechanical Engineering

Date:

ABSTRACT

Reservoir Hydropower Plants are more reliable than the Run-off Plants. Kulekhani First Hydropower Station is the reservoir type Hydropower Station. It is 60 MW plant and is very reliable power plant of Nepal. Electricity produced from each m^3 of reservoir water is calculated as 1.27 kWh. Sedimentation 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 sedimentation rate in total volume is found to be 0.73 Mm^3 and in active volume is found to be 0.65 Mm^3. 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. It is estimated that active volume will be filled in about 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.

Use of sediment removal system will gradually decrease the sediment content in the reservoir. The time period for dredging of all the sediments in active volume is found to be about 8 years and total cost incurred is found to be NRs. 21.57 Billion with simple payback period of about 50 years. The time period for dry excavation of all the sediments in active volume is found to be about 1 year and total cost incurred is found to be NRs. 26.98 Billion with simple payback period of about 78 years.

.

ACKNOWLEDGEMENTS

I sincerely thank all the people who provided the assistance, encouragement and constructive criticism leading to the completion of this thesis. I would like to express my gratitude to the Department of Mechanical Engineering, Institute of Engineering, Tribhuvan University for providing me an important platform to materialize out engineering knowledge gained during Masters program.

A perfect guidance with regular encouragement from my thesis supervisor Dr. Rajendra Shrestha, Professor, Department of Mechanical Engineering has made me indebted.

I am very greatful to my Head of Department Dr. Nawraj Bhattarai, Program Coordinator Dr. Shree Raj Shakya, Deputy HOD Sanjaya Neupane, Assistant Professor Laxman Motra, Assistant Professor Neeraj Adhikari and all teachers of the department who helped me in my thesis works.

I express my humblest gratitude to Plant Manager Ram Kumar Yadav, Civil Engineer Suman Shrestha, Electrical Engineer Bibas Raj Acharya, Mechanical Engineer Narendra Kumar Mandal, Mechanical Assistant Engineer Vishm Raj Chaudhary, Civil Foreman Bibek Timsina and all staffs of Kulekhani First Hydropower Station who helped me in providing necessary data and suggestions and supporting in my thesis related works.

I am very thankful to my Engineer friends Nipesh Regmi, Rama Sapkota, Sanjaya Pathak, Sajendra Man Bajracharya, Atmesh Poudyal, Prabesh Raj Devkota, Ganeshram Karmacharya, Chiranjibi Acharya, Shyam Maharjan and Mahesh Bashyal for their support, help and encouragement in each and every steps of my thesis works.

Last but not the least, I would like to acknowledge with gratitude, the continuous support and love of my family - my wife, Meela; my daughter, Jeeshna; my brothers, Dipesh and Pujan. Their continuous help and encouragement had always inspired me for my thesis works.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

FY	Fiscal Year
GW	Gigawatt
GWh	Gigawatt Hour
HPP	Hydro Power Project
HPS	Hydro Power Station
HSRS	Hydrosuction Sediment Removal System
KL1HPS	Kulekhani First Hydropower Station
kW	Kilowatt
kWh	Kilowatt Hour
Mm^3	Million Meter Cube
MW	Megawatt
MWh	Megawatt Hour
NEA	Nepal Electricity Authority
NRs.	Nepali Rupees
PPA	Power Purchase Agreement
ROR	Run Off River
TWh	Terawatt Hour

CHAPTER ONE: INTRODUCTION

1.1 Background

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 (IEA, 2019). 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 (NEA, 2019). 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 (IHA, 2019). 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 (Kaini & Annandale, 2019).

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 (Palmieri, et al., 2003). 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 the World Bank presented in (Mahmood, 1987) and cited by Carvalho et al. (2000) 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.

1.2 Brief Introduction of Kulekhani First Hydropower Station

Kulekhani –I, located at Dhorsing, Makwanpur is the only reservoir type Hydro-electric Power Station in Nepal. It is situated in Lower Mahabharat Range of Makwanpur District, Central region of Nepal at about 30 Km to the Southwest of Kathmandu, whereas the Kulekhani Dam itself is located at about 21 Km Southwest of Kathmandu. It covers two basins of different river systems i.e. the Kulekhani river basin and the upper Rapti river basin neighbouring to south of the Kulekhani river basin. Its Installed Capacity is 60 MW with two units of 30 MW each. This station was designed as a peaking power station but it is often operated to the system requirements for voltage improvement & system stability.

Table 1.1 Salient Features of Kulekhani First Hydropower Station

Type	Storage
Location	Dhorsing, Makwanpur
Installed Capacity	60 MW
Rated Head	550 m
Catchments Area	126 km^2
Maximum Discharge	13.1 m^3/sec
Turbine No. and Type Installed Capacity Rated Speed	 Two, Vertical Shaft Pelton 30 x 2 MW 600 rpm
Generator Rated Capacity Generating Voltage Frequency	 35 MVA 11kV 50 Hz
Dam	Zoned Rock Fill Dam with Inclined Core, 114m high, 406m crest length
Headrace Tunnel	Circular Section, Ø 2.5m x 6,233m in long
Penstock	Ø 2.0-1.5m, 1324m length
Main Transformer	Two, 35 MVA, 11/66 kV

(Source : Brochure of Kulekhani First Hydropower Station, 1982)

Figure 1.1 Kulekhani Reservoir *(Source: Google Earth, 2019)*

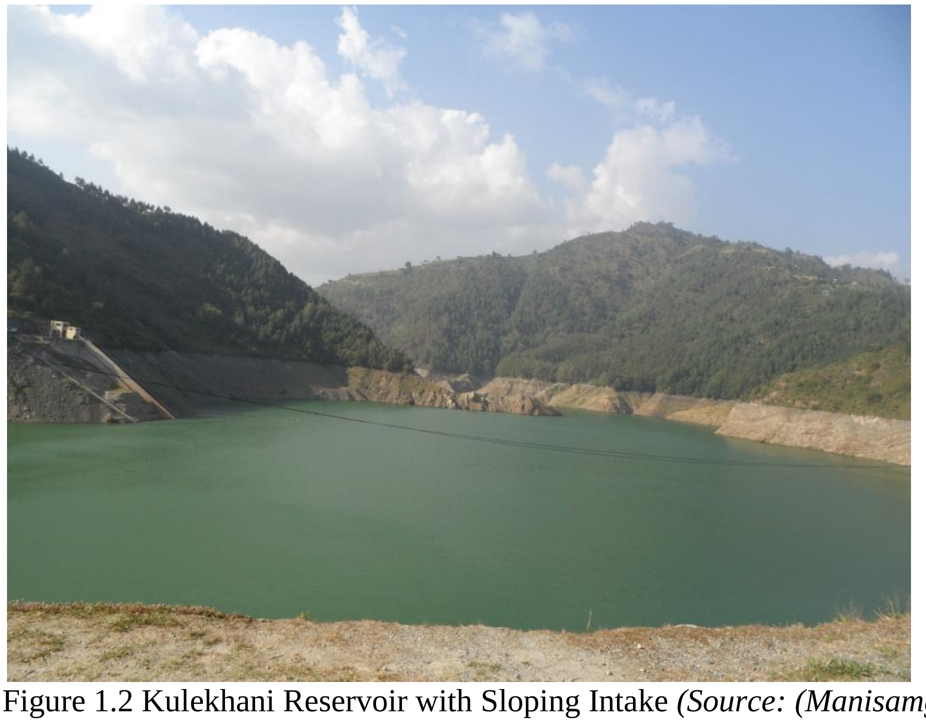
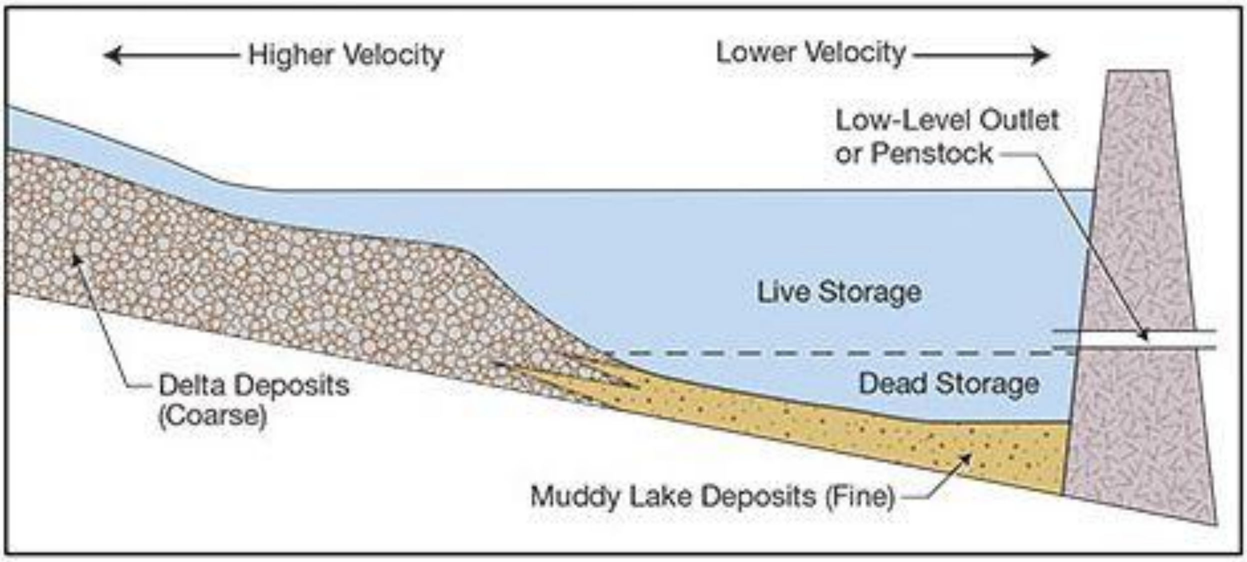


Figure 1.2 Kulekhani Reservoir with Sloping Intake *(Source: (Manisamg, 2012))*

1.3 Active and Dead Volume of Reservoir

Reservoir volume which can be used for power generation is called active volume or active storage or live storage and the volume which cannot be used for power generation is called dead volume or dead storage. More is the active volume more will be the power generation capacity of the reservoir. Dead volume is also important because if it is filled completely then power generation will be completely stopped. Sediment may accumulate in active or dead volume region. If the sediment accumulates in active volume region, then the power generation capacity of reservoir plant decreases and if it accumulates in dead volume region, then the life of reservoir decreases.



(Source: (Schellenberg, et al., 2019))

Figure 1.3. Active and Dead Volume of Reservoir

1.4 Problem Statement

Reservoir type hydropower projects are more reliable than run off river hydropower plants and can be operated anytime with full capacity. It contributes in effective management of load. The generation capacity of the power plant is dependent on the amount of water stored in the reservoir. More the holding capacity of the reservoir more will be the power generation. The reservoirs have their different sources of water intake. Mostly they are filled naturally through rivers and rivulets. Some rivers may be regular with variation of flow around the year and some may form only after rainfall.

Although rivers are the main source of water for reservoir, they are also the source of sediments. In run off river type hydropower plant, sediments are the main cause of erosion related damages in the mechanical parts like runner, guide vane, needle etc but for storage type hydropower plant, erosion related damages on the mechanical parts are minimum. But the main concern is on diminishing storage capacity.

Reservoir sedimentation is one of the main challenges in the storage type hydropower project diminishing the capacity of the reservoir hence decreasing the energy output from the project. If not monitored may create a huge problem ultimately filling up the reservoir with sediment and making it run off power plant.

Kulekhani Reservoir has many rivers and rivulets contributing to the storage of water. The rivers not only carry water, but also carry sediments with them. The main problem is in rainy season when the water level of the rivers rise and they bring lots of sediments with them. Another cause is the landslides at the sides of reservoir which also help in accumulating sediments on the bed. The yearly deposition of sediment is creating negative impact in the power generation of the plant. As the live storage is decreasing, the generation capacity is also decreasing. The study of Kulekhani Reservoir with respect to sediment deposit rate will help in designing the methods for controlling the sediments and hence maximising the energy output from the project.

1.5 Objectives

1.5.1 Main Objective

The main objective of this thesis work is to study the impacts of reservoir sedimentation in power generation of Kulekhani First Hydropower Station.

1.5.2 Specific Objectives

The main objectives will be accomplished with the following auxiliary objectives:

i. Analysis of electricity generation from each m^3 of reservoir water.

ii. Analysis of the energy generation from Kulekhani First Hydropower Station with respect to dam sedimentation.

iii. Review and analysis of sedimentation deposition rate in the Kulekhani Reservoir.

iv. Analysis of financial loss due to sediment deposition.

v. Analysis of sediment removal rate and cost using suitable dredger pump.

vi. Analysis of sediment removal rate and cost using dry excavation method.

1.6 Assumptions and Limitations

1.6.1 Assumptions

i. The deposition rate of sediment is constant.

ii. Annual energy generation is the energy generated if whole capacity of Kulekhani Reservoir is used.

1.6.2 Limitations

i. Latest sedimentation survey data available is of July 2017.

ii. Analysis is mainly based on secondary data.

1.7 Scope of Works

The scope of the study can be stated as follow:

The method can be used for analysis of power generation with respect to sedimentation deposition rate in reservoir type hydropower plant thus helping for the remedy of the problem.

CHAPTER TWO: LITERATURE REVIEW

A study by the World Bank presented in (Mahmood, 1987) and cited by Carvalho et al. (2000) is one of the most important publications 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.

Paiva (1993) conducted an interesting literature review on the influence of sedimentation on the energy production of some national reservoirs. Paiva performed a case study of the Taquaraçu HPP (Minas Gerais state, Brazil), which was built in 1935 and suffered a great loss of storage capacity (70%) along the years of operation, falling from the original 2,200,000 m^3 to 700,000 m^3 in 1992. As a consequence, the production of energy, which was 20,000,000 kWh/year in 1935, decreased to 12,000,000 kWh/year in 1992 (i.e., 40% of the production capacity of the plant). This plant was used to supply company Siderurgia Belgo-Mineira and, according to author, the cost of non-produced energy only in 1992 ranged between US$400,000 and US$500,000. Because of these losses, the company had to buy additional power to satisfy its demands, which resulted in an expenditure of US$1.5 to US$1.7 million.

Remenieras & Braudeau (1951), cited by Bufon (2006), analyzed the issue of siltation in some reservoirs in France. Among the sites studied by the authors is the case of the Motty Reservoir, which had a volume of 1,750,000 m^3 and was completely silted in 2 years.

Valera & Izquierdo (1984) reported on some problems resulting from the sedimentation of Anchicaya Reservoir (Colombia) and their possible solutions, considering that the reservoir lost approximately 60% of its initial storage capacity during a short period of 4 years (1958–1962).

Another interesting study that addresses siltation in a reservoir was conducted by Chanson & James (1998). Those authors analyzed four reservoirs in Australia whose lifetime was shorter than 25 years and concluded that several factors, such as the weather, production and transport of sediment in regions around the reservoirs, land use, and even errors of design and site selection for the construction of dams influenced the problem. They also cited other studies on sedimentation in Australian reservoirs, including Chanson (1998) and Chanson & James (1998).

Several studies carried out by Nippon Koei (1994), Shrestha (2001) and Sangroula (2005) recommended different sediment control measures for the sustainability of the Kulekhani Reservoir. One of them is the HSRS method. Based on the results of the RESCON model, HSRS is the best sediment management option. However, the author recommends to study the feasibility of reservoir flushing and HSRS separately.

A study by Winrock International (2004) states that the erosion processes in the Kulekhani watershed transport an enormous amount of sediment to the reservoir. This sediment deposited in the reservoir reduces the life of the reservoir. The study further states sedimentation measurement done in the reservoir shows that excessive sediment was deposited in the years 1993 to 1995 and heavy rainfall is one among the other factors to accelerate the process.

CHAPTER THREE: RESEARCH METHODOLOGY

Following methodologies were adopted for the thesis works.

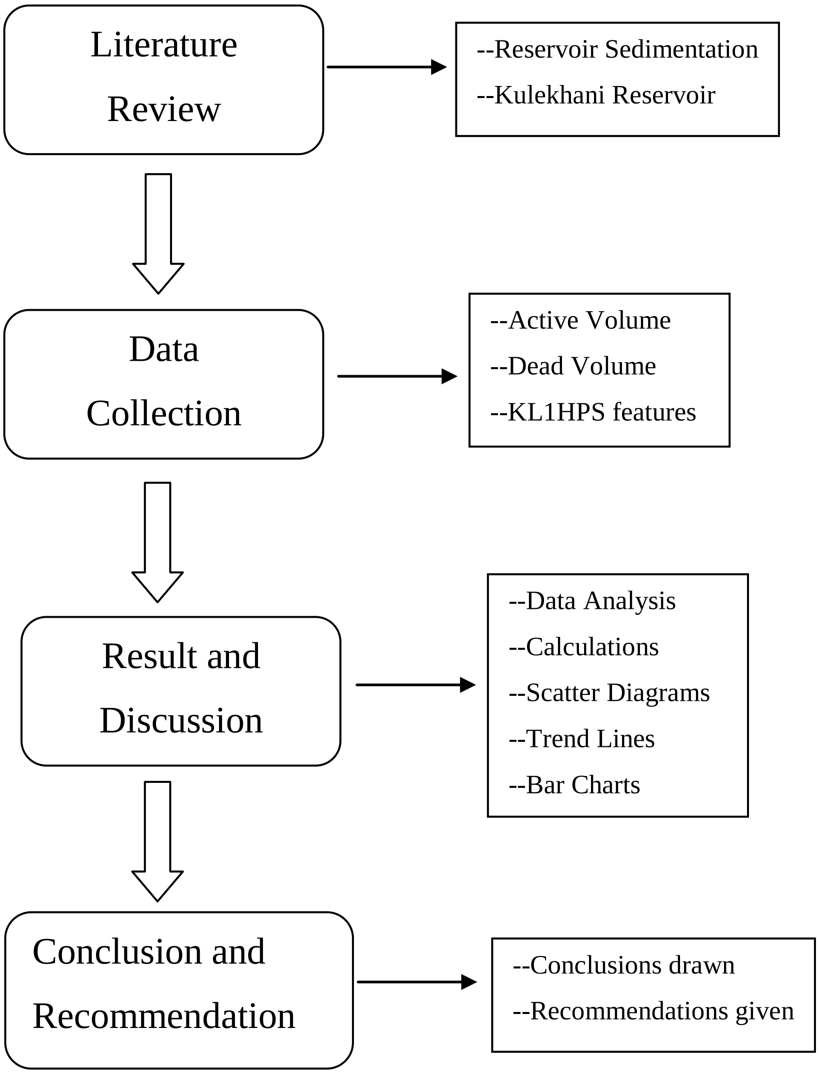


Figure 3.1 Research Methodology Chart

The Research Methodology includes Literature Review, Data Collection, Result and Discussion and Conclusion and Recommendation which are described below in detail.

3.1 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.

3.2 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.

3.3 Result and Discussion

<u>Active Volume, Energy Generation and Revenue Generation</u>

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

$P=H\rho gQ\eta$

Where,

P= Power Output (W)

H= Rated Head (m)

ρ= Density of water (kg/m^3)

g= Acceleration due to gravity (m/s)

Q= Flow rate (m^3/s)

η= Overall Efficiency

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

$E=H\rho g\eta/3600$

Where,

E= Electricity produced from each m^3 of reservoir water (Wh/m^3)

H= Rated Head (m)

ρ= Density of water (kg/m^3)

g= Acceleration due to gravity (m/s)

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.

<u>Actual and Theoretical Generation</u>

Then after, the actual generation of the KL1HPS from the starting was taken and bar diagram was plotted for the values. Also revenue generation of KL1HPS was calculated taking suitable PPA rate. Values were plotted in bar chart. Comparison between actual and theoretical generation of KL1HPS was done using the suitable chart.

Sediment Deposition in Active Volume

Calculations were done for the sediment deposition in active volume. Scatter diagram was plotted with year vs. sediment deposition in active volume. Trend line was added on the scatter diagram so the equation of the line with R^2 value was found. With the help of the equation obtained from the trend lines, the forecasting of the sediment deposit in active volume was done for the year 2019 to 2030 AD. Bar chart was drawn for that.

Sediment Removal in Active Volume by Dredging

Calculation for the sediment removal in active volume with suitable dredger pump was done. Using suitable data, the removal rate of the dredger pump was calculated. Table was drawn for the analysis of sediment deposition in active volume after the dredging operation started. Scatter diagram was plotted with year vs. sediment deposition in active volume. Trend line was added on the scatter diagram so the equation of the line with R^2 value was found. Also using suitable data, cost analysis of dredging in active volume was done and simple payback period was also calculated.

Sediment Deposition in Total Volume

After that, the calculations were done for the sediment deposition in total volume. Scatter diagram was plotted with year vs. sediment deposition in total volume. Trend line was added on the scatter diagram so the equation of the line with R^2 value was found. With the help of the equation obtained from the trend line, the forecasting of the sediment deposit in total volume was done for the year 2019 to 2031 AD. Bar chart was drawn for that.

Sediment Removal in Total Volume by Dredging

Calculation for the sediment removal in total volume with suitable dredger pump was done. Using suitable data, the removal rate of the dredger pump was calculated. Table was drawn for the analysis of sediment deposition in total volume after the dredging operation started. Scatter diagram was plotted with year vs. sediment deposition in total volume. Trend line was added on the scatter diagram so the equation of the line with R^2

value was found. Also using suitable data, cost analysis of dredging in total volume was done.

Sediment Removal in Active Volume by Dry Excavation

Calculation for the sediment removal in active volume with dry excavation was done. Using suitable data, the removal rate and total time period of the dry excavation was calculated. Also using suitable data, cost analysis of dry excavation in active volume was done and simple payback period was also calculated.

Sediment Removal in Total Volume by Dry Excavation

Calculation for the sediment removal in total volume with dry excavation was done. Using suitable data, the removal rate and total time period of the dry excavation was calculated. Also using suitable data, cost analysis of dry excavation in total volume was done.

3.4 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.

CHAPTER FOUR: RESULT AND DISCUSSION

4.1 Storage Data of Kulekhani Reservoir and Electricity Produced from Each m^3 of Reservoir Water

The actual survey data for the sedimentation of Kulekhani Reservoir was taken from the different sources and following analysis were done.

Table 4.1 Volume of Kulekhani Reservoir in different Time Periods

Year	Storage of Reservoir		
	Total Volume Mm^3	Active Volume Mm^3	Dead Volume Mm^3
1982	85.3	73.3	12
1993	75.11	69	6.11
1994	72.41	69.66	2.75
1995	70.83	67.78	3.05
2017	58.64	51.61	7.03

(Source: NEA, 2017; Staphit, 1996)

Calculation of Electricity Produced from Each m^3 of Reservoir Water

$P = H\rho gQ\eta$

Where,

P= Power Output = 60 MW

H= Rated Head = 550 m

ρ= Density of water = 1000 kg/m^3

g= Acceleration due to gravity = 9.81 m/s

Q= Flow rate = 13.1 m^3/s

η= Overall Efficiency

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

Again,

$E = H\rho g\eta/3600$

Where,

E= Electricity produced from each m^3 of reservoir water (Wh/m^3)

H= Rated Head = 550 m

ρ= Density of water = 1000 kg/m^3

g= Accl due to gravity = 9.81 m/s

η= Overall Efficiency = 85%

Thus electricity produced from each m^3 of reservoir water is calculated as 1.27 kWh.

4.2 Calculations for Active Volume, Energy Generation and Revenue Generation with Forecasting

Here, energy generation is the generated energy if all the active volume is used in electricity generation. Assuming $1m^3$ volume of reservoir water produces 1.27 kWh, below table can be generated.

Table 4.2 Active Volume of Kulekhani Reservoir and Theoretical Energy Generation of Kulekhani First HPS in different Time Periods

Year	**Active Volume Mm^3**	**Energy Generation MWh**
1982	73.3	93257.00
1993	69	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.

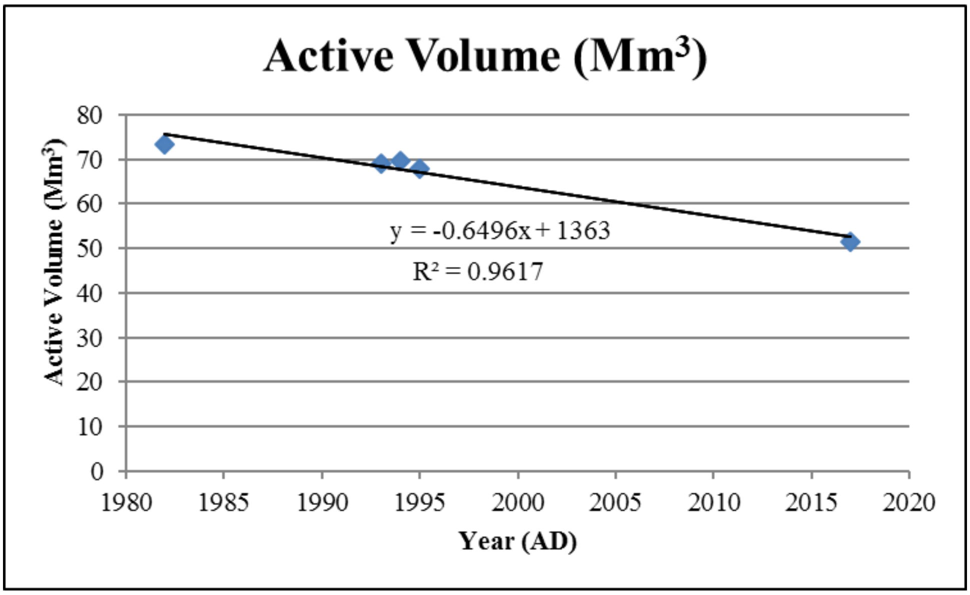


Figure 4.1 Change in Active Volume of Kulekhani Reservoir with Time

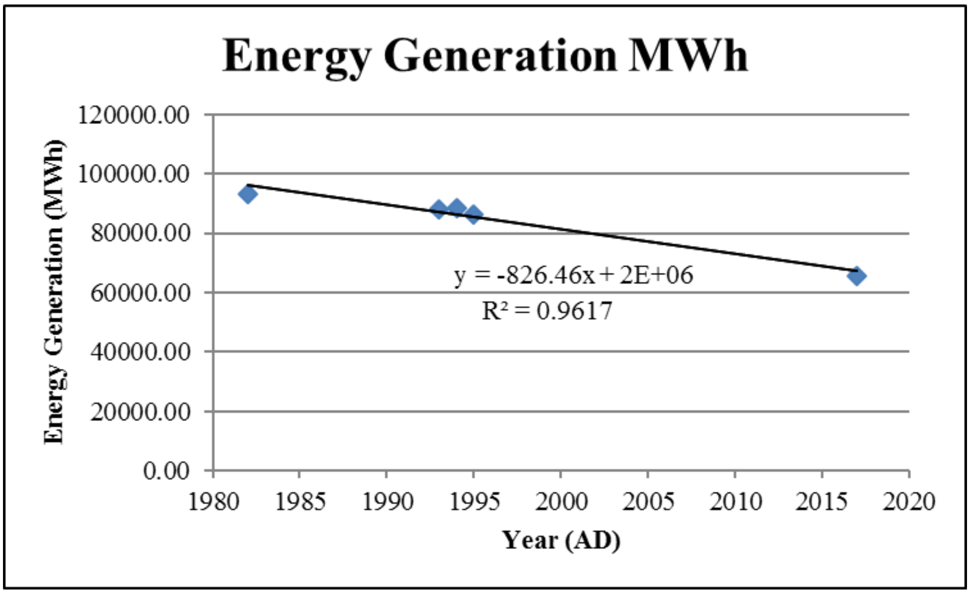


Figure 4.2 Change in Theoretical Energy Generation from KL1HPS with Time

The scatter diagram shows that the energy generation 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 4.3 Active Volume of Kulekhani Reservoir and Theoretical Energy Generation of Kulekhani First HPS in different Time Periods with Forecasting

Year	**Active Volume Mm^3**	**Energy Generation MWh**
1982	73.3	93257.00
1993	69	87786.26
1994	69.66	88625.95
1995	67.78	86234.10
2017	51.61	65661.58
Below data are forecasted using trend line equation		
2020	52.02	66183.21
2050	32.55	41412.21
2070	19.57	24898.22
2099	0.749	952.93
2100	0.1	127.23

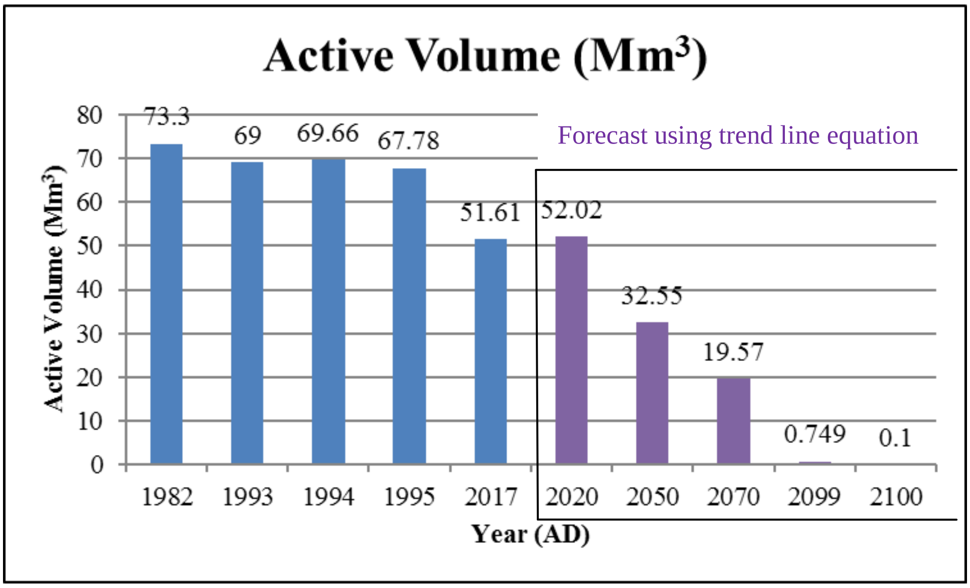


Figure 4.3 Change in Active Volume of Kulekhani Reservoir with Time with Forecasting

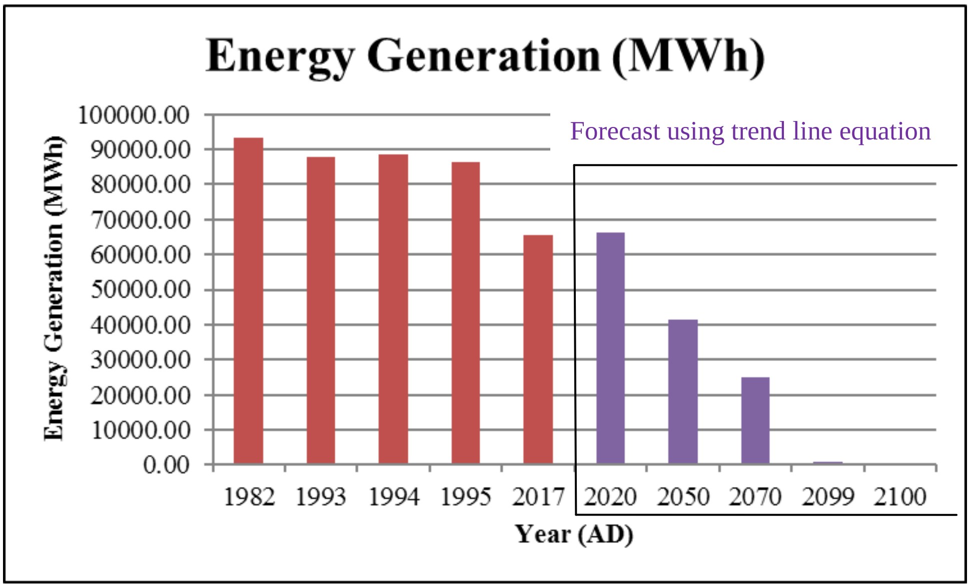


Figure 4.4 Change in Theoretical Energy Generation from KL1HPS with Time with Forecasting

Calculations for Revenue from Energy generated from Active Volume

Taking the PPA rate of NRs. 12.40/kWh (NEA, 2018/19) for reservoir hydropower plant for dry season, the revenue was calculated as follows. Also it was shown in Bar chart.

Table 4.4 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	73.3	93257.00	1156.39
1993	69	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
Below data are forecasted using trend line equation			
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	0.1	127.23	1.58

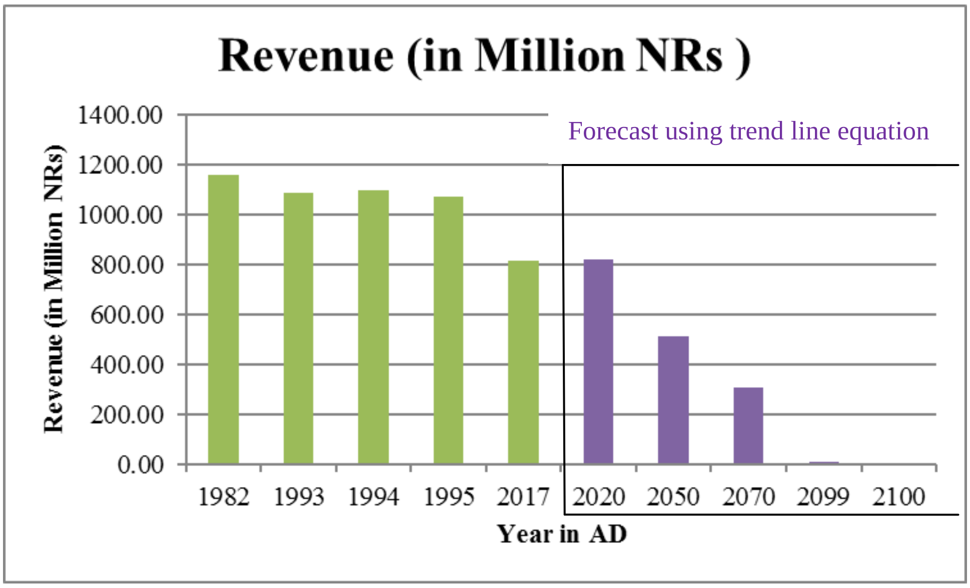


Figure 4.5 Change in Revenue Generation from KL1HPS with Time with Forecasting

Above chart shows that the revenue is decreasing. The forecast from year 2020 to 2100 are calculated using trend line equation and shows constant decrease in revenue. This also shows that the revenue in 2100 AD is almost zero. This is because in 2100 AD, the active volume of the reservoir will be about zero and almost no generation from stored water in active volume.

4.3 Actual Generation and Revenue Generation of KL1HPS

Actual Generation of the KL1HPS from the starting was taken from the Generation Magazine of NEA (2019). Bar Chart was also drawn.

Table 4.5 Actual Generation of KL1HPS

FY in BS	FY in AD	Actual Generation MWh
038/39	1981/82	**27,434.00**
039/40	1982/83	**87,417.00**
040/41	1983/84	**82,293.00**
041/42	1984/85	**104,012.00**
042/43	1985/86	**174,411.00**
043/44	1986/87	**190,395.00**
044/45	1987/88	**198,077.00**
045/46	1988/89	**170,883.00**
046/47	1989/90	**132,594.00**
047/48	1990/91	**163,410.00**
048/49	1991/92	**117,103.00**
049/50	1992/93	**71,292.00**
050/51	1993/94	**107,781.00**
051/52	1994/95	**113,048.00**
052/53	1995/96	**167,197.00**
053/54	1996/97	**167,985.00**
054/55	1997/98	**121,571.00**
055/56	1998/99	**195,737.00**
056/57	1999/00	**249,680.00**
057/58	2000/2001	**175,752.00**
058/59	2001/2002	**145,421.00**
059/60	2002/2003	**170,026.00**
060/61	2003/2004	**160,609.00**
061/62	2004/2005	**173,785.00**
062/63	2005/2006	**114,700.00**
063/64	2006/2007	**138,048.00**
064/65	2007/2008	**153,016.00**
065/66	2008/2009	**75,114.00**
066/67	2009/2010	**86,996.00**
067/68	2010/2011	**98,886.00**
068/69	2011/2012	**143,284.00**
069/70	2012/2013	**92,829.00**
070/71	2013/2014	**94,084.00**
071/72	2014/2015	**90,081.00**
072/73	2015/2016	**71,356.00**
073/74	2016/2017	**73,402.00**
074/75	2017/2018	**62,131.00**
075/76	2018/2019	**91,184.00**

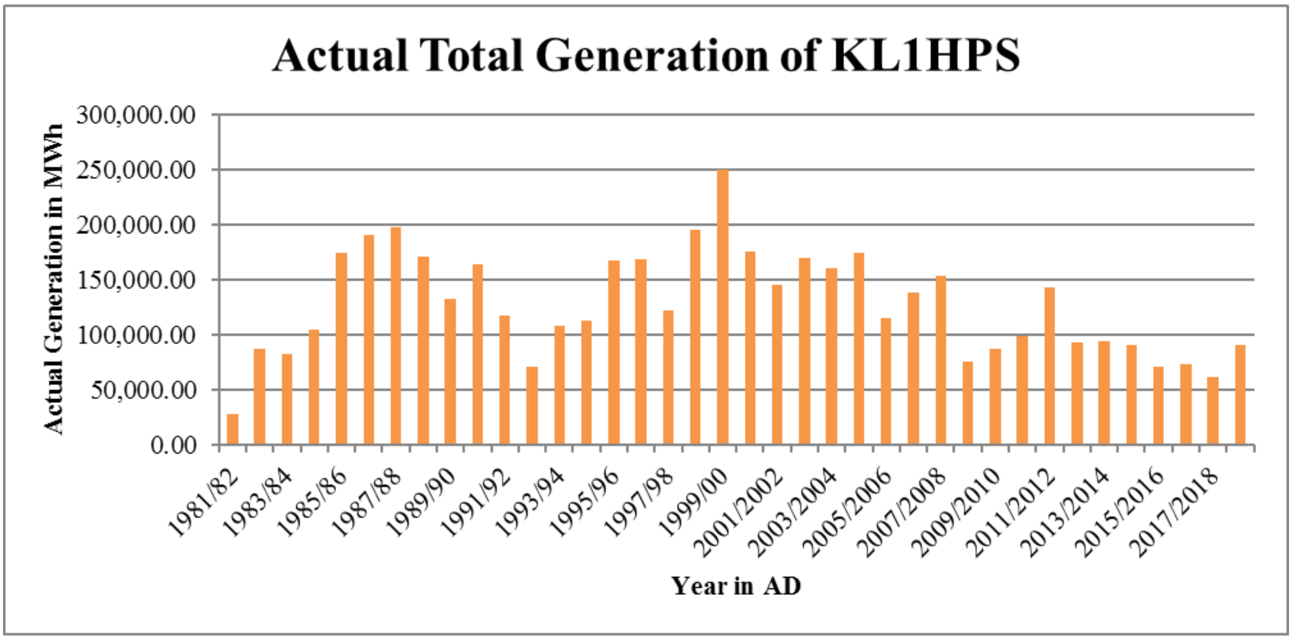


Figure 4.6 Change in Actual Generation from KL1HPS with Time

Above chart shows that the Actual Generation is fluctuating. This is because the power house is stand by type and only operates when needed. However, the overall trend shows that the generation is slowly decreasing. This shows that the sedimentation in the reservoir is slowly affecting the generation of the power house.

Actual Generation and Revenue Generation taking the PPA rate of NRs. 12.40/kWh (NEA, 2018/19) of the KL1HPS from the starting was generated. Corresponding Bar chart was also drawn.

Table 4.6 Actual Generation and Revenue Generation of KL1HPS

FY in BS	**FY in AD**	**Actual Generation MWh**	**Revenue Generation (Million NRs.)**
038/39	1981/82	27,434.00	**340.18**
039/40	1982/83	87,417.00	**1083.97**
040/41	1983/84	82,293.00	**1020.43**
041/42	1984/85	104,012.00	**1289.75**
042/43	1985/86	174,411.00	**2162.69**
043/44	1986/87	190,395.00	**2360.89**
044/45	1987/88	198,077.00	**2456.15**
045/46	1988/89	170,883.00	**2118.95**
046/47	1989/90	132,594.00	**1644.17**
047/48	1990/91	163,410.00	**2026.28**
048/49	1991/92	117,103.00	**1452.08**
049/50	1992/93	71,292.00	**884.02**
050/51	1993/94	107,781.00	**1336.48**
051/52	1994/95	113,048.00	**1401.79**
052/53	1995/96	167,197.00	**2073.24**
053/54	1996/97	167,985.00	**2083.01**
054/55	1997/98	121,571.00	**1507.48**
055/56	1998/99	195,737.00	**2427.13**
056/57	1999/00	249,680.00	**3096.03**
057/58	2000/2001	175,752.00	**2179.32**
058/59	2001/2002	145,421.00	**1803.22**
059/60	2002/2003	170,026.00	**2108.32**
060/61	2003/2004	160,609.00	**1991.55**
061/62	2004/2005	173,785.00	**2154.93**
062/63	2005/2006	114,700.00	**1422.28**
063/64	2006/2007	138,048.00	**1711.79**
064/65	2007/2008	153,016.00	**1897.39**
065/66	2008/2009	75,114.00	**931.41**
066/67	2009/2010	86,996.00	**1078.75**
067/68	2010/2011	98,886.00	**1226.19**
068/69	2011/2012	143,284.00	**1776.72**
069/70	2012/2013	92,829.00	**1151.08**
070/71	2013/2014	94,084.00	**1166.64**
071/72	2014/2015	90,081.00	**1117.00**
072/73	2015/2016	71,356.00	**884.81**
073/74	2016/2017	73,402.00	**910.18**
074/75	2017/2018	62,131.00	**770.42**
075/76	2018/2019	91,184.00	**1130.68**

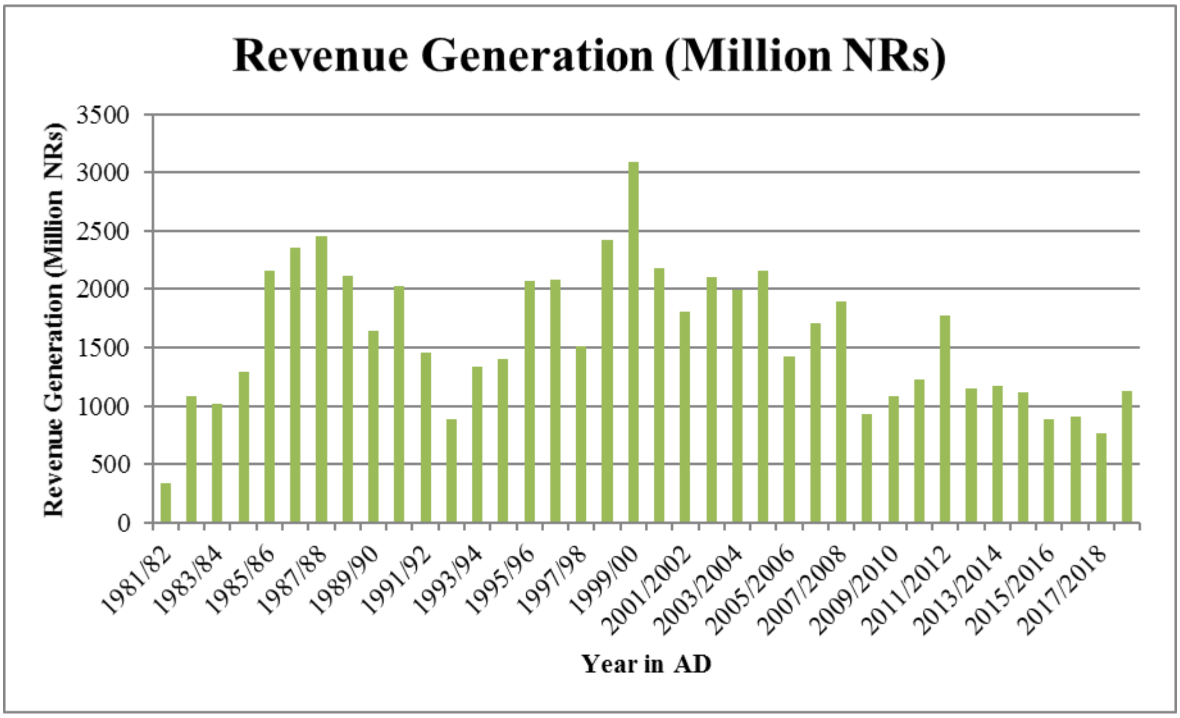


Figure 4.7 Change in Revenue Generation from KL1HPS with Time

Above chart shows that the Actual Revenue is fluctuating. This is because the power house is stand by type and only operates when needed. However, the overall trend shows that the revenue is slowly decreasing. This shows that the sedimentation in the reservoir is slowly affecting the revenue of the power house.

4.4 Comparison between Actual and Theoretical Generation of KL1HPS

Actual Generation of the KL1HPS from the starting was taken from the Generation magazine of NEA (2019). Theoretical generation was generated using trend line equation and formula. Bar Chart was also drawn.

Table 4.7 Theoretical and Actual Generation of KL1HPS

FY in AD	Theoretical Active Vol Mm^3	Theoretical Generation MWh	Actual Generation MWh
1981/82	76.68	**97,386.14**	**27,434.00**
1982/83	76.03	**96,561.91**	**87,417.00**
1983/84	75.38	**95,737.68**	**82,293.00**
1984/85	74.73	**94,913.45**	**104,012.00**
1985/86	74.09	**94,089.22**	**174,411.00**
1986/87	73.44	**93,264.99**	**190,395.00**
1987/88	72.79	**92,440.76**	**198,077.00**
1988/89	72.14	**91,616.53**	**170,883.00**
1989/90	71.49	**90,792.30**	**132,594.00**
1990/91	70.84	**89,968.07**	**163,410.00**
1991/92	70.19	**89,143.84**	**117,103.00**
1992/93	69.54	**88,319.61**	**71,292.00**
1993/94	68.89	**87,495.38**	**107,781.00**
1994/95	68.24	**86,671.15**	**113,048.00**
1995/96	67.60	**85,846.92**	**167,197.00**
1996/97	66.95	**85,022.69**	**167,985.00**
1997/98	66.30	**84,198.46**	**121,571.00**
1998/99	65.65	**83,374.23**	**195,737.00**
1999/00	65.00	**82,550.00**	**249,680.00**
2000/2001	64.35	**81,725.77**	**175,752.00**
2001/2002	63.70	**80,901.54**	**145,421.00**
2002/2003	63.05	**80,077.31**	**170,026.00**
2003/2004	62.40	**79,253.08**	**160,609.00**
2004/2005	61.75	**78,428.85**	**173,785.00**
2005/2006	61.11	**77,604.62**	**114,700.00**
2006/2007	60.46	**76,780.39**	**138,048.00**
2007/2008	59.81	**75,956.16**	**153,016.00**
2008/2009	59.16	**75,131.93**	**75,114.00**
2009/2010	58.51	**74,307.70**	**86,996.00**
2010/2011	57.86	**73,483.47**	**98,886.00**
2011/2012	57.21	**72,659.24**	**143,284.00**
2012/2013	56.56	**71,835.01**	**92,829.00**
2013/2014	55.91	**71,010.78**	**94,084.00**
2014/2015	55.26	**70,186.55**	**90,081.00**
2015/2016	54.62	**69,362.32**	**71,356.00**
2016/2017	53.97	**68,538.09**	**73,402.00**
2017/2018	53.32	**67,713.86**	**62,131.00**
2018/2019	52.67	**66,889.63**	**91,184.00**

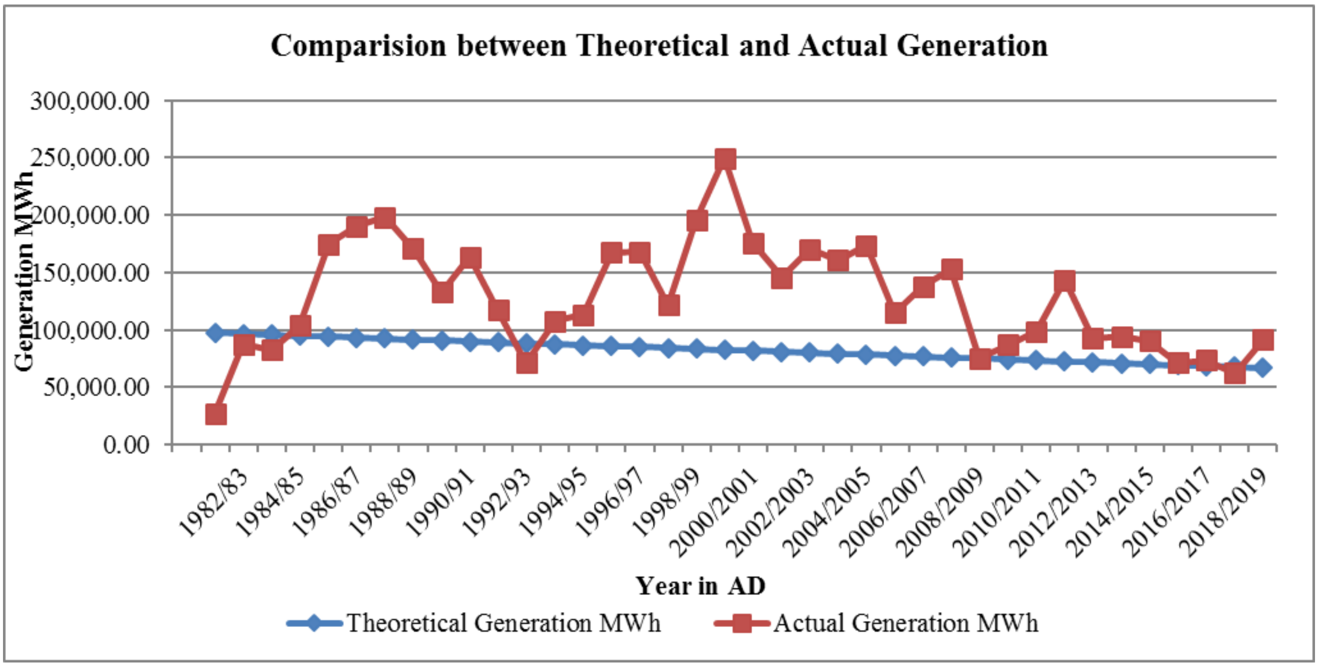


Figure 4.8 Change in Theoretical and Actual Generation of KL1HPS

Above chart shows that the actual generation is fluctuating but the theoretical generation is decreasing in a constant rate. However, the overall trend shows that both the actual and theoretical generations are slowly decreasing. Theoretical generation is mostly less than the actual generation because of the assumption that the annual theoretical generation is the energy generated annually if all the active volume of reservoir water is used in electricity generation. Rise in generation due to inflows from rivers and rain is not considered during the period. The actual generation may be more or less than the theoretical because the actual generation depends on many factors like load demand, inflow from rivers and rain etc.

4.5 Calculations for Sediment Deposit and Removal by Dredger Pump in Active Volume

Calculations for Sediment Deposition in Active Volume

The actual survey data for the sedimentation of Kulekhani Reservoir was taken from the different sources and following analysis were done.

Table 4.8 Reservoir Volume and Sediment Deposited in Active Volume till Date

Year	Storage of Reservoir			Sediment Deposited in Active Volume till date Mm^3
	Total Volume Mm^3	Active Volume Mm^3	Dead Volume Mm^3	
1982	85.3	73.3	12	0
1993	75.11	69	6.11	4.3
1994	72.41	69.66	2.75	3.64
1995	70.83	67.78	3.05	5.52
2017	58.64	51.61	7.03	21.69

(Source: NEA, 2017; Staphit, 1996)

Scatter diagram was plotted with year vs. sediment deposition in active volume. Trend line was added on the scatter diagram so the equation of the line with R^2 value was found.

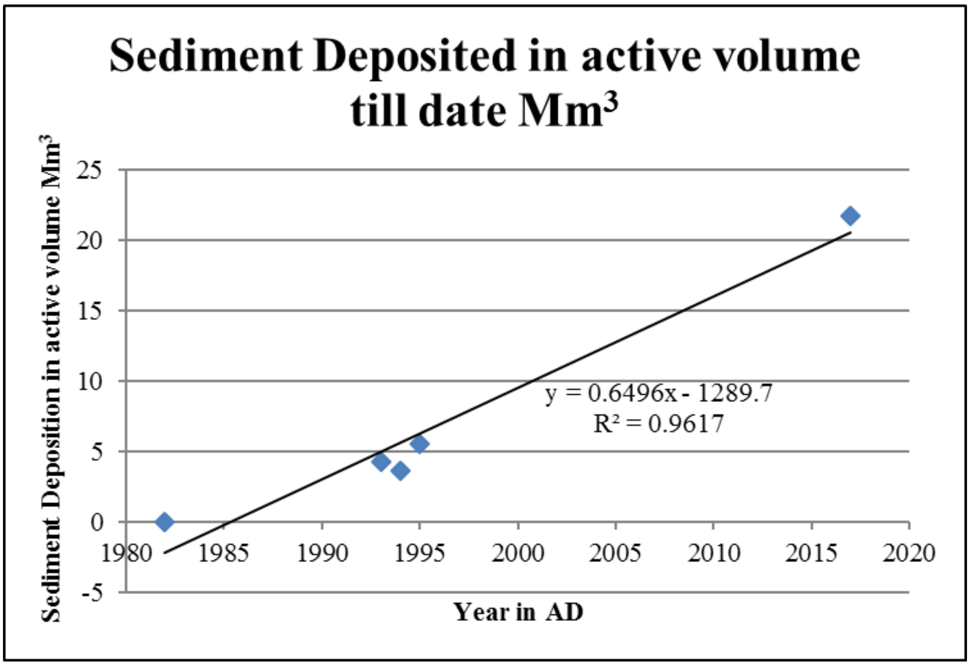


Figure 4.9 Sediment Deposited in Active Volume till Date

From the scatter diagram, it can be found that the annual sedimentation rate in active volume of Kulekhani reservoir is 0.65 Mm^3/year.

With the help of equation obtained from the trend line, the forecasting of the sediment deposit in active volume was done for the year 2019 to 2030 AD.

Table 4.9 Sediment Deposit in Active Volume

Year	Sediment Deposit in Active Volume Mm^3
1982	0
1993	4.3
1994	3.64
1995	5.52
2017	21.69
Below data are forecasted using trend line equation	
2019	21.33
2020	21.98
2021	22.63
2022	23.28
2023	23.93
2024	24.58
2025	25.23
2026	25.87
2027	26.52
2028	27.17
2029	27.82
2030	28.47

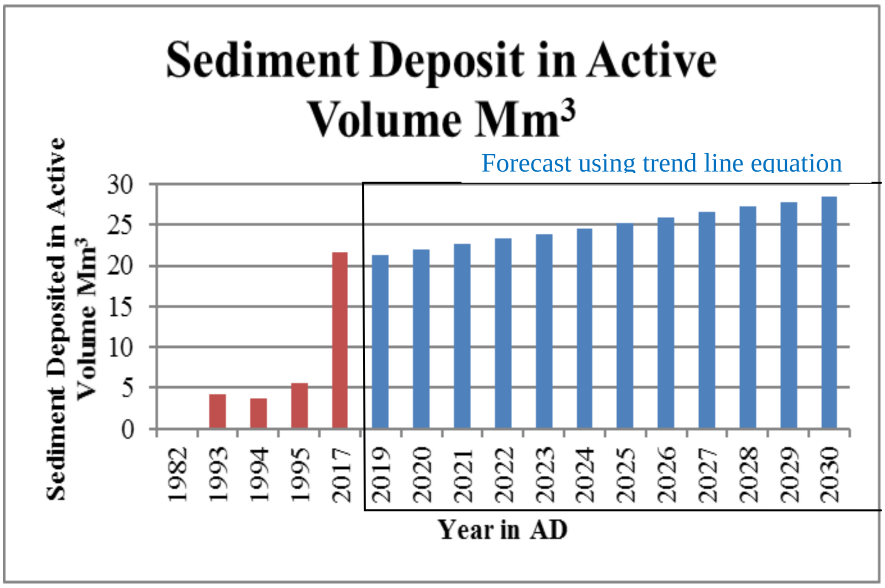


Figure 4.10 Sediment Deposit in Active Volume

Calculations for Sediment Removal in Active Volume with Dredger Pump

Dredging pump was selected with following specifications:
(as per ANNEX A)

Name of Manufacturer: BELL Dredging Pump
Country of Origin: Netherlands
Model: BELL CUTTER DREDGER 400
Dredge Capacity (water and solids): 3150 m^3/hr
Dredge capacity in dry volume (max.): 630 m^3/hr
Stone size diameter (max.): 210 mm
Installed power on the dredge pump: 500 kW
Power source dredger: Diesel engine

From the Technical Spec of dredger pump, following calculations can be done:
Mixture dredging rate = 3150 m^3/hr
Dry sediment dredging rate = 630 m^3/hr
Dry sediment dredging rate (working 18 hrs per day) = 11340 m^3/day
Dry sediment dredging rate (working 300 days per year) = 3.40 $Mm^3/year$

Thus, taking 3.4 $Mm^3/year$ as the capacity of dredger pump to remove out the sediment deposited in Kulekhani Reservoir, following table can be generated. It is assumed that the dredging of sediment in active volume started from 2020 AD.

Table 4.10 Change in Sediment Deposition in Active Volume after Dredging

Year in AD	Sediment Deposition in Active Volume Mm^3	Annual Sedimentation Rate in Active Volume Mm^3	Annual Sediment Dredging Rate Mm^3	Sediment at end of year in Active Volume Mm^3	Remarks
1982	0				
1993	4.3				
1994	3.64				
1995	5.52				
2017	21.69				
2019	21.33				
2020	21.98	0.65	3.4	19.23	**Dredging Started**
2021	19.23	0.65	3.4	16.48	
2022	16.48	0.65	3.4	13.73	
2023	13.73	0.65	3.4	10.98	
2024	10.98	0.65	3.4	8.23	
2025	8.23	0.65	3.4	5.48	
2026	5.48	0.65	3.4	2.73	
2027	2.73	0.65	3.4	-0.02	
2028	-0.02	0.65	3.4	-2.77	

From the analysis table, it can be found that it will take about 8 years to remove the complete sediment in active volume using the selected dredger pump.

Scatter diagram was plotted with year vs. sediment deposition in active volume. Trend line was added on the scatter diagram so the equation of the line with R^2 value was found.

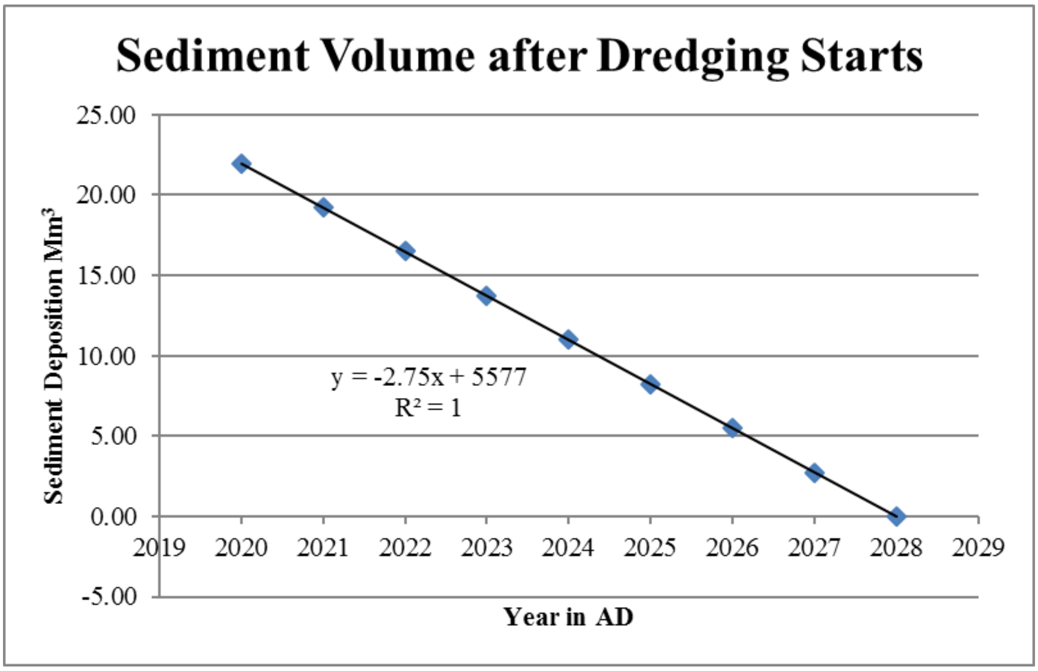


Figure 4.11 Change in Sediment Deposition in Active Volume after Dredging

<u>Cost Analysis of Dredging in Active Volume</u>

<u>Cost Analysis of Dredging</u>

Year in AD: 2028

Sediment in active volume without dredging = 27.17 Mm^3

Cost of dredging = NRs. 745/m^3 *(Source: IEA, 1998)*

Total dredging cost = NRs. 20.24 Billion

<u>Cost Analysis of Lost Water in Dredging</u>

Year in AD: 2028

Sediment in active volume without dredging = 27.17 Mm^3

Lost water volume in Dredging Operation = 27.17 x 4 = 108.68 Mm^3

Energy generation from 1 m^3 of water = 0.00127 MWh

Energy generation from lost water = 138023.6 MWh

Revenue lost from water loss = NRs. 1.71 Billion

Total Cost of Dredging and Lost Water

= Total dredging cost + Revenue lost from water loss

= NRs. 21.95 Billion

Revenue generated from increased Active Volume

Total Active volume increased in 8 years = 27.17 Mm^3

Energy Generation from 1 m^3 of water = 0.00127 MWh

Energy Generation from increased Active Volume MWh

= $(27.17-2.73) \times 10^6 \times 0.00127$ MWh

= 31038.8 MWh

Revenue generated from increased active volume = NRs. 384.88 Million = NRs. 0.384 Billion

Total Cost incurred in Dredging Sediment in Active Volume

Total cost incurred in dredging sediment in active volume = 21.95 - 0.384

= NRs. 21.57 Billion

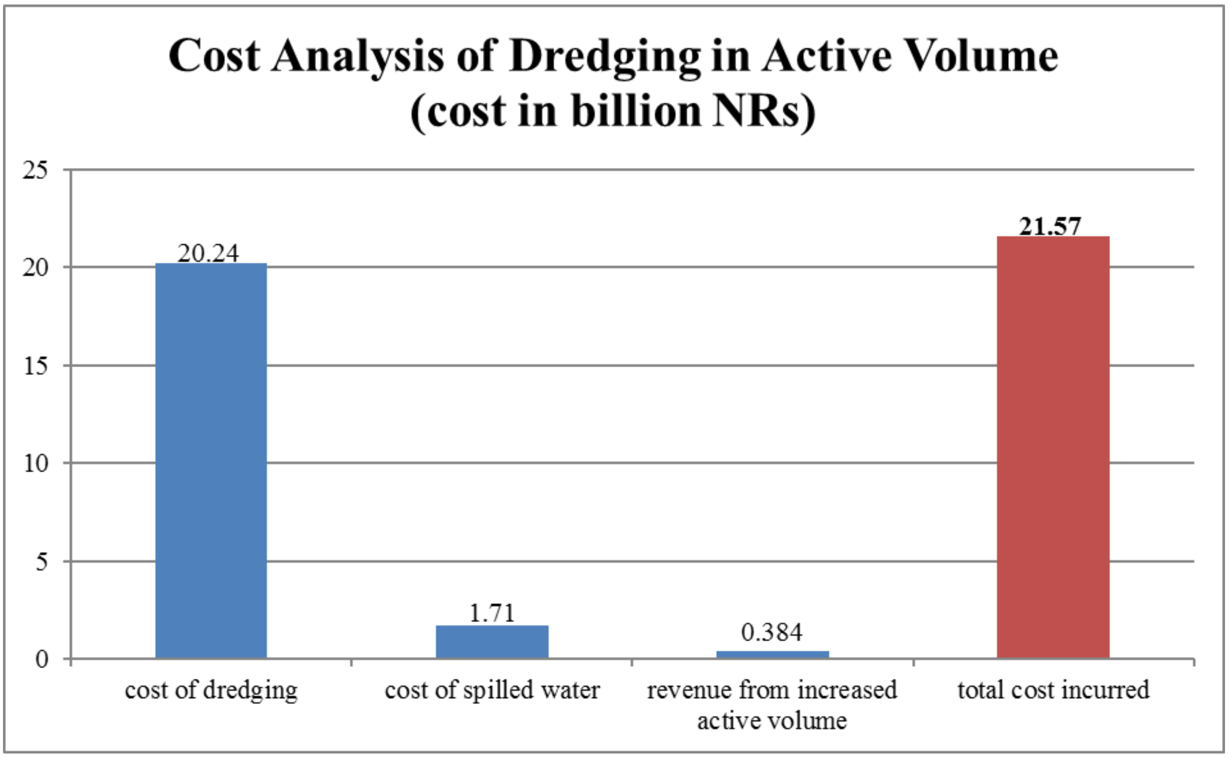


Figure 4.12 Cost Analysis of Dredging in Active Volume

Calculation for Simple Payback Period

Simple Payback Period = Total cost incurred in dredging / yearly cost return

= NRs. 21.57 Billion / Cost of energy generation from 27.17 Mm^3 of water

= NRs. 21.57 Billion / NRs. 427.87 Million per year

= about 50 Years

This shows that the cost incurred in dredging is very much higher than the yearly cost return. As the obtained simple payback period is very long, dredging operation comes to be very costly. Using dredger pump to remove the sediment is financially not feasible.

4.6 Calculations for Sediment Deposit and Removal by Dredger Pump in Total Volume

Calculations for sediment deposit in total volume

The actual survey data for the sedimentation of Kulekhani Reservoir was taken from the different sources and following analysis were done.

Table 4.11 Storage and Sediment Deposition in Total Volume with Time

Year	Storage of Reservoir			Total Sediment Deposited till date Mm^3
	Total Volume Mm^3	Active Volume Mm^3	Dead Volume Mm^3	
1982	85.3	73.3	12	0
1993	75.11	69	6.11	10.19
1994	72.41	69.66	2.75	12.89
1995	70.83	67.78	3.05	14.47
2017	58.64	51.61	7.03	26.66

(Source: NEA, 2017; Staphit, 1996)

Scatter diagram was plotted with year vs. sediment deposition in total volume. Trend line was added on the scatter diagram so the equation of the line with R^2 value was found.

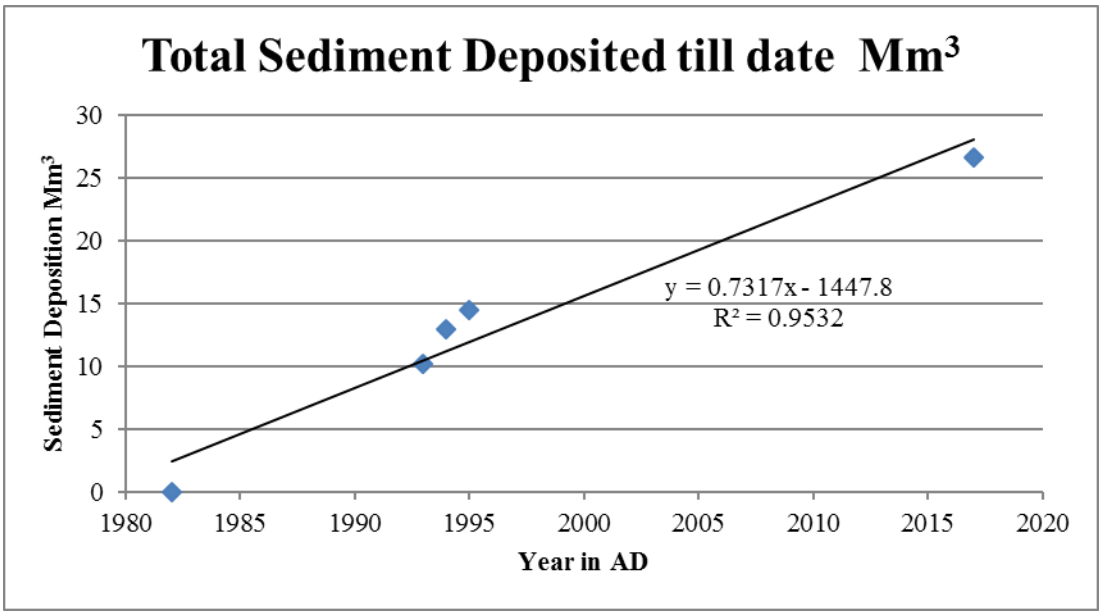


Figure 4.13 Sediment Deposition in Total Volume with Time

From the scatter diagram, it can be found that the annual sedimentation rate of Kulekhani Reservoir in total volume is 0.73 Mm^3/year.

With the help of equation obtained from the trend line, the forecasting of the sediment deposited in total volume was done for the year 2019 to 2031 AD.

Table 4.12 Sediment Deposit in Total Volume

Year	Total Sediment Deposition Mm^3
1982	0
1993	10.19
1994	12.89
1995	14.47
2017	26.66
Below data are forecasted using trend line equation	
2019	28.89
2020	29.62
2021	30.35
2022	31.08
2023	31.81
2024	32.54
2025	33.27
2026	34.01
2027	34.74
2028	35.47
2029	36.20
2030	36.93
2031	37.66

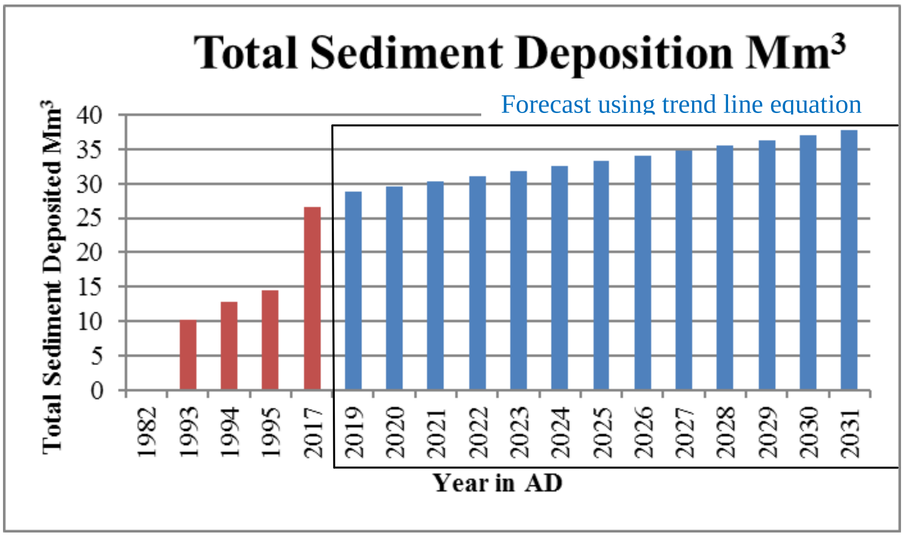


Figure 4.14 Sediment Deposit in Total Volume

Calculations for Sediment Removal in Total Volume with Dredger Pump

Dredging pump was selected with following specifications:

(specs as per ANNEX A)

Name of Manufacturer: BELL Dredging Pump

Country of Origin: Netherlands

Model: BELL CUTTER DREDGER 400

Dredge Capacity (water and solids): 3150 m^3/hr

Dredge capacity in dry volume (max.): 630 m^3/hr

Stone size diameter (max.): 210 mm

Installed power on the dredge pump: 500 kW

Power source dredger: Diesel engine

From the Technical Spec of dredger pump, following calculations can be done:

Mixture dredging rate = 3150 m^3/hr

Dry sediment dredging rate = 630 m^3/hr

Dry sediment dredging rate (working 18 hrs per day) = 11340 m^3/day

Dry sediment dredging rate (working 300 days per year) = 3.40 Mm^3/year

Thus, taking 3.4 Mm^3/year as the capacity of dredger pump to remove the total sediment deposited in Kulekhani Reservoir, following table can be generated. It is assumed that the dredging of sediment in total volume started from 2020 AD.

Table 4.13 Change in Sediment Deposition in Total Volume after Dredging

Year in AD	**Total Sediment Deposition Mm^3**	**Annual Sedimentation Rate Mm^3**	**Annual Sediment Dredging Rate Mm^3**	**Sediment at end of year Mm^3**	**Remarks**
1982	0				
1993	10.19				
1994	12.89				
1995	14.47				
2017	26.66				
2019	28.89				
2020	29.62	0.73	3.4	26.95	**Dredging Started**
2021	26.95	0.73	3.4	24.28	
2022	24.28	0.73	3.4	21.61	
2023	21.61	0.73	3.4	18.94	
2024	18.94	0.73	3.4	16.27	
2025	16.27	0.73	3.4	13.60	
2026	13.60	0.73	3.4	10.93	
2027	10.93	0.73	3.4	8.26	
2028	8.26	0.73	3.4	5.59	
2029	5.59	0.73	3.4	2.92	
2030	2.92	0.73	3.4	0.25	
2031	0.25	0.73	3.4	-2.42	

From the analysis table, it can be found that it will take 11 years to remove the complete sediment in total volume using the selected dredger pump.

Scatter diagram was plotted with year vs. sediment deposition in total volume after the use of dredger pump in 2020 AD. Trend line was added on the scatter diagram so the equation of the line with R^2 value was found.

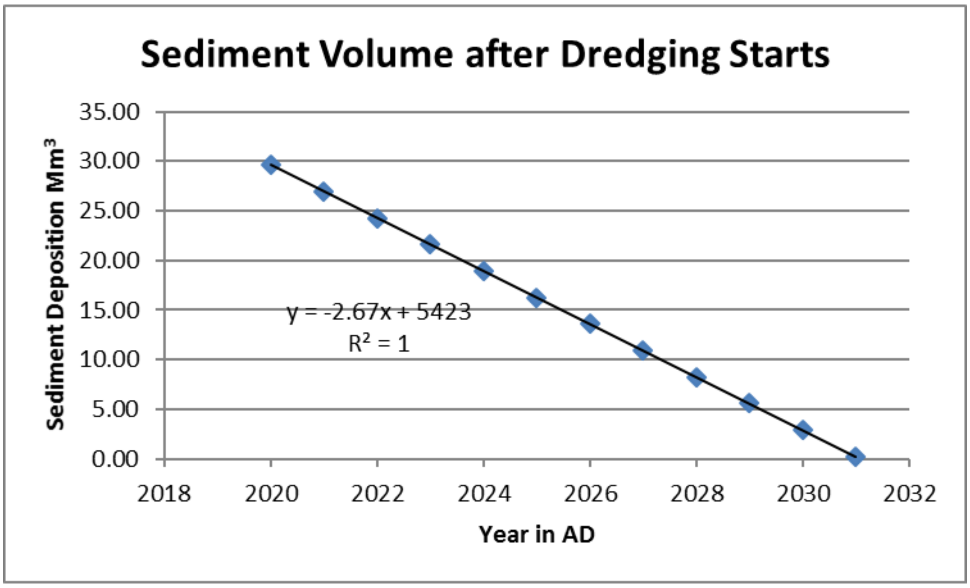


Figure 4.15 Change in Sediment Deposition in Total Volume after Dredging

<u>Cost Analysis of Dredging in Total Volume</u>

<u>Cost Analysis of Dredging</u>

Year in AD: 2031

Sediment in total volume without dredging = 37.66 Mm^3

Cost of dredging = NRs. 745/m^3 *(Source: IEA, 1998)*

Total dredging cost = NRs. 28.06 Billion

4.7 Dry Excavation Calculations for Active Volume

Specification of Wheel Loader is selected as per ANNEX B.

Specification of Tipper Truck is selected as per ANNEX C.

Time required for Dry Excavation

Bucket volume of wheel loader = 2.9 m^3

Time for excavation and delivery to tipper = 1 min (assumed)

Delivery of sediment in 1 min = 2.9 m^3

Delivery in 1 hour = 174 m^3/hr

Delivery in one day assuming 12 working hrs per day = 2088 m^3/day

Delivery in one year assuming 350 working days per year = 0.73 Mm^3/year

Annual delivery rate using 30 nos of wheel loaders = 21.9 Mm^3/year

Sediment deposition in 2020 AD in active volume = 21.98 Mm^3

Thus it takes about one year to clean all the sediments in active volume using above conditions.

Cost Calculations for Dry Excavation

Unit cost of dry excavation of sediment = NRs. 1190/ m^3 *(Source: IEA, 1998)*

Sediment deposition in 2020 AD in active volume = 21.98 Mm^3

Cost for dry excavation = NRs. 26.16 Billion

Calculations for revenue lost due to dry excavation for 2020 AD

Loss of active volume in 2020 = 52.02 Mm^3

Loss of energy generation in 2020 = 66183.21 MWh

Loss of revenue in 2020 = 66183.21 x 1000 x 12.4 = NRs. 0.82 Billion

Total cost incurred due to dry excavation = 26.16+0.82 = NRs. 26.98 Billion

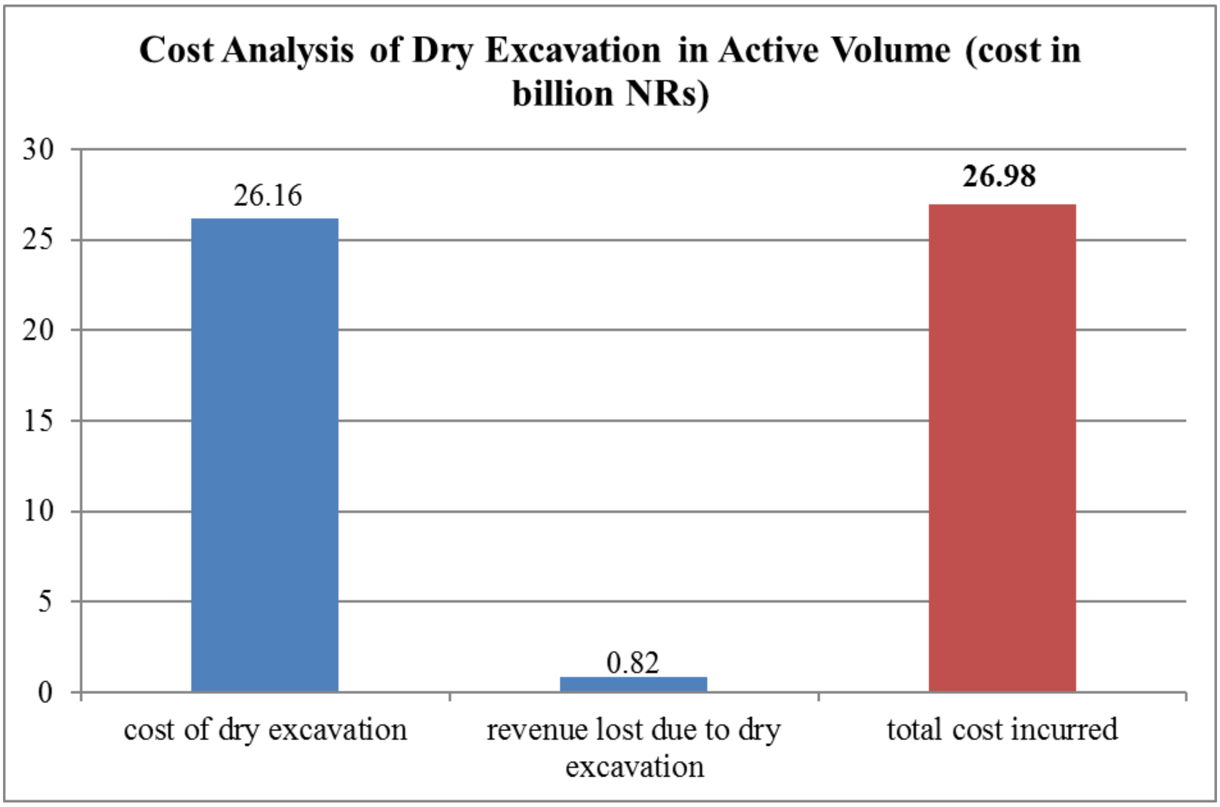


Figure 4.16 Cost Analysis of Dry Excavation in Active Volume

Calculation for Simple Payback Period

Simple Payback Period = Total cost incurred in dry excavation / Yearly cost return

= NRs. 26.98 Billion / Cost of energy generation from 21.98 Mm^3 of water

= NRs. 26.98 Billion / NRs. 346.14 Million per year

= about 78 Years

This shows that the cost incurred in dry excavation is very much higher than the yearly cost return. As the obtained simple payback period is very long, dry excavation operation comes to be very costly. Using dry excavation to remove the sediment is financially not feasible.

4.8 Dry Excavation Calculations for Total Volume

Specification of Wheel Loader is selected as per ANNEX B.

Specification of Tipper Truck is selected as per ANNEX C.

Time required for Dry Excavation

Bucket volume of wheel loader = 2.9 m^3

Time for excavation and delivery to tipper = 1 min (assumed)

Delivery of sediment in 1 min = 2.9 m^3

Delivery in 1 hour = 174 m^3/hr

Delivery in one day assuming 16 working hrs per day = 2784 m^3/day

Delivery in one year assuming 350 working days per year = 0.97 Mm^3/year

Annual delivery rate using 30 nos of wheel loaders = 29.23 Mm^3/year

Sediment deposition in 2020 AD in total volume = 29.62 Mm^3

Thus it takes about one year to clean all the sediments in active volume using above conditions.

Cost Calculations for Dry Excavation

Unit cost of dry excavation of sediment = NRs. 1190/ m^3 *(Source: IEA, 1998)*

Sediment deposition in 2020 AD in total volume = 29.62 Mm^3

Cost for dry excavation = NRs. 35.25 Billion

Calculations for Revenue Lost due to Dry Excavation for 2020 AD

Loss of active volume in 2020 = 52.02 Mm^3

Loss of energy generation in 2020 = 66183.21 MWh

Loss of revenue in 2020 = 66183.21 x 1000 x 12.4 = NRs. 0.82 Billion

Total cost incurred due to dry excavation = 35.25+0.82 = NRs. 36.07 Billion

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

1. The Electricity produced from each m^3 of reservoir water is calculated as 1.27 kWh.
2. 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.
3. The annual sedimentation rate of Kulekhani Reservoir in total volume is found to be 0.73 Mm^3 and in active volume is found to be 0.65 Mm^3.
4. The annual sedimentation 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.
5. The time period for dredging all the sediments in active volume is found to be 8 years and total cost incurred is found to be NRs. 21.57 Billion with simple payback period of about 50 years.
6. The time period for dry excavation all the sediments in active volume is found to be 1 year and total cost incurred is found to be NRs. 26.98 Billion with simple payback period of about 78 years.
7. Proper use of sediment removal system helps in removing the sediment and increasing the life of reservoir.

5.2 Recommendation

1. Proper sediment removal techniques such as dredging, dry excavation or HSRS method should be implemented so as to remove the sediments deposited in the Kulekhani Reservoir.
2. The intakes of the reservoir shall be monitored and measures should be taken to stop the sediment before the intake.
3. Yearly bathymetric survey of the reservoir is necessary for proper understanding of sediment condition in the reservoir.
4. Proper techniques should be used to avoid the landslides and erosion from the sides of the reservoir.

REFERENCES

Chanson, H. & James, P., 1998. *Rapid reservoir sedimentation of four historic thin arch dams in Australia,* s.l.: s.n.

D., M., 2011. *Climate Change Impacts on Reservoir based Hydropower,* s.l.: s.n.

IEA, 1998. *lake-dredging.pdf.* [Online] Available at: http://www.epa.state.il.us/water/conservation/lake-notes/lake-dredging.pdf
[Accessed 11 September 2019].

IEA, 2019. *Global energy demand rose by 2.3% in 2018, its fastest pace in the last decade.* [Online] Available at: https://www.iea.org/newsroom/news/2019/march/global-energy-demand-rose-by-23-in-2018-its-fastest-pace-in-the-last-decade.html
[Accessed 11 September 2019].

IHA, 2019. *Hydropower Status Report | International Hydropower Association.* [Online] Available at: https://www.hydropower.org/status2019
[Accessed 11 September 2019].

Jansen, L., Sidek, L. M. & Jajarmizadeh, M., 2016. Impact of Sedimentation hazard at Jor Reservoir, Batang Padang Hydroelectric Scheme in Malaysia. *IOP Conference Series Earth and Environmental Science,* 32(1).

Kaini, P. & Annandale, 2019. *Hydro Review: The Way Forward for Nepal's Hydropower Development.* [Online] Available at: https://www.hydroreview.com/2019/01/11/hydro-review-the-way-forward-for-nepal-s-hydropower-development/
[Accessed 11 September 2019].

Khawaja, B. A. & Sanchez, M., 2011. A study of the factors and processes involved in the sedimentation of Tarbela reservoir, Pakistan. *Environmental Earth Sciences,* 62(5), pp. 927-933.

Mahmood, K., 1987. *Reservoir sedimentation : impact, extent, and mitigation,* s.l.: The World Bank.

Manisamg, 2012. *Kulekhani_manish.JPG.* [Online] Available at: https://upload.wikimedia.org/wikipedia/commons/1/13/Kulekhani_manish.JPG
[Accessed 11 Septemeber 2019].

Miranda, R. B. d. & Mauad, F. F., 2015. Influence of Sedimentation on Hydroelectric Power Generation: Case Study of a Brazilian Reservoir. *Journal of Energy Engineering,* 141(3).

NEA, 2019. *NEA, A Year in Review 2018/19,* Kathmandu, Nepal: Nepal Electricity Authority.

NEA, 2019. *Nepal Electricity Authority Generation Directorate, 11th Issue,* Kathmandu, Nepal: Nepal Electricity Authority.

Paiva, J. M., 1993. *Sedimentação de reservat´orios de barragens,* São Paulo, Brazil: Universidade de São Paulo.

Palmieri, A., Shah, F., Annandale, G. W. & Dinar, A., 2003. *Reservoir Conservation Volume I- The RESCON Approach economic and engineering evaluation of alternative strategies for managing sedimentation in storage reservoirs,* Washington, DC: The Work Bank.

Remenieras, G. & Braudeau, G., 1951. *Quelques observationssur l'alluvionnement dans les reservoirs français.* New Delhi, India, Int.Congress on Large Dams, ICOLD, pp. 197-236.

Rohi, D., Bisri, M., Seoemarno & Lom, A., 2015. The Impact of Sedimentation in Reservoirs on Performance Operation of Hydropower: A Case Study Sutami Hydropower Indonesia. *International Journal of Science and Research (IJSR),* 4(1), pp. 2784-2788.

Sangroula, D. P., 2019. Sediment Management for Sustainability of Storage Projects in Himalayas-A case study of the Kulekhani Reservoir in Nepal. pp. 22-24.

Schellenberg, G., Donnelly, C. R., Holder, C. & Ahsan, R., 2019. *Dealing with Sediment: Effects on Dams and Hydropower Generation.* [Online] Available at: https://www.hydroreview.com/2017/02/22/dealing-with-sediment-effects-on-dams-and-hydropower-generation/
[Accessed 11 September 2019].

Shrestha, D. B. & Karmacharya, N., 2017. *Report on Kulekhani Reservoir Sedimentation Study, Technical report, NEA, 2017*, Kathmandu: Nepal Electricity Authority.

Shrestha, H., 2012. *Sedimentation and Sediment Handling in Himalayan Reservoirs,* s.l.: s.n.

Staphit, K. M., 1996. *Sedimentation monitoring of Kulekhani Reservoir.* Colorado, USA., The International Conference on Reservoir Sedimentation.

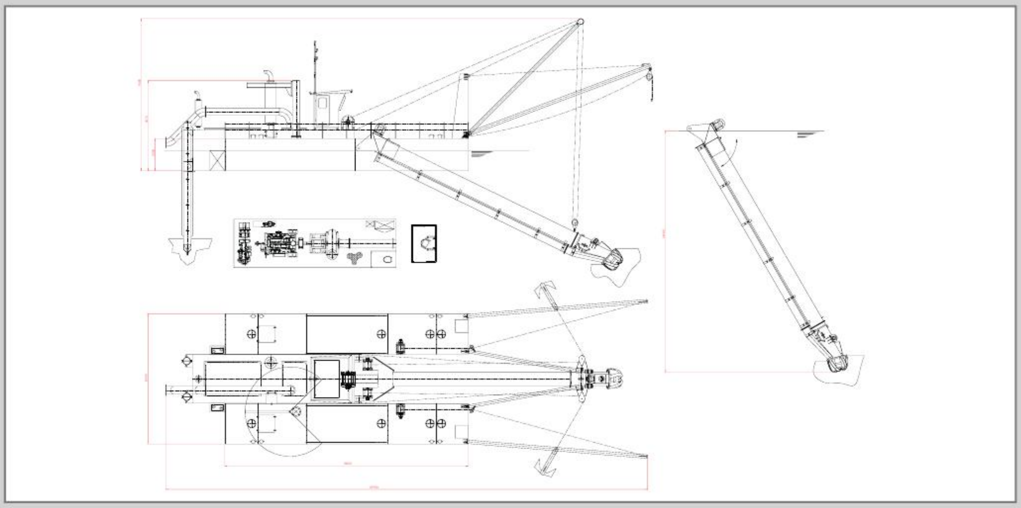
Valera, N. E. & Izquierdo, G. C., 1984. *Problemas y soluciones de sedimentaci´on en la planta del bajo Anchicaya*, Bogotá, Colombia: Seminario Latinoamericano Sobre Presas y Embalses..

Yogacharya, K. S., 2008. A Review on Status of Sediment Studies in Nepal. *Journal of Hydrology and Meteorology*, 5(1), pp. 77-90.

Zhao-yinWANG & HU, C., 2009. Strategies for managing reservoir sedimentation. *International Journal of Sediment Research,* 24(4), pp. 369-384.

ANNEX A: BROCHURE OF BELL CUTTER DREDGER 400

BELL CUTTER DREDGER 400



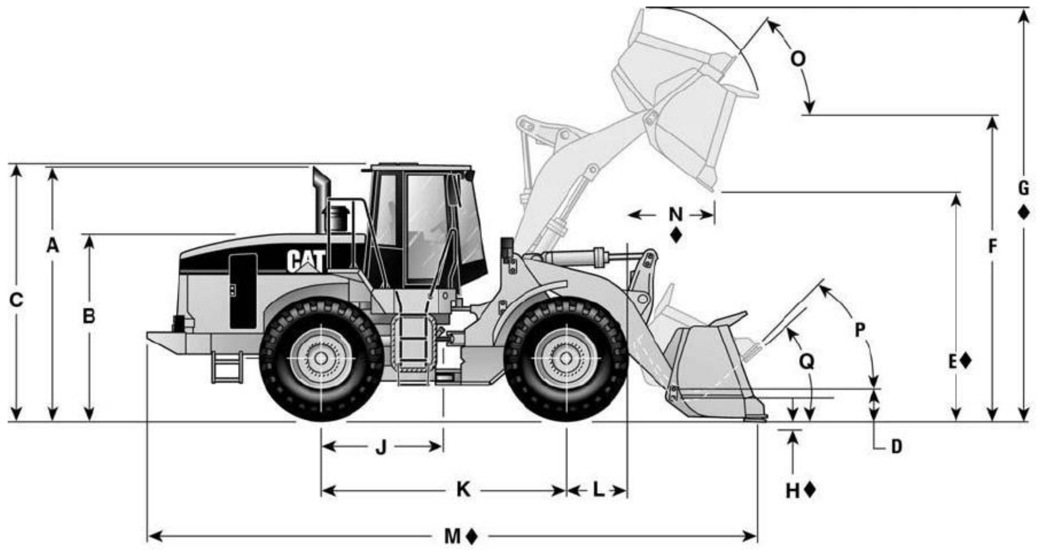
BELL CUTTER DREDGER 400

- Dredge pump: BELL 400
- Dredge capacity (water & solids): 3150 m³/hr
- Dredge capacity in dry volume (max.): 630 m³/hr
- Stone size diameter (max.): 210 mm
- Installed power on the dredge pump: 500 kW
- Power source dredger: Diesel engine
- Positioning entities: 2x mooring winches & 2x spud poles

ANNEX B: BROCHURE OF CAT 950H WHEEL LOADER

Cat 950H Wheel Loader

Fuel Burn	Low duty	Medium Duty	High Duty
L/hr	7.9 – 11.4	11.4 – 14.7	14.7 – 18.5



Dimension	Description	Measurement
A	Height to top of Stack	3.37m
B	Height to top of engine compartment	2.46m
C	Height to top of ROPS	3.45m
D	Hinge pin height at carry position	.455m
E	Dump clearance at full lift and 45* discharge angle	2.92m
F	Hinge pin height at full lift	3.99m
G	Maximum overall height	5.44m
H	Maximum digging depth	.092m
J	Machine centre point to axle	1.68m
K	Wheel base	3.35m
L	Radius of tire	.835m
M	Maximum overall length	7.99m
N	Reach at full tilt	1.202m
O	Maximum rollback at maximum lift	59*
P	Maximum rollback at carry height	45*
Q	Maximum rollback at ground	39*
	Ground Clearance	.412m
	Tread width	2.14m
	Width over tyres	2.78m

Specifications

Item	Specification
Flywheel Power Gross	161 kW
Engine Model	C7 ATAAC
Rated Engine RPM	1800
No Cylinders	6
Max forward speed	37.0 km/h
Max reverse speed	40.0 km/h
Hydraulic cycle time (raise, dump, lower)	10.0 sec
Fuel tank Capacity	314L
Hydraulic tank Capacity	110L

Performance Data

Item	Measurement
Bucket Capacity (heaped)	2.9m3
Operating Load at rated capacity	5290 kg
Struck capacity	2.5m3
Tipping load straight	12 276kg
Static tipping load full turn	10 581kg
Breakout force	164 kN
Operating weight	18 145kg

ANNEX C: BROCHURE OF TATA SK1613 TIPPER TRUCK

Specifications

ENGINE	
Engine type	Cummins 6BTAA5.9, water cooled, direct injection, turbocharged, intercooled diesel engine
Engine capacity (cc)	5883
Max engine output	89 kW at 2500 rpm
Bore / stroke	102 mm x 120 mm
Max engine torque	400 Nm at 1400 - 1700 rpm
TRANSMISSION AND STEERING	
Clutch	300 mm, single plate dry friction type
Gearbox	TATA GBS-40
No. of gears	5 Forward, 1 Reverse
1st	7.51
2nd	3.99
3rd	2.5
4th	1.5
5th	1
Reverse	6.93
FRAME	
Type	Ladder type heavy duty frame with rivetted / bolted cross members
Chassis	223 mm x 60 mm x 6 mm
Frame width	903 mm
SUSPENSION	
Front	Semi elliptical leaf spring
Rear	Semi elliptical leaf spring

BRAKES

Service brake	Fully duplicated, full air S-CAM brake system
Engine exhaust brake	Pneumatically operated interlinked with service brake

WHEELS AND TYRES

Tyre size	10.00 x 20 -16 PR
Wheel rim	7.50 x 20
Rear axle	TATA RA - 109 RR
Final drive ratio	5.86 : 1 (41 / 7)
Front axle	Heavy duty forged I beam, Reverse Elliot type

DIMENSIONS

Wheel base	3625
TCD	14800
Front track	1964
Rear track	1817
Ground clearance	259
Max. width	2434
Overall height	2460
Box body options (CBM)	6.5, 8.5 and 10
Scoop body options (CBM)	6.5

WEIGHTS

Max GVW	16200
Max. FAW	6000
Max. Raw	10200
Tare weight	4425