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Formulation of Electromechanical Cost Estimation Nomogram for Small Hydropower Project in Nepal

by

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The undersigned certify that they have read and recommended to the Institute of Engineering for acceptance, a thesis entitled "**Formulation of Electromechanical Cost Estimation Nomogram for Small Hydropower Project in Nepal**" submitted by Kapil Pudasaini in partial fulfillment of the requirements for the Degree of Master of Science in Renewable Energy Engineering.

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ABSTRACT

Power generation from flowing water is known as Hydropower generation. It is one of the major capital-intensive projects that require detailed technical as well as financial analysis before making an investment decision. The cost of Electro-Mechanical (EM) equipment including turbines, generators, controls autonomous and auxiliaries hold the remarkable portion of the hydropower project budget. The cost of the EM equipment is mainly related to the installed capacity and net head of hydropower. This research aims to develop the mathematical relation as well as the cost estimation nomogram to estimate the unit cost (per kW) of EM equipment accounting for the installed capacity of the hydropower plant and available water head. Technical and Financial Details of eighteen hydropower projects with either Pelton or Francis type turbine units were collected and analyzed for the actual unit cost by multivariate linear regression method. Obtained mathematical relationships were then compared against the primary data of actual costs. The developed relations show that the MAPE (Mean Absolute Percentage Error), Standard Deviation (SD), and adjusted R^2 for Pelton and Francis-based hydropower yields 5.81%, 6.9%, 75.89% and 8.12%, 10.2%, 80.93% respectively. From the value of MAPE obtained, it can be inferred that the modeled equation provides an excellent accurate estimation. A cost estimation nomogram for the range of 50m to 800m net head for Pelton and 30m to 300m for Francis-based hydropower with an installed power range of 1,000kW to 25,000kW in a single graph has been modeled in this research to make easier for the hydropower developer to estimate the electromechanical cost for the budgeting purpose.

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LIST OF SYMBOLS

ρ	Density of Water
g	Acceleration Due to Gravity
Q	Design Flow Rate
H	Net Water Head
P	Installed Capacity of Hydropower Project
C	Actual Unit Cost of EM Equipment
C'	Modeled Unit Cost of EM Equipment
η	Energy Conversion Efficiency of Hydraulic Turbines
€	European Currency
r	Correlation Coefficient
R^2	Coefficient of Determination
f	function
m	meter
e	Euler's Number

LIST OF ABBREVIATIONS

3D	Three Dimensional
CV	Coefficient of Variance
DDA	Due Diligence Assessment
DoED	Department of Electricity Development
EM	Electromechanical
GA	Generic Algorithm
GDP	Gross Domestic Product
GoN	Government of Nepal
HVAC	Heating, Ventilation and Air Conditioning
INR	Indian Rupees
IPP	Independent Power Producer
kW	Kilo Watt
MAPE	Mean Absolute Percentage Error
MATLAB	Matrix Laboratory
MCDM	Multi-Criteria Decision Making
MS	Microsoft
MW	Mega Watt
NEA	Nepal Electricity Authority
NPR	Nepalese Rupees
RMSE	Root Mean Square Error
RoR	Run-of-River
PRoR	Peaking Run-of-River
SD	Standard Deviation
SHP	Small Hydropower Project/ Plant
US$	United States Dollar

CHAPTER 1: INTRODUCTION

1.1 Background

Hydropower is now counted as the proven largest renewable energy resource contributing more than 92% of total renewable energy generation globally. It can be stored (Storage and Pumped Storage type plants) to balance the demand-supply cycle which is one of the best opportunities among the other renewable energy resources (IHA et al., 2000).

Following the hydropower trends, global installed capacity is raising to reach around 1,197GW in 2021 (REN21, 2022). Based on the report published by REN21, China is leading in capacity addition in 2021 in terms of installed capacity by 20.6GW, followed by Canada (0.9GW), India (0.8GW), Nepal (0.7GW), Lao PDR (0.6GW), Turkey (0.5GW), Indonesia (0.5GW), Norway (0.4GW), Zambia (0.3GW) and Kazakhstan (0.3GW).

1.2 Hydroelectricity in Nepal at Glance

Nepal is blessed with 6000 river networks which are confined to mainly four main river basins namely Koshi River Basin, Gandaki River Basin, Karnali River Basin and Mahakali River Basin with large geographical variations from the High Himalayas to the plane of the Terai within a short distance. These rivers and rivulets carry about 225 billion cubic meters of water every year and flow down to the Indian Ocean via India (Thakuri, 2019). The ample water sources and the geographical variations are extending immense hydropower potential in the country.

Three major river basins i.e. Koshi, Gandaki and Karnali have multiple tributaries rising around the high Himalayas in Nepal and Tibet keeping the significant water flows during the summer and spring seasons (Alam et al., 2017)(Sharma and Awal, 2013). The definition of the small hydropower project in terms of capacity is different for different countries worldwide. In Nepal, hydropower project with a capacity greater than 1 MW to 25 MW is considered small hydropower (WECS, 2019).

Out of 42,000MW technically as well as financially feasible potentials, only 2,190MW of power has been harnessed (which is around 5% of the total). Independent Power Producers under IPPAN are generating 1020.52MW of electricity from hydropower through the 122 hydropower stations and supplied to the power distribution system of Nepal Electricity Authority (NEA) to minimize the domestic power shortage. Out of the 122 power stations, 95 power plants are Small Hydropower Plant (SHP) of installed capacity equal to or above 1MW to equal or less than 25MW each (NEA, 2022).

NEA in 2021 published an annual report which shows that the total energy sold in FY 2021/22 was 8632GWh which is in increasing order. Out of total energy contribution in FY 2021/22, NEA has supplied 29.44% from their own powerplant, 13.94% imported from India, 20.69% from NEA's subsidiary hydropower plants and the remaining 35.92% from the domestic independent power producers in Nepal (NEA, 2022). The Figure 1.1 shows the energy balance pie-chart reported by NEA in 2022.

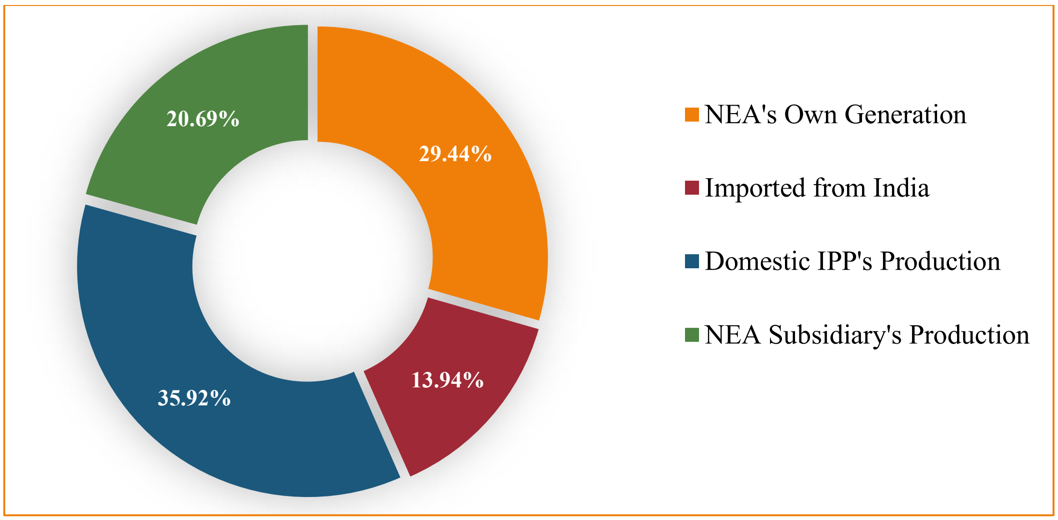

Figure 1.1: Energy Balance Chart of Nepal

(NEA, 2022)

(Herath Gunatilake, Priyantha Wijayatunga, 2020) studied the economic growth of the people in Nepal through the development of hydropower and found that the Gross Domestic Product (GDP) could dramatically increase by 87% from the baseline values by the end of 2030 if the generation of hydropower capacity increased by 20%. Also, the researcher concluded that real output, concerning the baseline, increases by more than 100% which leads 66% increment in per capita household consumption of electricity.

Department of Electricity Development (DoED), a government body of Nepal, that regulates electricity development in Nepal, published an annual report in 2021 showing the hydropower development scenario in Nepal based on the generation license provided.

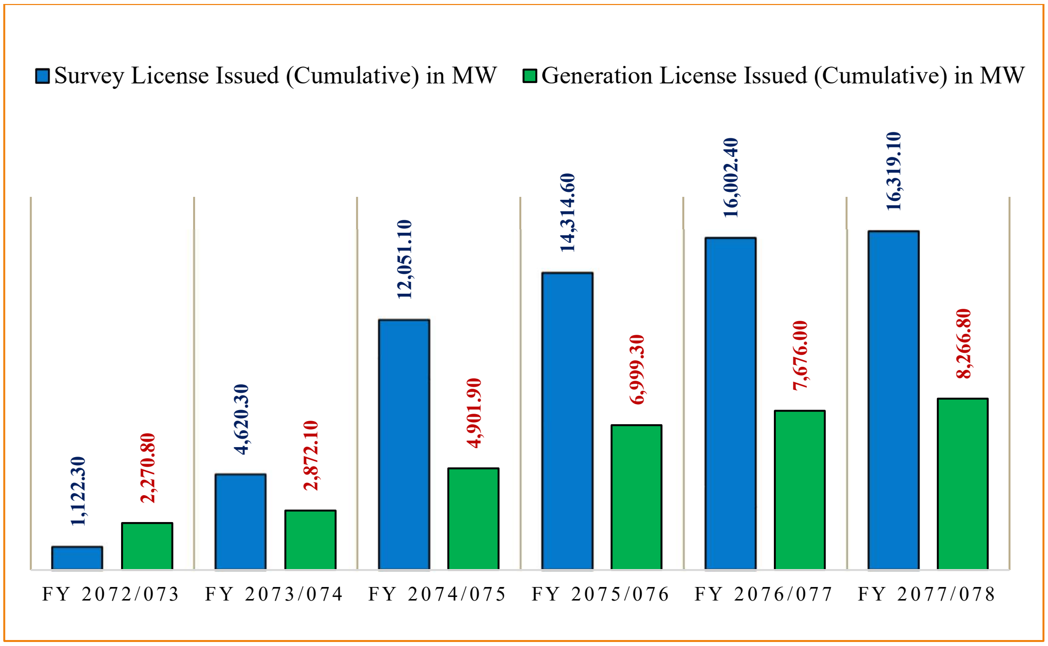

Figure 1.2: Survey and Generation License Status on Different FY

(DoED, 2021)

The Figure 1.2 shows that the survey license has already been issued for a total installed capacity of 16,319.10MW hydropower projects from which 8,266.80MW plants were granted the generation license from DoED.

The main components of the Run-of-River (RoR) type hydropower project can be classified into two sub-components i.e. civil works and electromechanical works. The main structures under the civil works are (Singal, Saini and Raghuvanshi, 2010):

- Weir and diversion
- Under-sluice structure
- Intake structure
- Gravel trap and gravel flushing
- Settling basin chamber
- Headrace pipe/tunnel/channel
- Surge tank or forebay
- Penstock pipe

- Powerhouse
- Tailrace

The main structures under the electromechanical works are:

- Valves, turbines and their governing systems
- Generator with excitation system, circuit breakers, switch gears, control mechanism, protection equipment
- Electrical and mechanical auxiliaries
- Power and auxiliary transformers
- Switchyard equipment

The electromechanical equipment denotes all the mechanical, electrical as well as electrical – mechanical coupling/interfacing equipment required to generate electricity on a water-to-wire basis. This includes turbines, governors, main inlet valves, turbine and generator shafts, cooling and drainage water systems, overhead traveling cranes, workshops, generators, transformers, earthing systems, control and automation equipment, telecommunication systems, Heating, Ventilation and Air Conditioning (HVAC) systems and auxiliary system (Ogayar and Vidal, 2009)(Alvarado Ancieta, 2016)(Mishra, Singal and Khatod, 2012).

Unlike the thermal power plant, the hydropower project is strongly site-specific (IFC, 2012). A particular hydropower site produces a specific amount of power and energy that no other hydropower site can duplicate. That means the overall cost of the hydropower project is very much dependent on the project site locations. Remoter sites may demand higher infrastructure costs, storage costs, transportation costs, access road costs, resettlement, etc. (Karki, 2004).

1.3 Research Gap and Problem Statement

A quick review of types of turbines employed in Nepalese rivers and rivulets shows that Pelton, Francis, Horizontal Kaplan, Turgo, and Cross flow are being used in at least two or more sites. With strong domination of Pelton (Peltric Sets) and Cross flow in microhydro systems (< 1MW), Small and Medium hydropower project (≤ 25MW) in Nepal has either Pelton or Francis turbine installed for power generation (Singh and Nachtnebel, 2014). Besides the favorable environment for hydropower generation with the predictable flow in the river and ample head, most of the potential sites for hydropower generation are still in planned and proposed states. With the availability of expert houses for repair and maintenance as well as erection of hydro-mechanical and electro-mechanical components of the generation, Nepal has no turbine design and fabrication house except for micro hydro turbine systems. Accounting for the current scenario, all the hydropower developers in Nepal import the electromechanical machine and equipment either from India, China, or Europe. In the overall cost estimation and budgeting of a hydropower plant, the cost of the electromechanical equipment is a vital point to be considered along with the cost of civil works, hydro-mechanical costs, instrumentation-automation cost and transmission costs. Principally, the cost of the electromechanical equipment is the function of the available static net head and installed capacity of the plant which are very much site-specific (Ogayar and Vidal, 2009). In Nepal, a contract agreement between the project developer and the electromechanical equipment supplier is done based on the 'water-to-wire' concept for most the small hydropower project. Hydropower developers in Nepal assume the unit cost considering the similar capacity project constructed in past for the estimating and budgeting purpose. The rate is dependent on the machine type, rotation axis, unit capacity, design discharge, manufacturer's profile, country of origin, etc. With this rate being assumed for cost estimate purposes, most of the sites have experienced a variety of costs during the execution phase, which has been a prime cause of disputes between contractor and developer and has largely hindered the timely completion of the construction works. This study aims to provide a feasible estimation relationship for estimating the cost of electromechanical equipment (especially for small and medium generation stations) in the context of Nepal. It is believed that the outcome will benefit many developers in proper estimation and budgeting.

1.4 Objectives

1.4.1 Main Objective

The main objective of this research is

- To generate the cost estimation nomogram chart applicable for estimating the cost of electro-mechanical equipment for small hydropower in Nepal.

1.4.2 Specific Objectives

This research has the following specific objectives.

- To study the relationship between Installed Capacity and Net Head concerning the total electromechanical cost for Pelton and Francis turbine-based Hydropower Project by graphical analysis.

- To derive an empirical equation for computing total electromechanical cost from static Installed Capacity and Net Head.

- To develop a cost estimation nomogram for both Francis and Pelton type electro-mechanical equipment

1.5 Scope and Limitations of Work

The assumption and limitations considered in this research for simplifying the modeling are:

- Considering the Nepalese context, with strong domination of run-of-river (RoR) type schemes in small and medium hydropower plants employing either Pelton or Francis machines. Hence, this research is limited to RoR type schemes with the aforementioned two turbine types only.

- The cost considered in this study shall be the contract cost and no discrete analysis shall be done for each and every component for example costing of runners, the costing of shafts, automation sensor costs, etc.

- Due course of the research and for different projects considered in this study, the cost may have either increased due to the escalation of the US$ or may have decreased due to recent advances in the manufacturing technology and competition in the market. No price adjustment factor shall be considered accounting to this factor in this research.

CHAPTER 2: LITERATURE REVIEW

Electromechanical equipment converts the hydro potential energy into transmissible electrical energy with the help of mechanical and electrical machines/ equipment. The power available to the turbine shaft is directly proportional to the product of water discharge and effective net water head. The available power can be formulated as presented in Equation (2.1).

$$P = (\rho g Q H)\eta \tag{2.1}$$

For the determination of the tentative cost of the electromechanical equipment, some researchers have invented the cost estimation nomogram for the simplification of the process. Since the cost of the electromechanical equipment is dependent on the timeline and the electro-mechanical manufacturer/ vendor does not provide any information about the cost, it is very difficult to estimate the budget during the study phase of the hydropower project.

The total cost of the project is the summation of the cost for civil works, hydromechanical cost, electromechanical cost, electrical transmission cost and cost of miscellaneous items. Miscellaneous items cover the design, accounting cost, tools, communication expenses, reporting, site survey and investigation cost, land costs, etc. miscellaneous cost covers almost 13% of the civil and electromechanical costs (Roorkee, 2013).

The construction of hydropower is a capital-intensive task and requires a long lead time (IREA, 2020). The lead time includes all the project activities from planning to project testing and commissioning. IREA in 2020 published a report 'Renewable Power Generation Costs in 2020' showing the weighted average share of total installed costs in percentage for 25 hydropower projects in China, India and Sri Lanka commissioned between 2010 to 2016.

In total, cost share of the hydromechanical and electromechanical works covers almost 32.04% of the total cost incurred in the hydropower project (IREA, 2020) as presented Figure 2.1.

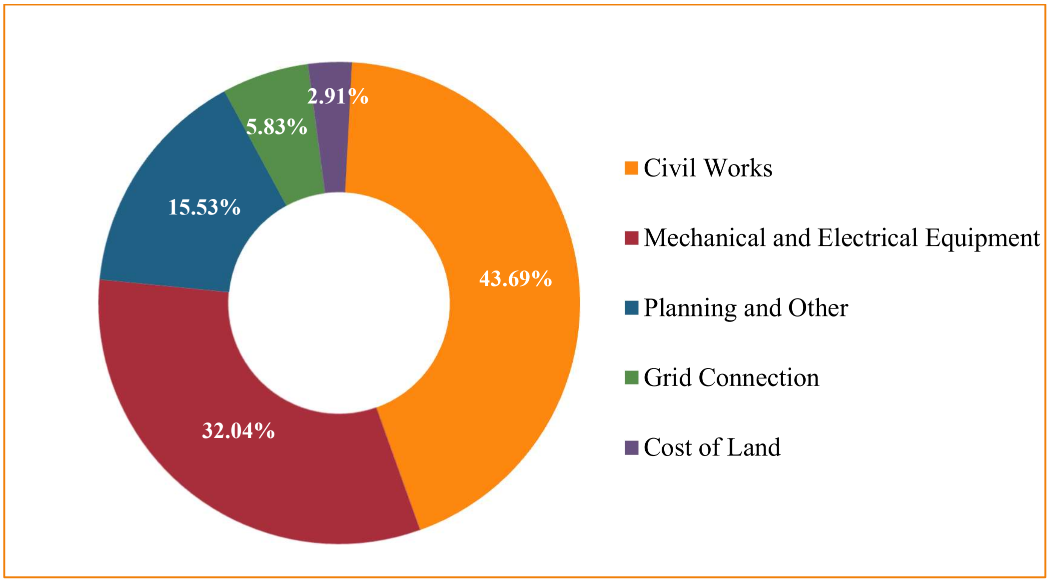

Figure 2.1: Cost Share of Total Installed Cost in Hydropower Project

(IREA, 2020)

Additionally, previous literature shows that the cost of the electromechanical equipment carries almost 30% to 40% of the total budget of the plant. Estimation of the electro-mechanical cost is vital stem since it could influence the project viability (Ogayar and Vidal, 2009).

2.1 Global Scenario

S.K. Singal and R.P. Saini in 2007, analyzed the cost function for the low-head hydropower projects and developed a relation presented in Equation (2.2) below.

$$C = 437403.P^{-0.2206}.H^{0.1435} \qquad (2.2)$$

Where, C is in per kW EM cost in Indian Rupees, P in kW and H in meter. For validation, they calculated the error percentage and found the maximum deviation within the range of ±12% (Singal and Saini, 2007).

Cesar Adolfo Alvarado-Ancieta, in 2009 compiled statistical data on costs of electrical and mechanical equipment for 81 selected hydro power projects with net head of 9m to 800m and installed capacity of 0.5MW to 800MW in America, Asia, Europe and Africa with the latest information and generated the cost estimation formula and diagrams which allow a close cost estimation of electro-mechanical equipment in powerhouses. He further suggested that the diagrams he presented could be used for Due Diligence Assessment (DDA) study, pre- and feasibility study levels and need to be updated each year considering the actual price escalation. The formula proposed by him is presented in Equation (2.3).

$$\text{Cost} = 1.1948\ P^{0.7634} \qquad (2.3)$$

Where, cost denoted the generating cost for Electromechanical equipment in Millions of US$ with respect to December 2008.

Sachin Mishra et. al. in 2011 analyzed the three main cost estimation methods for EM equipment accounting for the power and head as influencing factors (Mishra, Singal and Khatod, 2011). They compared the actual EM cost with the modeled cost calculated by the sigma plot, linest method and logest method to observe the reliability of the methods. They recommended using either sigma plot or linest plot as the error percentages to the actual cost are relatively small.

Sachin Mishra et. al. in 2012 again developed a correlation equation for the cost estimation of the EM equipment based on the power and head as the influencing parameters (Mishra, Singal and Khatod, 2012). They developed a correlation equation in terms of Indian Rupees per kW with ±10% accuracy from the actual cost. The relation proposed by them is presented below in Equation (2.4).

$$\text{Cost} = 6.882.\, H^{-0.0782}.\, P^{0.6369} \qquad (2.4)$$

Where C is the cost per kW in Indian Rupees.

Giovanna Cavazzini et al. in 2016, proposed a new method for the estimation of EM equipment cost by accounting for the installed power, net head as well as design flow rate. They observe and compare results with the cost estimation technique developed by (Ogayar and Vidal, 2009) and concluded that the obtained mean errors values were smaller: 9.2% in place of 10.2% for Pelton turbine and 9.8% in place of 11.5% for Francis turbine.

Likewise, Peaking Run-of-River (PRoR) or Run-of-River (RoR) project, Gaydaa AlZohbi in 2018, developed new correlations to estimate the cost of Pelton unit with size ≤ 25MW, Kaplan unit with size 5MW ≤ P ≤233 MW, Francis Unit with size 1MW ≤ P ≤ 32MW more than 88% coefficient of determination (Alzohbi, 2018). The equation he developed for the Pelton turbine and Francis turbines are presented below in Equation (2.5) and Equation (2.6).

$$C_{Pelton} = 1.984. P^{1.427}. H^{-0.4808} \quad (2.5)$$

Where, C_{Pelton} is in Million Euro, P in MW and H in meters.

$$C_{Francis} = 1.984. P^{1.427}. H^{-0.4808} \quad (2.6)$$

Where, $C_{Francis}$ is in Million Euro, P in MW and H in meter.

He concluded, with his arguments, that the cost of EM equipment is very much sensitive to the net head and installed power as the total cost of the EM equipment is positively correlated with installed power and negatively correlated with the net head.

Amèdédjihundé Hypolite et. Al. in 2019 proposed the cost estimation methodology for electromechanical equipment by considering the continental factors. He established the mono-and multi-objective Generic Algorithm (GA) to optimize the cost correlation (Hounnou *et al.*, 2019). The continental factor K_j for each continent was calculated by accounting for the transport costs for EM equipment and obtained the results more accurate.

Sanchit Asran Agrawal and Mitthan Lal Kansal in 2020 suggested a methodology based on the Multi-Criteria Decision-Making (MCDM) process for hydropower cost estimation. They also suggested their philosophy to be used during the pre-feasibility stage to analyze the risk factors and their impact based on their case study of Leshka Hydropower Project (126MW), India (Agarwal and Kansal, 2020).

Later, in 2021, P. Malhan and M. Mittal established different statistical techniques to estimate the EM cost as well as the total project cost for micro hydropower projects in India (Malhan and Mittal, 2021). He proposed the multivariate polynomial regression approach to estimate the cost as it fits the actual cost scatter plot really well. The correlation, he gave, forecasted the cost within ±10% accuracy from the actual cost which is almost the same as the formula developed by (Mishra, Singal and Khatod, 2012). However, almost 75% of the estimated data had an error value of less than 8%. The polynomial equation of EM cost is expressed as;

$$C_{em} = (6.9041\ 10^4 - 1080.\mathrm{P} - 596.\mathrm{H} + 127.6.P^2 - 124.6.\mathrm{P.H} + 44.94.H^2 - 1.02.P^3 + 0.6473.P^2.\mathrm{H} + 0.3239.P.H^2 - 0.2877.H^3 \quad (2.7)$$

Where C_{em} is electromechanical equipment cost in INR/kW.

2.2 Nepalese Scenario

No specific costing methods are derived for the Nepalese context so far but some previous literatures are found in the field of cost estimation for electromechanical equipment.

The electromechanical cost is governed by the type, capacity, designed water discharge, net available head, automation facility, the safety level of the turbine equipment along with the location of the plant. The cost of electromechanical equipment varies among different manufacturers and types due to differences in construction technologies. Hence, it is very difficult to obtain a single accurate relation for cost estimation of all turbine types and sizes. A government body of Nepal, Water and Energy Commission Secretariat (WECS) in 2019 recommended to use relation derived by (Alvarado Ancieta, 2016) presented in Equation (2.8) for the estimation of electromechanical equipment cost for Nepal. The cost function derived by Alvarado Ancieta was based on the electromechanical costs collected from hydropower plants in 2008 and before. The relation, however, estimates the electromechanical cost of smaller installed capacity on the higher side. The relation estimates the prices with reference to December 2008. The cost may have increased due to the escalation of the US$ but also may have decreased due to recent advances in manufacturing technology and competition in the market. So, no adjustment is recommended to the costs computed by the relation (WECS, 2019).

$$C_{EM} = 1.1948\ P^{0.7634} \quad (2.8)$$

Where C_{EM} is an electromechanical cost in million US$; P is the installed capacity in MW. Some other cost functions, which are found in literature, and devised by various researcher in past are presented in Table 2.1.

Table 2.1: Cost Function Derived in Past

Cost Functions	Country	Year	Author
$Cost\ (\$) = 9000\ P^{0.7}\ H^{-0.35}$	Canada	1978	Gordon and Penman
$Cost\ (\$) = 97436\ P^{0.53}\ H^{-0.53}$	Sweden	1979	Lasu and Persson
$Cost\ (\$) = 9600\ P^{0.82}\ H^{-0.35}$	USA	1984	Gulliver and Dotan
$Cost\ (\$/kW) = 31500\ P^{0.25}\ H^{-0.75}$	UK	1988	Whittington et al.
$Cost\ (\$) = 40000\ P^{0.70}\ H^{-0.35}$	Greece	2000	Voros et al.
$Cost\ ((€/kW) = 10^{3}(34.12+16.99\ P^{0.91}\ H^{-0.14})$	Switzerland	2000	Chenal
$Cost\ (\$/kW) = 12900\ P^{0.82}\ H^{-0.246}$	U.S.A.	2003	Gordon
$Cost\ (€/kW) = 3300\ (P^{-0.122}\ H^{-0.107})$	Greece	2007	Keldellis
$Cost\ (€/kW) = 3300\ (P^{-0.122}\ H^{-0.107})$ – *Pelton*	Spain	2009	Ogayar and Vidal
$Cost\ (€/kW) = 3300\ (P^{-0.122}\ H^{-0.107})$ – *Francis*	Spain	2009	Ogayar and Vidal
$Cost\ (€) = 1358677.67\ H^{0.014} + 8489.85\ Q^{0.515} + 3382.1\ P^{0.416} - 1479160.63$ – *for Pelton*	Italy	2016	Giovanna Cavazzini et al.
$Cost\ (€) = 190.37\ H^{1.27963} + 1441610.56\ Q^{0.03064} + 9.62402\ P^{1.28487} - 1621571.28$ - *Francis*	Italy	2016	Giovanna Cavazzini et al.

(Cavazzini et al., 2016; Alzohbi, 2018)

CHAPTER 3: RESEARCH METHODOLOGY

As shown in Figure 3.1, the research commenced with the approval of the research proposal. Reviewing the previous research literature, collection of technical and financial data from the various hydropower developers, analysis of such data with the various methods, and validation of the research outcome followed by the interpretation of conclusions are the main steps adopted for this research.

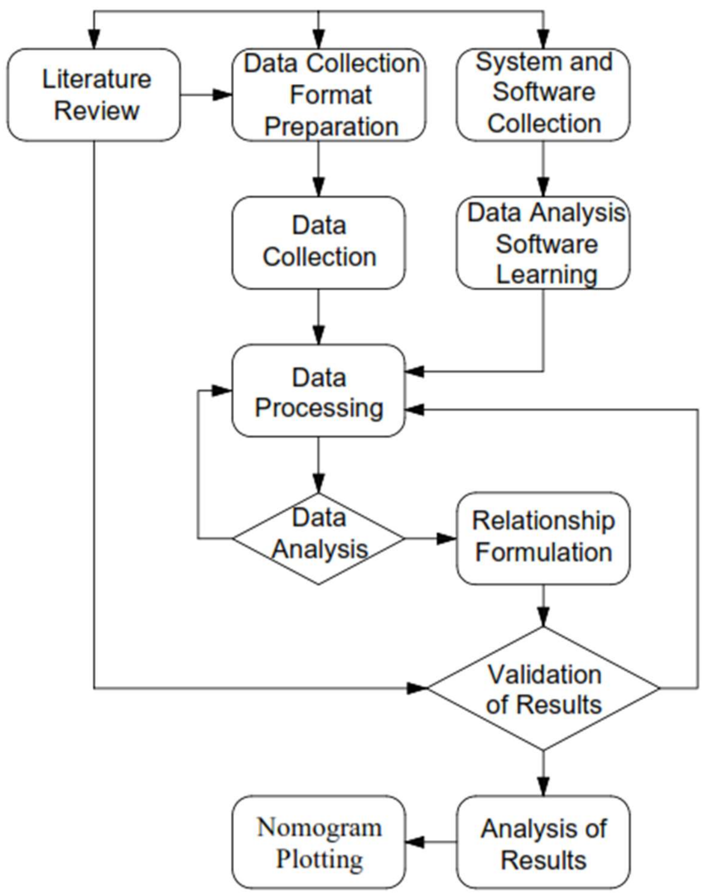

Figure 3.1: Methodology Work Flow Chart for Research

The following methods and steps were adopted to carry out the proposed research.

3.1 Literature Review

Literature from different books, research papers, journals, review papers and reports prepared by the previous researchers were studied for strengthening the knowledge in the field of hydropower, hydraulic machines, powerhouse components, water to wire concepts, cost estimation techniques, statistical analysis, interpretation of the output data, etc.

3.2 Sampling Techniques

Population size was identified based on the installed capacity of the hydropower plant/project and the developer type within Nepal.

The sampling technique chosen in this research is non-probabilistic sampling at which the following points were taken care of:

- Each hydropower is to be located within Nepal and Power Purchase Agreement (PPA) concluded projects.
- Each population must be a small hydropower plant/project with an installed capacity of 1000 kW $\leq$ P $\leq$ 25000 kW.
- The population must have Francis or Pelton machine installed as a generating unit.
- Powerplants based on other than hydro was neglected.
- The sample selection has been done based on the data available in such a way that all the provinces of Nepal are represented (except Madhesh and Lumbini Province) at which the net available head is medium or high.

Considering the above points as well as the water-to-wire Contract Agreement concluded after 2010, the total population size was identified as 228 within the country. All the hydropower (NEA, 2021) considered in this research has been tabulated in Annexure C. Population counted for this hydropower are either already in operation or construction going on. All the hydropower considered in this research is developed by the domestic Independent Power Producers (IPP) in Nepal. All the small hydropower developed by the NEA are very old and may mislead the research output. Hence, hydropower plants developed by NEA were ignored from the population size.

Total 36 hydropower plant/projects were preliminarily identified as the sample size by considering 95% confidence level with 15% confidence interval. Among those sample size, 18 Pelton-based hydropower and another 18 Francis-based hydropower were planned to be chosen for the data collection.

For the fair representation of the sample from all seven Provinces of Nepal, collection of samples was done based on the Table 3.1.

Table 3.1: Province-wise Population Distribution

S.N.	Province	No. of Hydropower (Population Size)	Total Capacity (MW)	No. of Hydropower (Sample Size taken)
1	Province -1	75	739.91	13
2	Madhesh	-	-	-
3	Bagmati	60	592.58	4
4	Gandaki	70	738.92	15
5	Lumbini	5	22.82	-
6	Karnali	8	49.40	3
7	Sudurpashchim	10	70.46	1
Total		228	2,214.07	36

It was very difficult to collect the turbine type and other details for all the population considered here. Hence, 18 each type of hydropower was planned to be collected for efficient and realistic research output.

3.3 Data Collection

Data collection is one of the vital processes that determine the quality of research output. Proper planning was done for the data collection. The data collection method was developed systematically with the level of hypothesis and evaluation of outcomes.

A survey questionnaire was prepared considering the objectives of the research paper and critical parameters that influence the unit cost of the EM equipment as tabulated in Table 3.2:

Table 3.2: Survey Questionnaires

Particulars	Required Data/Information	Remarks:
Name of the Project:		
Project Location:		
Developer's Name:		

Installed Capacity (kW):		
No. of Generating Unit:		
Design Discharge per unit (m^3/sec):		
Rated Static Net Head (m):		
EM Manufacturer/Supplier:		
Type of Turbine:		
Proposed Speed of Turbine (rpm):		
Axis of Turbine:		
Country of Origin:		
Year of Contract Signing:		
Cost of Electromechanical Equipment:		
Issues and Comments:		

A survey questionnaires table was provided to the hydropower developer, Consultants, EM Contractors, and Lenders Engineers by either face-to-face meetings or by email or phone calls requesting the technical and cost detail of the electromechanical items of their respective projects/plants. The survey questionnaire table prepared for this research has been presented in Annexure B.

All the data required by the research were tried to be collected in every possible way. However, the project officials and other shareholders were found to be very reluctant to the information sharing as they think that the financial information is a confidential matter of the company.

The sample size is normally taken as much as possible to represent the behavior of the population. A greater sample size always provides an accurate result (Kaur, 2017). The sample size in this research was judged based on the quality of the resulting estimates. Because of the limited available data, total of 36 hydropower projects/plants were considered randomly for this research work. To maintain the province-wise quota sampling, the confidence interval is to be increased that results the poor-quality research output.

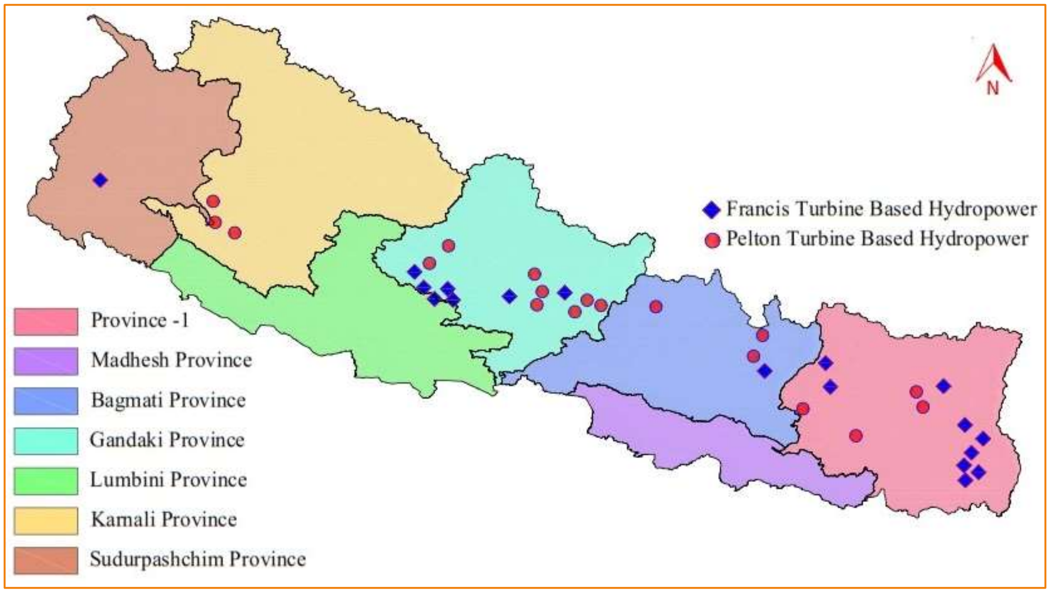

Figure 3.2: Location Map of Hydropower Considered in this Research

Hydropower considered for this research have been plotted in Figure 3.2: Location Map of Hydropower Considered and listed in Table 3.3 below.

Table 3.3: Sample Size Considered for this Research

S.N.	Project Name	District	Province	Net Head (H) m	Installed Capacity (P) kW
1	Buku-Kapate	Okhaldhunga	Province -1	248.18	5000
2	Super Hewa	Sankhuwasabha		321.81	6000
3	Upper Rawa	Khotang		153.81	3000
4	Upper Hewa	Sankhuwasabha		236.2	8500
5	Upper Ignwa	Taplejung		186.92	9700
6	Mai Beni	Ilam		135.02	9510
7	Lower Jogmai	Ilam		123.49	6200
8	Upper Solu	Solukhumbu		177.06	18000
9	Madhya Solu	Solukhumbu		113.46	9500
10	Lower Hewa	Panchthar		170.95	21600
11	Super Mai	Ilam		123.93	7800
12	Super Mai-A	Ilam		186.30	9600
13	Super Mai Cascade	Ilam		47.35	3000

14	Mathillo Mailung	Rasuwa	Bagmati	486.5	14300
15	Upper Suri	Dolakha		434.21	7000
16	Suri Khola	Dolakha		273.19	6400
17	Tallo Khare Khola	Dolakha		128.00	11000
18	Upper Machha	Gorkha	Gandaki	211.67	4550
19	Super Chepe	Gorkha		527.46	9050
20	Thapa Khola	Myagdi		375.9	13600
21	Upper Midim	Lamjung		439	7500
22	Rudi Khola-A	Lamjung		276.89	8800
23	Rudi Khola-B	Lamjung		299.81	6600
24	Thulo Khola	Myagdi		347.25	21300
25	Chepe Khola	Gorkha		217.8	8630
26	Theule Khola	Baglung		81.00	1500
27	Bhim Khola	Baglung		165.25	4960
28	Daram Khola	Baglung		111.20	9600
29	Dordi -1	Lamjung		121.00	12000
30	Daram Khola A	Baglung		83.30	2500
31	Madhya Tara	Baglung		119.09	2200
32	Seti Nadi	Kaski		163.00	25000
33	Padam Khola	Dailekh	Karnali	233.18	4500
34	Upper Lohore	Dailekh		190	4000
35	Dwari Khola	Dailekh		427	3750
36	Upper Gaddi Gad	Doti	Sudur pashchim	95.00	1550

3.3.1 Projects with Pelton Unit:

Eighteen hydropower project/plant which has Pelton unit installed, within Nepal, were collected and analyzed at which net water head ranges from 153.81m to 527.46m and installed capacity from 3750kW to 21300kW. Collected data are listed in Table 3.4 below.

Table 3.4: Sample Size for Pelton Turbine-Based Units

Project Name	Net Head (H) m	Installed Capacity (P) kW	Actual Total Cost (US$)	Actual Unit Cost (US$/kW)
Upper Rawa	153.81	3000	1,002,230.90	334.08
Upper Lohore	190	4000	1,269,153.90	317.29
Suri Khola	273.19	6400	1,801,217.62	281.44
Rudi Khola-A	299.81	6600	1,815,131.16	275.02
Dwari Khola	427	3750	1,003,529.88	267.61
Upper Machha	211.67	4550	1,197,704.81	263.23
Super Hewa	321.81	6000	1,554,000.00	259.00
Buku-Kapate	248.18	5000	1,284,626.28	256.93
Upper Hewa	236.2	8500	2,176,000.00	256.00
Upper Midim	439	7500	1,913,872.98	255.18
Padam Khola	233.18	4500	1,148,261.43	255.17
Chepe Khola	217.8	8630	2,160,220.58	250.32
Upper Suri	434.21	7000	1,750,279.04	250.04
Rudi Khola-A	276.89	8800	1,962,977.52	223.07
Thulo Khola	347.25	21300	4,572,491.82	214.67
Super Chepe	527.46	9050	1,927,116.33	212.94
Thapa Khola	375.9	13600	2,788,000.00	205.00
Mathillo Mailung	486.5	14300	2,618,000.00	183.08

3.3.2 Projects with Francis Unit:

Eighteen hydropower projects/plants which have Francis units installed, within Nepal, were collected and analyzed at which net water head ranges from 47.35m to 186.92m and installed capacity from 1550kW to 25000kW. Collected data are listed in Table 3.5 below:

Table 3.5: Sample Size for Francis Turbine Based Units

Project Name	Net Head (H) m	Installed Capacity (P) kW	Actual Total Cost (US$)	Actual Unit Cost (US$/kW)
Upper Gaddi Gad	95.00	1550	657,404.86	424.13

Daram Khola A	83.30	2500	887,500.00	355.00
Theule Khola	81.00	1500	525,000.00	350.00
Super Mai Cscd.	47.35	3000	907,475.00	302.49
Madhya Tara	119.09	2200	616,742.50	280.34
Lower Jogmai	123.49	6200	1,673,209.16	269.87
Tallo Khare	128.00	11000	2,626,752.66	238.80
Upper Ignwa	186.92	9700	2,279,500.00	235.00
Super Mai	123.93	7800	1,833,000.00	235.00
Bhim Khola	165.25	4960	1,114,745.29	224.75
Mai Beni	135.02	9510	2,126,229.66	223.58
Madhya Solu	113.46	9500	2,091,706.49	220.18
Upper Solu	177.06	18000	3,757,287.45	208.74
Super Mai-A	186.30	9600	1,984,314.60	206.70
Lower Hewa	170.95	21600	4,153,602.61	192.30
Daram Khola	111.20	9600	1,816,685.26	189.24
Dordi -1	121.00	12000	2,226,793.15	185.57
Seti Nadi	163.00	25000	4,413,750.00	176.55

3.4 Data Analysis

3.4.1 Initial Conversion of Data

Actual cost, as well as other technical parameters, were collected from the different informers and then preliminary analyzed using Microsoft Excel. The cost of the EM equipment provided in NPR, INR and Euro were converted into the US$ considering the EM Contract signing date as the base date. https://www.exchangerates.org.uk/ was used to convert the different currencies into US$. Calculated cost in US$ then converted into the unit rate as US$ per kW for further analysis.

3.4.2 Analysis in Scatterplot

Scatterplots of the one dependent variable (C) with respect to one independent variable (P or H) were plotted in MATLAB R2018a for both Pelton and Francis Based hydropower in order to observe whether only one independent variable can define the dependent variable or not. Also, the data of Pelton and Francis-based Hydropower were merged for generalization and analyzed whether a single relation could define the overall hydropower EM cost in Nepal. A Linear Regression plot was done on MATLAB and generated the linear correlation equation along with r, R^2 and RMSE to analyze the result further.

3.4.3 Formulation of Empirical Relation

Different types of mathematical correlations were used by various researcher for the estimation of the electromechanical equipment cost globally. Most of the previous literature shows that the cost (C') of the electromechanical equipment is dependent on net static water head (H) and power output (P) as presented in Equation (3.1).

$$C' = aP^b H^c \tag{3.1}$$

Whare, a, b and c are constants.

Applying the logarithms on both sides in Equation (*3.1*), we get

$$\log C' = \log (aP^b H^c)$$

$$\log C' = \log a + b \, log \, P + c \, log \, H \tag{3.2}$$

Carrying out the variable change,

$$Z = \log C'$$

$$X = \log P$$

$$Y = \log H$$

We get,

$$Z = log \, a + bX + cY \tag{3.3}$$

Substituting the collecting data of cost, power and head of selected plants it is obtained as,

$$Z_1 = log \, a + bX_1 + c \, Y_1 \tag{3.4}$$

$$Z_2 = log\, a + bX_2 + c\, Y_2$$

$$Z_3 = log\, a + bX_3 + c\, Y_3$$

$$Z_4 = log\, a + bX_4 + c\, Y_4$$

$$Z_n = log\, a + bX_n + c\, Y_n$$

And so on. Plotting the above Equation (*3.4*) in MS Excel and carrying the multivariate regression between the independent variables (X, Y) and (Z),

$$AX + BY + CZ + D = 0 \tag{3.5}$$

Finding out the value of Z considering C ≠ 0 in From Equation (*3.5*),

$$Z = -\left(\frac{D}{C}\right) - \left(\frac{A}{C}\right)X - \left(\frac{B}{C}\right)Y \tag{3.6}$$

Now, comparing Equations (*3.3*) and (*3.6*), we get the values of constants as,

$$\begin{aligned} a &= e^{-\frac{D}{C}} \\ b &= -\frac{A}{C} \\ c &= -\frac{B}{C} \end{aligned} \tag{3.7}$$

Therefore, unit EM cost can be expressed as,

$$C' = aP^b H^c \tag{3.8}$$

The constants a, b and c are determined by using enough data on costs depending on net head and power (Alzohbi, 2018), (Ogayar and Vidals, 2009).

The multivariate linear regression analysis has been done on MS Excel to analyze the Correlations, R^2 and error. Surface derived from Equation (3.8) then plotted in MATLAB along with the scatterplot of the actual cost to visualize the deviations.

3.5 Validation of the Estimation Relationship

3.5.1 Validation by Primary Data

Validation of the estimation relationship has been done by calculating the real and simulated costs for small hydropower plants equipped with Pelton and Francis along with the generalized form (by combining both types of turbines). The relation used to calculate the error is presented in Equation (3.9) below:

$$Error\ (\%) = \frac{Market\ Cost - Estimated\ Cost}{Market\ Cost} x100 \qquad (3.9)$$

MAPE of all three scenarios were analyzed based on the deviations obtained from the actual cost. As suggested by Eva Ostertagová in 2012, MAPE values were interpreted as noted in Table 3.6 below;

Table 3.6: MAPE Value Interpretation

MAPE	Interpretation
< 10%	Excellent Accurate Estimation
10% to 20%	Good Estimation
20% to 50%	Acceptable Estimation
> 50%	Inaccurate Estimation

(Ostertagová, 2012)

3.5.2 Validation by Secondary Data

The result simulated in this research has also been validated using secondary data derived in past by Alzohbi (Alzohbi, 2018), Ogaryer (Ogayar and Vidal, 2009) and Cavazzini (Cavazzini *et al.*, 2016).

Deviations in unit cost calculated in this research has been compared and analyzed with respect to those relations proposed by three researchers mentioned above for both

Francis and Pelton based units and calculated the results as well. The formula used to calculate the deviation is presented below in Equation (3.10).

$$Error\ (\%) = \frac{Modeled\ Cost - Cost\ Derived\ in\ Past}{Cost\ Derived\ in\ Past} x100 \qquad (3.10)$$

The result obtained from all three data sets were plotted in the line graph in MS Excel showing the deviation in unit cost from modeled value and then compared with the past researches for the validation.

3.5.3 Formulation of Cost Estimation Nomogram

After validating the research output with primary as well as secondary data, a cost estimation nomogram has been plotted in MATLAB considering net head 50m to 800m for Pelton-based hydropower and 30m to 300m for Francis-based hydropower in a single graph. Power considered for both types has been taken from 1,000kW to 25,000kW.

Nomogram has been plotted with H on the x-axis and P on the y-axis with cost variation of 180 US$ /kW to 400 US$/kW with 10 US$/kW interval for easy use.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Scatter Plot

The scattergram or scatterplot has been presented to visualize the relationship between the two quantitative variables i.e., Installed Capacity (P) vs. Unit EM Cost (C) and Net Head (H) vs. Unit EM Cost (C). Also, the residuals with respect to the best fit linear model line have also been analyzed in MATLAB R2018a to record the deviations.

Scatterplot along with the residual plot of Installed Capacity (P) vs. Unit EM Cost (C) has been plotted for the 18 hydropower plants having Pelton unit by carrying out the linear correlation. As shown in Figure 4.1, a line equation was obtained as follows:

$$C_{p,P} = f(P) = -0.006106. P + 301.70 \quad (4.1)$$

With,

Parameters	Value
r	- 0.7465
R^2	0.5573
RMSE	25.54

The analysis showed that at least 55.73% of the variance in Unit EM Cost (C) is associated with the variance in Installed Capacity (P). From Figure 4.1, it can be concluded that the Installed Capacity (P) and the Unit EM Cost (C) have a high negative correlation. From the residuals graph, it has also been observed that maximum positive and maximum negative deviation from the linear model line were found for Upper Rawa Khola Hydropower Project and Upper Midim Hydropower Project respectively.

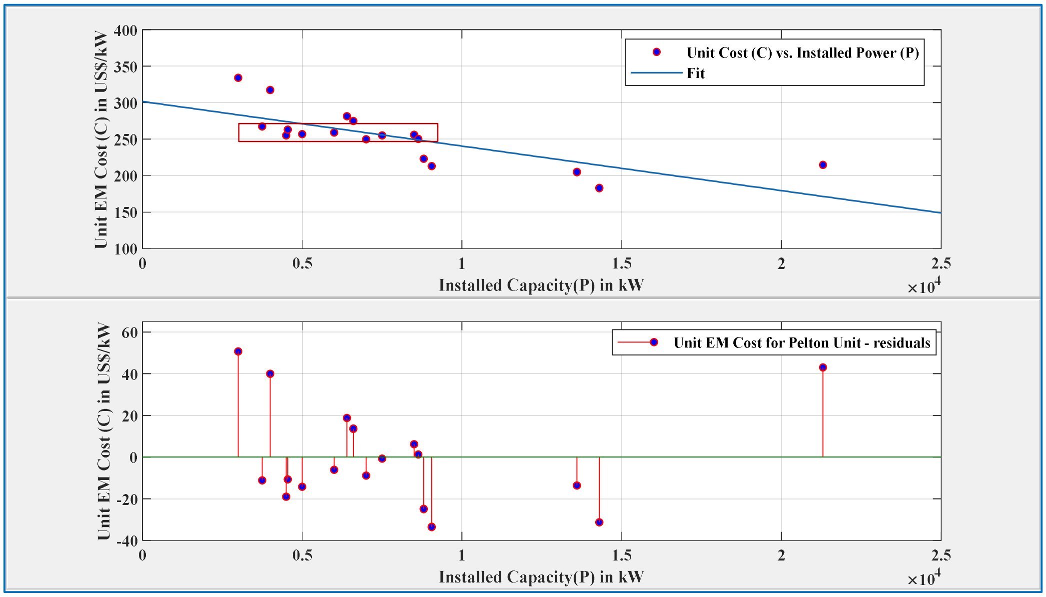

Figure 4.1: Scatterplot and Residual Plot with respect to P vs. C for Pelton Units

Similarly, a scatterplot with a linear correlation model was plotted for the Pelton unit considering Net Head (H) vs. Unit EM Cost (C) and found the following equation:

$$C_{p,H} = f(H) = -0.2257.H + 324.80 \quad (4.2)$$

With,

Parameters	Value
r	- 0.664
R^2	0.441
RMSE	28.69

The analysis showed that at least 44.10% of the variance in Unit EM Cost (C) is associated with the variance in Net Head (H). From Figure 4.2, it can be concluded that the Net Head (H) and the Unit EM Cost (C) have a moderate negative correlation as the correlation coefficient is only 0.664. From the graph, it has also been observed that maximum positive and maximum negative residuals were found for Upper Rawa Khola Hydropower Project and Rudi Khola -A Hydropower Project respectively.

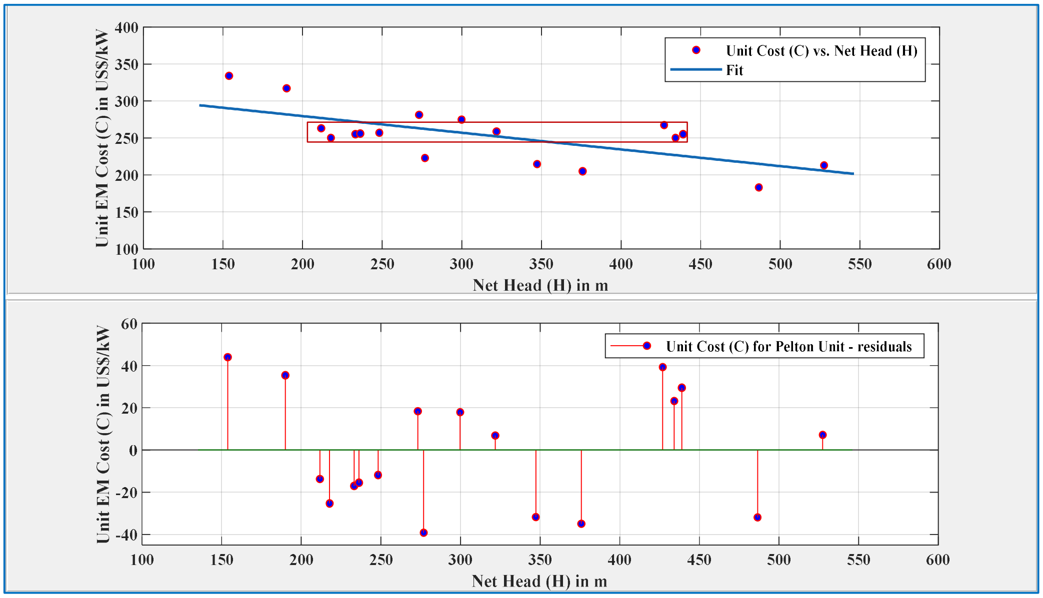

Figure 4.2: Scatterplot and Residuals with Respect to H vs. C for Pelton Units

In the P, C' scatterplot, it was observed that numerous numbers of hydropower projects with different installed capacities have almost the same unit cost value which is basically due to the variations in the net head of the respective project. Similarly, in H, C' scatterplot, hydropower projects with different net heads have almost the same unit cost which is due to the variations in the installed power.

Same as the Pelton unit, scatterplot along with the residual plot of Installed Capacity (P) vs. Unit EM Cost (C) was plotted for the 18 hydropower plants having Francis Turbine units by carrying out the linear correlation. A line equation was obtained by analyzing the slope and intercept value from Figure 4.3, as follows:

$$C_{f,P} = f(P) = -0.00749. P + 319.8 \tag{4.3}$$

With,

Parameters	Value
r	- 0.7428
R^2	0.5527
RMSE	46.80

The analysis showed that at least 55.27% of the variance in Unit EM Cost (C) is associated with the variance in Installed Capacity (P). From Figure 4.3, it can be concluded that the Installed Capacity (P) and the Unit EM Cost (C) have a high negative correlation. From the graph, it has also been observed that maximum positive and maximum negative deviation from the linear model line were found for Upper Gaddi Gad Hydropower Project and Bhim Khola Small Hydropower Project respectively.

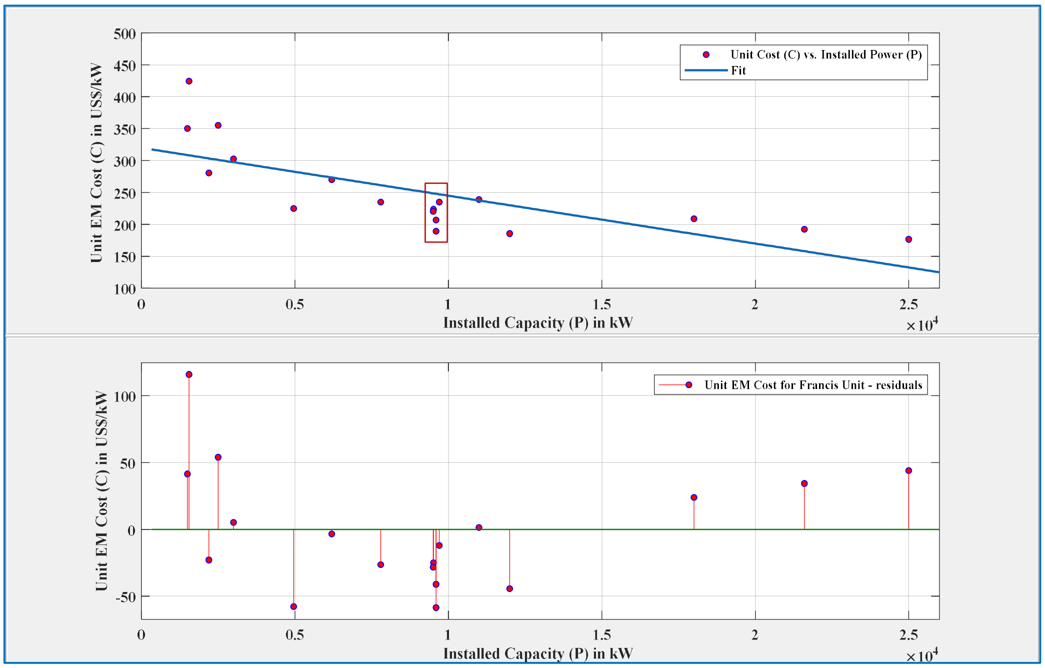

Figure 4.3: Scatterplot and Residuals with Respect to P vs. C for Francis Units

Similarly, a scatterplot with a linear correlation model for the Francis turbine projects was plotted for the Pelton unit considering Net Head (H) vs. Unit EM Cost (C) and found the following equation:

$$C_{f,H} = f(H) = -1.122.H + 396.30 \tag{4-4}$$

With,

Parameters	Value
r	- 0.6489
R^2	0.4211
RMSE	53.24

This showed that at least 42.11% of the variance in Unit EM Cost (C) is associated with the variance in Net Head (H). From Figure 4.4, it can be concluded that the Net Head (H) and the Unit EM Cost (C) have a moderate negative correlation as the correlation coefficient is only 0.649. From the graph, it has also been observed that maximum positive and maximum negative residuals were found for Upper Gaddi Gad Hydropower Project and Daram Khola Hydroelectric Project respectively.

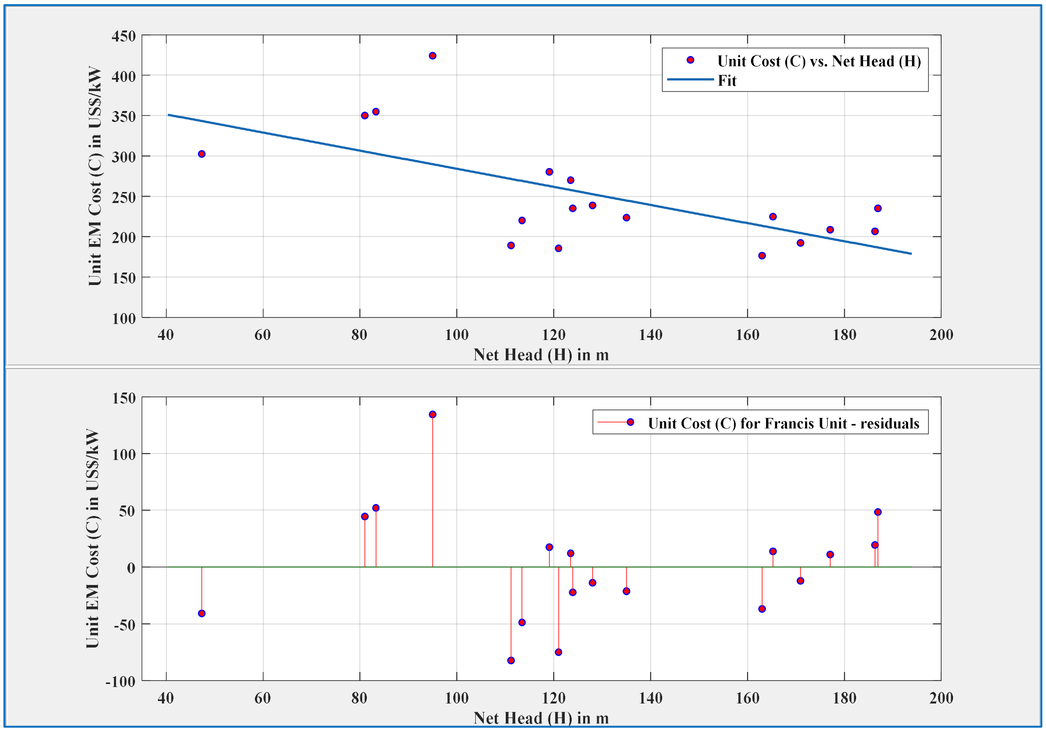

Figure 4.4: Scatterplot and Residuals with Respect to H vs. C for Francis Units

In the P - C' scatterplot of the Pelton-based hydropower, it was observed that five hydropower projects with almost the same installed capacity have a measurable difference in unit cost value which is basically due to the variations in the net head of the respective project.

To observe the deviation in the unit cost with respect to the independent variables for a combination of 18 numbers of hydropower with Pelton and other 18 numbers of hydropower with Francis turbine, scatterplot along with the residual plot of Installed Capacity (P) vs. Unit EM Cost (C) and Net Head (H) vs. Unit EM Cost (C) were plotted by carrying out the linear correlation.

A line equation was obtained for the P vs. C by analyzing the slope and intercept value obtained from Figure *4.5*, as follows:

$$C_{g,P} = f(P) = -0.007.P + 311.90 \quad (4.5)$$

With,

Parameters	Value
r	- 0.7387
R^2	0.5456
RMSE	36.91

The analysis showed that at least 54.56% of the variance in Unit EM Cost (C) is associated with the variance in Installed Capacity (P). From Figure 4.5, it can be concluded that the Installed Capacity (P) and the Unit EM Cost (C) have a high negative correlation. From the graph, it has also been observed that maximum positive and maximum negative deviation from the linear model line were found for Upper Gaddi Gad Hydropower Project and Daram Khola Hydroelectric Project respectively.

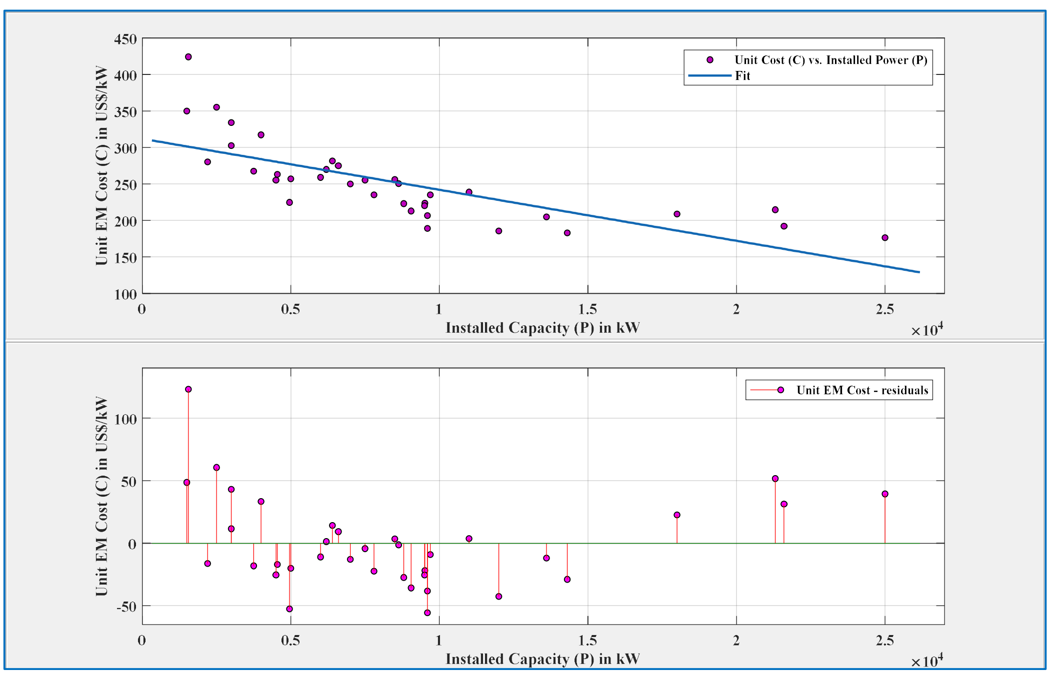

Figure 4.5: Scatterplot and Residuals with Respect to P vs. C for in General

Similarly, the scatterplot with a linear correlation model considering Net Head (H) vs. Unit EM Cost (C) was plotted and found the following equation:

$$C_{g,H} = f(H) = -0.1312. H + 281.40 \quad (4.6)$$

With,

Parameters	Value
r	- 0.3033
R^2	0.0920
RMSE	52.18

This showed that at least 9.2% of the variance in Unit EM Cost (C) is associated with the variance in Net Head (H). From Figure 4.6, it can be concluded that the Net Head (H) and the Unit EM Cost (C) have very little negative correlation as the correlation coefficient is only - 0.303. From the graph, it has also been observed that maximum positive and maximum negative residuals were found for Upper Gaddi Gad Hydropower Project and Seti Nadi Hydropower Project respectively.

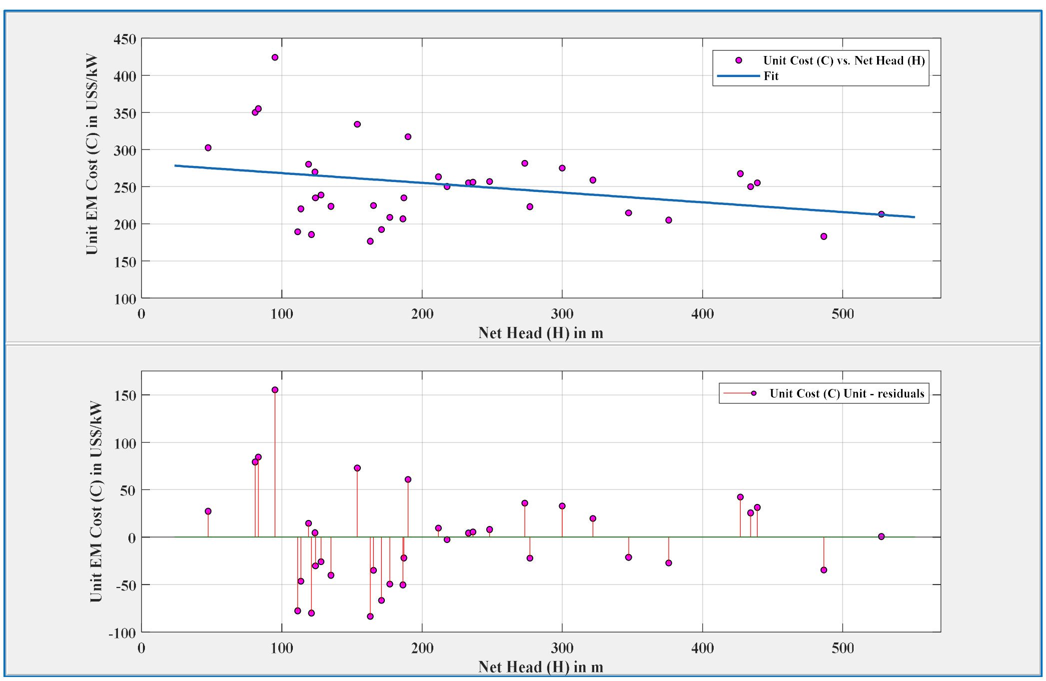

Figure 4.6: Scatterplot and Residuals with Respect to H vs. C in General

After observing the linear regression model for Francis and Pelton-based units, EM equipment costs have a high negative correlation with the installed capacity but a relatively lower negative linear correlation with the net head compared with installed power. Also, by observing the R^2 and RMSE for all units, it has been clear that estimation of the unit cost by relating only the installed capacity or net head would not give a real scenario of the unit cost variation.

Based on the above facts, a statement can be established that the cost function cannot be defined solely by accounting for the installed power or net head for the formulation of the cost estimation function.

4.2 Multivariate Regression Analysis

Linear regression analysis was done in excel for ln(C) as a dependent variable and ln(P) and ln(H) as the independent variables. By equating the coefficient with Equation (3.3), an equation of plane was obtained.

$$Z_p = f(X, Y) = 8.0467 - 0.1920. X - 0.1444. Y \tag{4.7}$$

75.90% coefficient of determination (adjusted R^2) was obtained from the multivariate linear regression model which shows that nearly 76% of the variance in the dependent variable i.e. Unit EM Cost (C) can be explained by the independent variable i.e. Installed Power (P) and Net Head (H). Ogayar and AlZohbi calculated comparatively good values of R^2 as 93.16% and 88.03% respectively for the Pelton turbine.

A surface equation was obtained by substituting the value of a, b, and c in Equation (3.8) as shown below.

$$C'_p = f(P, H) = e^{8.0467} P^{-0.1920} H^{-0.1444} \tag{4.8}$$

Actual data as well as the modeled surface equation were plotted in MATLAB and obtained in the graph which is shown in Figure 4.7.

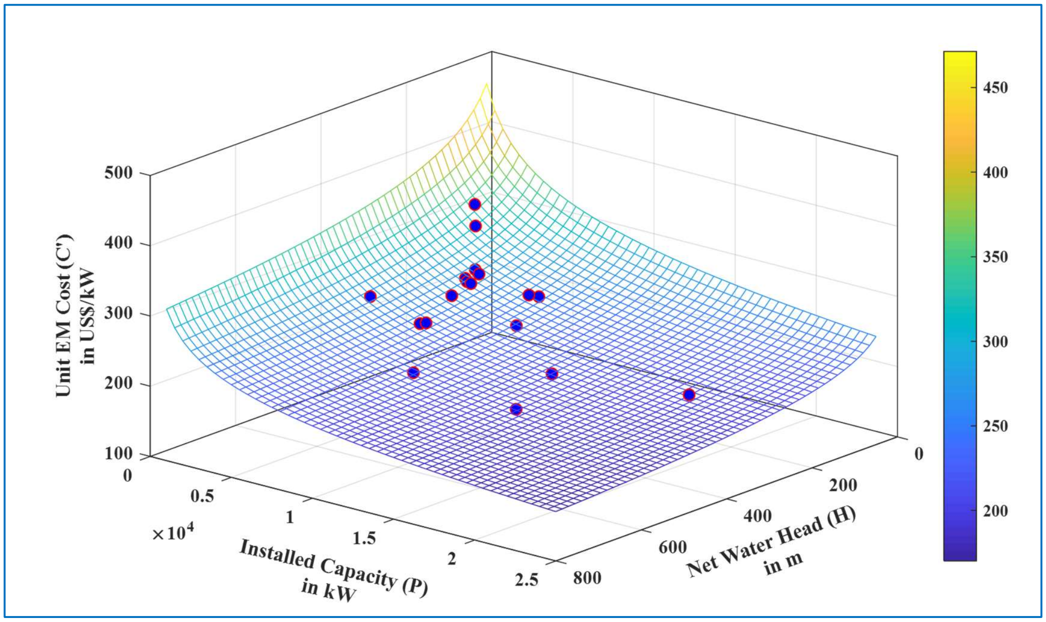

Figure 4.7: Graph Showing Mesh and 3D Scatterplot of EM Cost for Pelton Units

The scatterplot shows the actual unit cost per kW of the EM that was collected during primary data collection. However, the 3D mesh plot shows the projected data obtained from the above Equation (4.8). It is clearly visible that the unit cost of the EM equipment for the Pelton unit is negatively correlated to the Installed Capacity (P) and the Net Head (H) available. Interpreting Figure 4.7, the Unit cost of the EM equipment is remarkably varying for the plant capacity of less than 5000kW and head below 200m.

Using Equation (3.9) given in the methodology, errors obtained from the actual and modeled unit cost were calculated which are tabulated here in Table 4.1.

Table 4.1: % Errors in Modeled Cost in Projects with Pelton Unit

Project Name	Net Head (H) m	Installed Capacity (P) kW	Actual Unit Cost (US$/kW)	Modeled Unit Cost (US$/kW)	Error %
Upper Rawa	153.81	3000	334.08	324.51	-2.9%
Upper Lohore	190.00	4000	317.29	297.84	-6.1%
Suri Khola	273.19	6400	281.44	258.24	-8.2%
Rudi Khola-B	299.81	6600	275.02	253.3	-7.9%
Dwari Khola	427.00	3750	267.61	268.28	0.3%
Upper Machha	211.67	4550	263.23	286.07	8.7%

Super Hewa	321.81	6000	259.00	255.35	-1.4%
Buku-Kapate	248.18	5000	256.93	274.56	6.9%
Upper Hewa	236.20	8500	256.00	249.74	-2.4%
Upper Midim	439.00	7500	255.18	233.91	**-8.3%**
Padam Khola	233.18	4500	255.17	282.7	10.8%
Chepe Khola	217.80	8630	250.32	251.95	0.7%
Upper Suri	434.21	7000	250.04	237.41	-5.1%
Rudi Khola-A	276.89	8800	223.07	242.45	8.7%
Thulo Khola	347.25	21300	214.67	198.02	-7.8%
Super Chepe	527.46	9050	212.94	219.72	3.2%
Thapa Khola	375.90	13600	205.00	213.38	4.1%
Mathillo Mailung	486.50	14300	183.08	203.61	**11.2%**

As presented in Table 4.1, calculated errors in the modeled unit costs with respect to the actual unit costs have a maximum positive and negative deviation of 11.2% and -8.3% respectively with an error mean of 0.2% and SD of 6.9%. This shows CV (Coefficient of Variation) is higher than 1. This means the errors in the modeled unit cost have high variance. However, MAPE calculated was 5.81% which shows that the relationship given, provides an excellent accurate estimation with reference to Table 3.6. In comparison to the equation derived by Cavazzini, the mean error was comparatively smaller but a slightly higher SD was obtained for Pelton units as he calculated the mean error and SD 6.4% and 6.5% respectively.

The actual unit cost and modeled unit cost vs. respective hydropower projects were plotted in Figure 4.8.

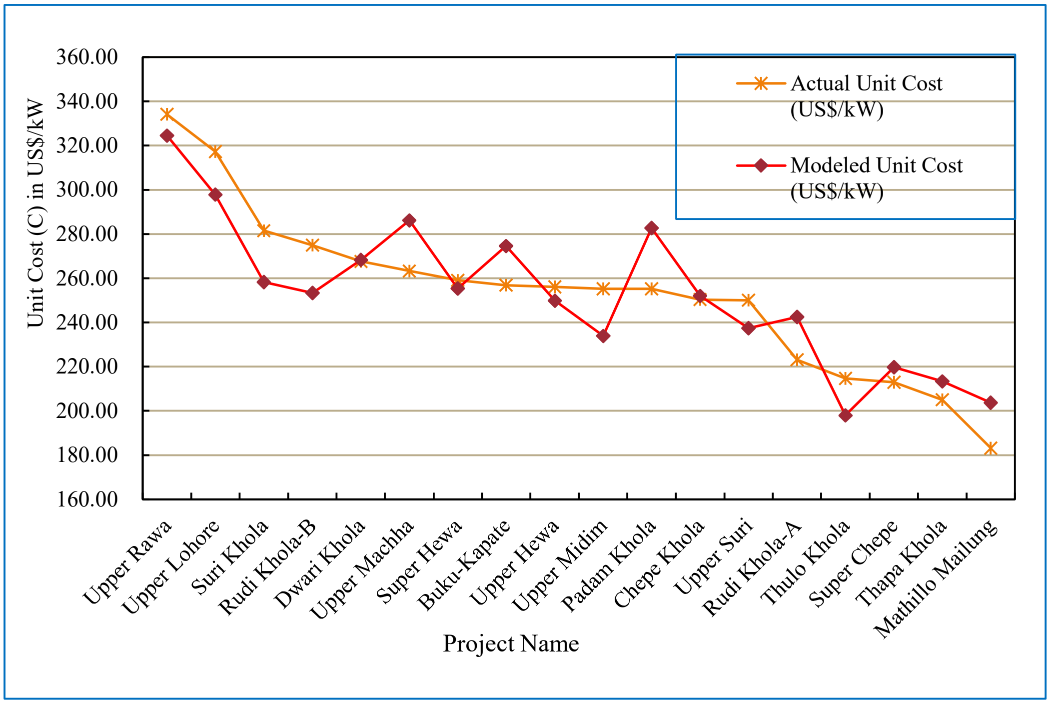

Figure 4.8: Line Diagram for Actual and Modeled Unit EM Cost of Pelton Unit

Same as for Pelton Turbine, linear correlation analysis was done in excel for ln(C) vs. ln(P) and ln(H). By equating the coefficient with Equation (3.3), an equation of plane was obtained.

$$Z_f = f(X, Y) = 7.8842 - 0.2494.X - 0.0392.Y \qquad (4.9)$$

A relatively good coefficient of determination (adjusted R^2 = 80.93%) was obtained from the multivariate linear regression model which shows that nearly 81% of the variance in the dependent variable i.e. Unit EM Cost (C) can be explained by the independent variable i.e. Installed Power (P) and Net Head (H) for the Francis turbine units. AlZohbi calculated a comparatively good value of R^2 as 92.61% than the Ogayar. (72.26%) for Pelton turbine. That shows the cost relation for Francis, derived in this research, would represent a more sample size than those derived by Ogayer.

A surface equation was obtained by substituting the value of a, b and c in Equation (3.8) as shown in Equation (4.10).

$$C'_f = f(P, H) = e^{7.8842} P^{-0.2494} H^{-0.0392} \quad (4.10)$$

Actual data as well as the modeled surface equation were plotted in MATLAB and obtained the graph which is shown in Figure 4.9.

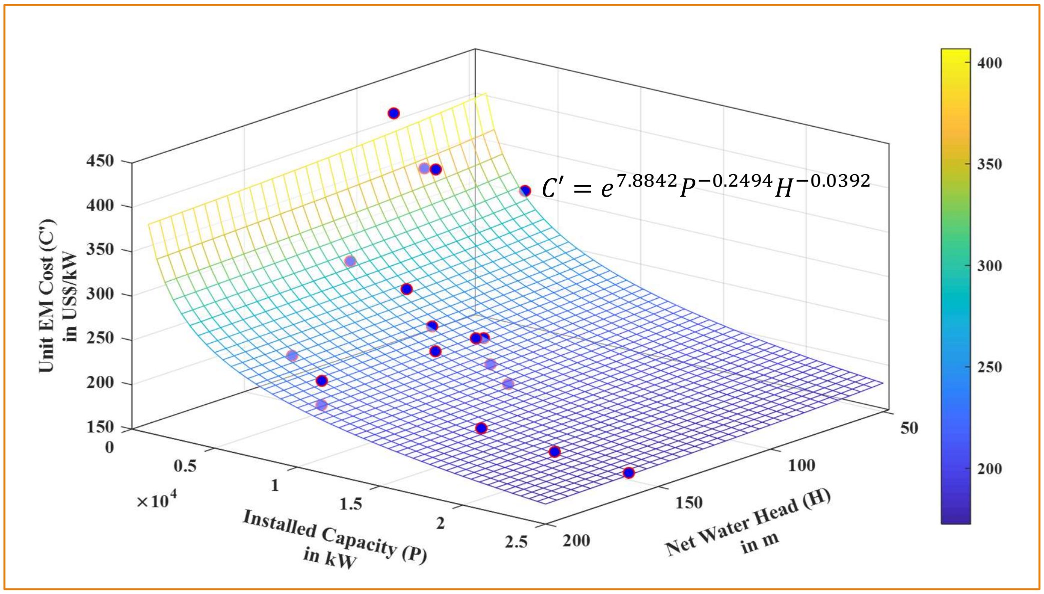

Figure 4.9: Graph Showing Mesh and 3D Scatterplot of EM Cost for Francis Units

In the above Figure 4.9, the scatterplot shows the actual unit cost per kW of the Francis EM equipment and the 3D mesh plot shows the projected data obtained from the above Equation (4.10). It is clearly visible that the unit cost of the EM equipment for the Pelton unit is negatively correlated to the Installed Capacity (P) remarkably and the Net Head (H) slightly. Interpreting Figure 4.9, the Unit cost of the EM equipment is strongly varying for the plant capacity of less than 5000kW.

Using equation (3.9), errors obtained from the actual and modeled unit cost were calculated which are tabulated here in Table 4.2.

Table 4.2: % Errors in Modeled Cost in Projects with Francis Unit

Project Name	Net Head (H) m	Installed Capacity (P) kW	Actual Unit Cost (US$/kW)	Modeled Unit Cost (US$/kW)	Error %
Upper Gaddi Gad	95.00	1550	424.13	355.52	**-16.2%**
Daram Khola A	83.30	2500	355.00	317.2	10.6%

Theule Khola	81.00	1500	350.00	360.69	3.1%
Super Mai Cscd.	47.35	3000	302.49	309.88	2.4%
Madhya Tara	119.09	2200	280.34	322.92	15.2%
Lower Jogmai	123.49	6200	269.87	249.03	-7.7%
Tallo Khare	128.00	11000	238.80	215.55	-9.7%
Upper Ignwa	186.92	9700	235.00	219.14	-6.7%
Super Mai	123.93	7800	235.00	235.14	0.1%
Bhim Khola	165.25	4960	224.75	260.29	15.8%
Mai Beni	135.02	9510	223.58	223.05	-0.2%
Madhya Solu	113.46	9500	220.18	224.63	2.0%
Upper Solu	177.06	18000	208.74	188.22	-9.8%
Super Mai-A	186.30	9600	206.70	219.73	6.3%
Lower Hewa	170.95	21600	192.30	180.1	-6.3%
Daram Khola	111.20	9600	189.24	224.22	**18.5%**
Dordi -1	121.00	12000	185.57	211.38	13.9%
Seti Nadi	163.00	25000	176.55	173.98	-1.5%

Referring to Table 4.2, calculated errors in the modeled unit costs with respect to the actual unit costs have a maximum positive and negative deviation of 18.5% and -16.2% respectively with an error mean of 0.5% and standard deviation of 10.2%. This shows CV is higher than 1. This means the errors in the modeled unit cost have high variance. The actual unit cost and modeled unit cost vs. respective hydropower projects were plotted in Figure 4.10.

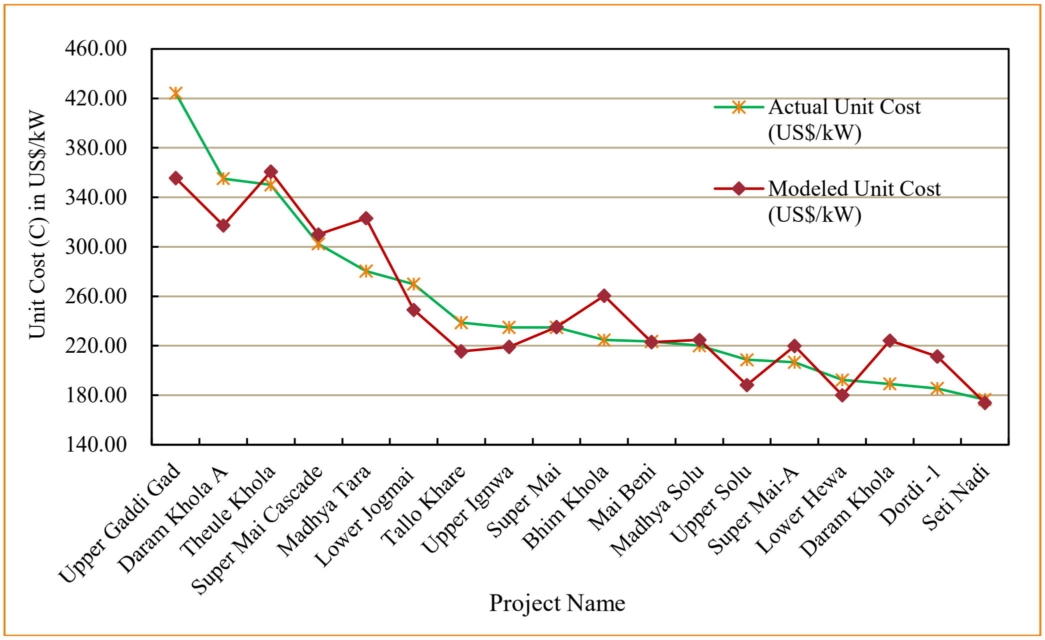

Figure 4.10: Line Diagram for Actual and Modeled Unit EM Cost of Pelton Unit

During the error analysis, MAPE calculated was 8.12% which shows that the relationship given also provides an excellent accurate estimation with reference to Table 3.6. In comparison to the equation derived by Cavazzini, the mean error was comparatively smaller but a higher value of SD was obtained for Francis units as he calculated the mean error and SD, 10.6% and 4.4% respectively.

To analyze the collective figure, data of all the hydropower with Penton and Francis units were merged in a single sheet and linear correlation analysis was done in excel for ln(C) vs. ln(P) and ln(H). By equating the coefficient with Equation (3.3), an equation of plane was obtained.

$$Z_g = f(X, Y) = 7.7652 - 0.2571.X + 0.0031.Y \tag{4.11}$$

77.66% adjusted R^2 was obtained from the multivariate linear regression model which shows that nearly 78% of the variance in the dependent variable i.e. Unit EM Cost (C) can be explained by the independent variable i.e. Installed Power (P) and Net Head (H) for the hydropower in general.

A surface equation was obtained by substituting the value of a, b and c in Equation (3.8) as shown in Equation (4.12).

$$C'_g = f(P, H) = e^{7.7652} P^{-0.2571} H^{0.0031} \quad (4.12)$$

Actual data as well as the modeled surface equation were plotted in MATLAB and obtained the graph which is shown in Figure 4.11.

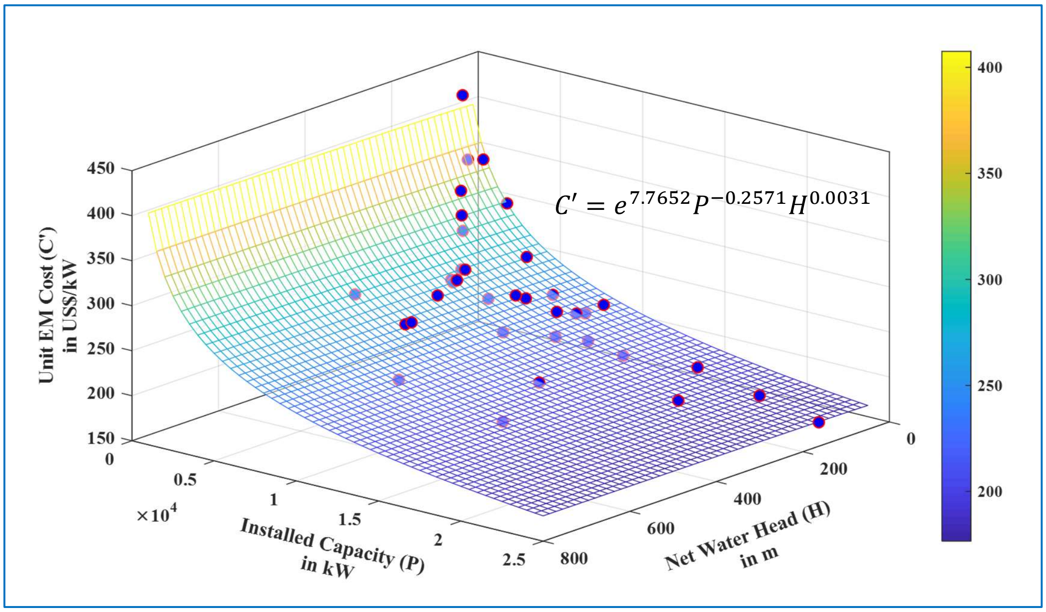

Figure 4.11: Graph Showing Mesh and 3D Scatterplot of EM Cost in General

In Figure *4.11*, the scatterplot shows the actual unit cost per kW of the Francis EM equipment and the 3D mesh plot shows the projected data obtained from the above Equation (4.12). It is clearly visible that the unit cost of the EM equipment is negatively correlated to the Installed Capacity (P) remarkably but it is positively correlated to the Net Head (H) a little. Interpreting Figure 4.11, the Unit cost of the EM equipment is strongly varying for the plant capacity of less than 10,000kW.

Using Equation (3.9), errors obtained from the actual and modeled unit cost were calculated which are tabulated here in Table 4.3.

Table 4.3:% Errors in Modeled Cost in Hydropower Projects in General

Project Name	Net Head (H) m	Installed Capacity (P) kW	Actual Unit Cost (US$/kW)	Modeled Unit Cost (US$/kW)	Error %
Upper Gaddi Gad	95.00	1550	424.13	361.64	**-14.7%**
Daram Khola A	83.30	2500	355.00	319.69	-9.9%

Theule Khola	81.00	1500	350.00	364.52	4.1%
Upper Rawa	153.81	3000	334.08	305.63	-8.5%
Upper Lohore	190.00	4000	317.29	284.03	-10.5%
Super Mai Cscd.	47.35	3000	302.49	304.52	0.7%
Suri Khola	273.19	6400	281.44	251.98	-10.5%
Madhya Tara	119.09	2200	280.34	330.74	18.0%
Rudi Khola-A	299.81	6600	275.02	250.07	-9.1%
Lower Jogmai	123.49	6200	269.87	253.42	-6.1%
Dwari Khola	427.00	3750	267.61	289.5	8.2%
Upper Machha	211.67	4550	263.23	274.86	4.4%
Super Hewa	321.81	6000	259.00	256.33	-1.0%
Buku-Kapate	248.18	5000	256.93	268.41	4.5%
Upper Hewa	236.20	8500	256.00	234.15	-8.5%
Upper Midim	439.00	7500	255.18	242.27	-5.1%
Padam Khola	233.18	4500	255.17	275.73	8.1%
Chepe Khola	217.80	8630	250.32	233.18	-6.8%
Upper Suri	434.21	7000	250.04	246.6	-1.4%
Tallo Khare	128.00	11000	238.80	218.71	-8.4%
Upper Ignwa	186.92	9700	235.00	226.17	-3.8%
Super Mai	123.93	7800	235.00	238.9	1.7%
Bhim Khola	165.25	4960	224.75	268.63	19.5%
Mai Beni	135.02	9510	223.58	227.09	1.6%
Rudi Khola-A	276.89	8800	223.07	232.18	4.1%
Madhya Solu	113.46	9500	220.18	227.03	3.1%
Thulo Khola	347.25	21300	214.67	185.11	-13.8%
Super Chepe	527.46	9050	212.94	230.98	8.5%
Upper Solu	177.06	18000	208.74	192.9	-7.6%
Super Mai-A	186.30	9600	206.70	226.77	9.7%
Thapa Khola	375.90	13600	205.00	207.79	1.4%
Lower Hewa	170.95	21600	192.30	184.04	-4.3%
Daram Khola	111.20	9600	189.24	226.4	**19.6%**
Dordi -1	121.00	12000	185.57	213.84	15.2%
Mathillo Mailung	486.50	14300	183.08	205.29	12.1%
Seti Nadi	163.00	25000	176.55	177.23	0.4%

Analyzing the Table 4.3, calculated errors in the modeled unit costs with respect to the actual unit costs have maximum positive and negative deviations of 19.5% and -14.7%

respectively with an error mean 0.4% and standard deviation 8.6%. This shows CV is higher than 1. This means the errors in the modeled unit cost have high variance.

The actual unit cost and modeled unit cost vs. respective hydropower projects were plotted in Figure 4.12.

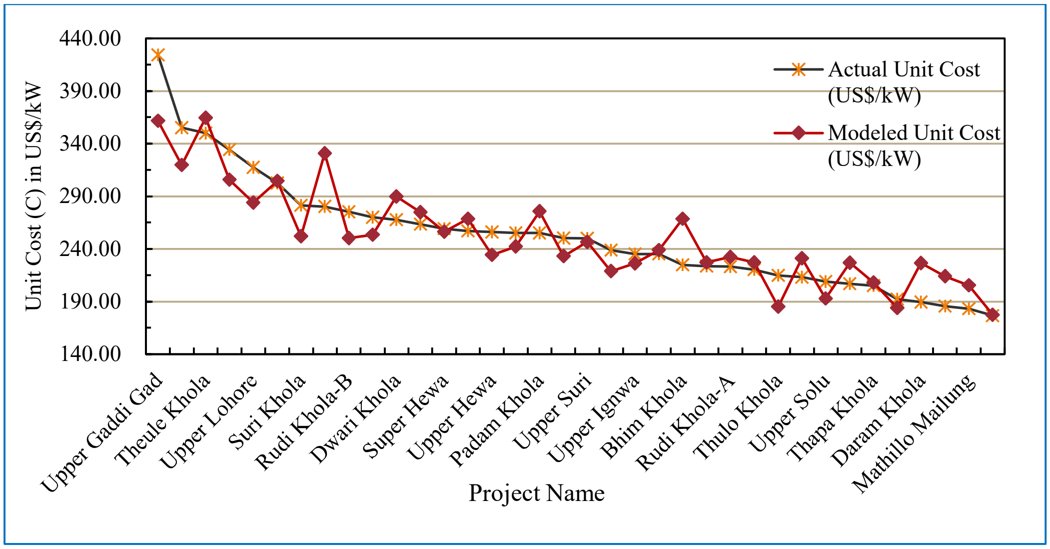

Figure 4.12: Line Diagram for Actual and Modeled Unit EM Cost in General

During the error analysis, MAPE calculated was 6.96% which shows that the relationship derived by combining the Francis and Pelton-based hydropower also gives an excellent accurate estimation with reference to Table 3.6. However, for both Pelton and Francis-based hydropower, the unit cost is negatively correlated to the net head. That means, for a higher head project, the unit cost would be lower with comparing to the low head project. The value of c or coefficient of Y in Equation (3.3) is found to be positive which contradicts the above statements. Hence, formulation of the Nomogram based on the generalized equation was halted.

4.3 Result Validation

Validation of primary data was already done in the above headings comparing the value of r, R^2, Mean Error, SD and MAPE which satisfies the result obtained from this research.

Outputs from this research were also validated by comparing and analyzing the result with past research. The past researches by Alzohbi (Alzohbi, 2018), Ogayar (Ogayar and Vidal, 2009) and Cavazzini (Cavazzini *et al.*, 2016) were adopted to validate this research output by adopting Equation (3.10) for error analysis.

For Pelton-based hydropower, the deviations of the modeled unit EM cost with respect to AlZohbi's equation were found to be -56.82% to 35.65% maximum with 21.57% SD and 20.38% MAPE. Also, with respect to Ogayar error range was found to be 34.48% to 110.88% with 20.68 SD and 71.53% MAPE. Considering Cavazzini's equation, the error range was found to be 75.26% to 289.80% with SD 56.01% and MAPE 162.82%. Table *4.4* below shows the calculations for unit cost validation results for Pelton Units.

Analyzing the result obtained above, AlZohbi's equation was found to fit the newly developed correlation in this research than others. Error percentages with Ogayar's and Cavazzini's equations in comparison to AlZohbi's equation were found to be very high because both the researches were done by considering the relatively small hydropower project with an installed capacity of less than 1,000kW.

Table 4.4: Validation of Research Output with Secondary Data for Pelton Units

S.N.	Project Name	Net Head (H) m	Installed Capacity (P) kW	Design Flow Rate (m3\sec)	Modeled Unit Cost (US$/kW)	Alzohbi Equation (US$/kW)	Alzohbi Equation % Deviation	Ogaryar Equation (US$/kW)	Ogaryar Equation % Deviation	Cavazzini Equation (US$/kW)	Cavazzini Equation % Deviation
1	Upper Rawa	153.81	3000	2.32	324.51	293.77	10.46%	241.31	34.48%	185.16	75.26%
2	Upper Lohore	190	4000	2.40	297.84	300.08	-0.75%	204.73	45.48%	145.24	105.07%
3	Suri Khola	273.19	6400	2.75	258.24	308.01	-16.16%	155.73	65.83%	101.27	155.00%
4	Rudi Khola-B	299.81	6600	2.55	253.3	298.44	-15.13%	150.01	68.86%	95.75	164.54%
5	Dwari Khola	427	3750	1.05	268.28	197.78	35.65%	166.85	60.79%	113.71	135.93%
6	Upper Machha	211.67	4550	2.60	286.07	301.01	-4.96%	189.49	50.97%	134.05	113.41%
7	Super Hewa	321.81	6000	2.20	255.35	276.95	-7.80%	152.24	67.73%	98.55	159.11%
8	Buku-Kapate	248.18	5000	2.40	274.56	290.3	-5.42%	175.06	56.84%	119.5	129.76%
9	Upper Hewa	236.2	8500	4.20	249.74	372.88	-33.02%	146.3	70.70%	92.87	168.91%
10	Upper Midim	439	7500	1.94	233.91	262.38	-10.85%	128.59	81.90%	77.54	201.66%
11	Padam Khola	233.18	4500	2.29	282.7	285.97	-1.14%	185.13	52.70%	128.68	119.69%
12	Chepe Khola	217.8	8630	4.82	251.95	390.23	-35.44%	148.86	69.25%	96.92	159.96%
13	Upper Suri	434.21	7000	4.08	237.41	256.12	-7.31%	132.28	79.48%	111.58	112.77%
14	Rudi Khola-A	276.89	8800	3.72	242.45	350.6	-30.85%	138.14	75.51%	85.86	182.38%
15	Thulo Khola	347.25	21300	7.29	198.02	458.63	-56.82%	93.9	110.88%	50.8	289.80%
16	Super Chepe	527.46	9050	2.05	219.72	260.28	-15.58%	114.03	92.69%	67.39	226.04%
17	Thapa Khola	375.9	13600	8.40	213.38	364.51	-41.46%	108.14	97.32%	81.71	161.14%
18	Mathillo Mailung	486.5	14300	3.53	203.61	328.98	-38.11%	98.74	106.21%	54.97	270.40%

Table 4.4 shows the percentage error calculated by comparing the modeled cost with simulated cost proposed by the previous researchers.

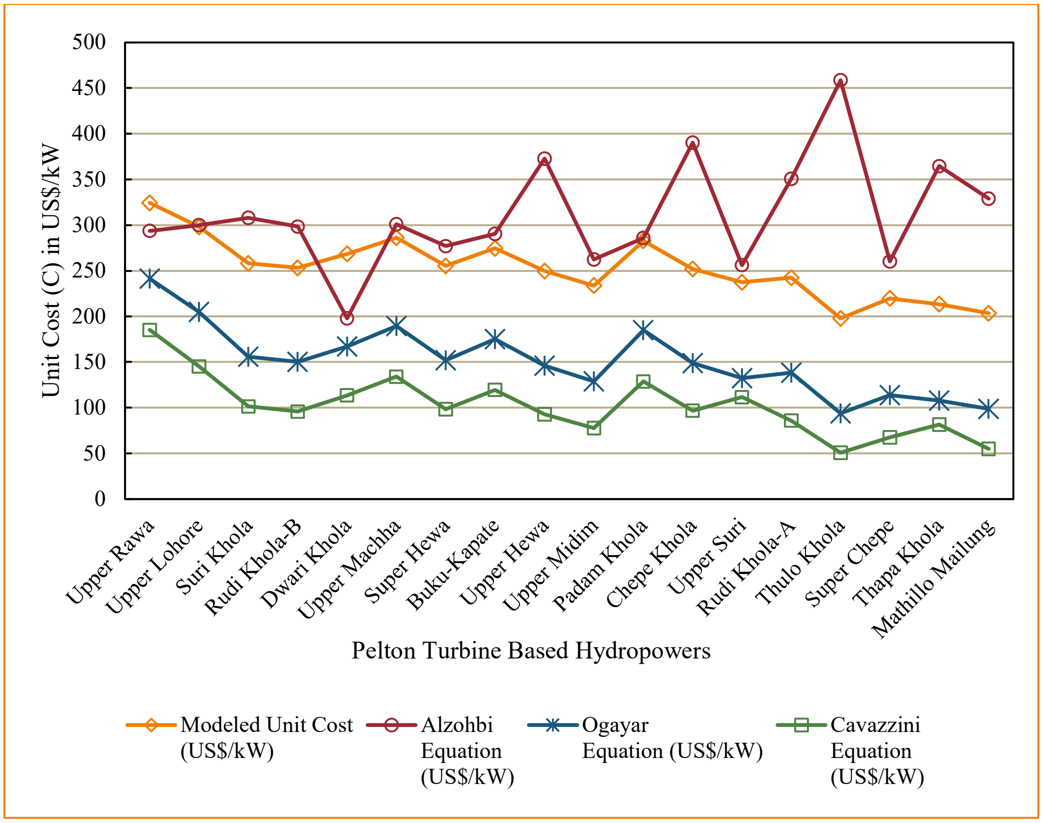

Figure 4.13: Pelton Unit Modeled Cost Vs. Referenced Past Equation's Cost

For Francis-based hydropower, the deviations of the modeled unit EM cost with respect to AlZohbi’s equation were found to be -59.83% to 2.02% maximum with 19.18% SD and 36.42% MAPE. Also, with respect to Ogayar, the error range was found to be 41.54% to 260.8% with 66.43 SD and 143.89% MAPE. Considering Cavazzini’s equation, the error range was found to be -12.39% to 49.31% with SD 18.28% and MAPE 28.34%. Table 4.5 below shows the calculations for unit cost validation results for Francis-based units.

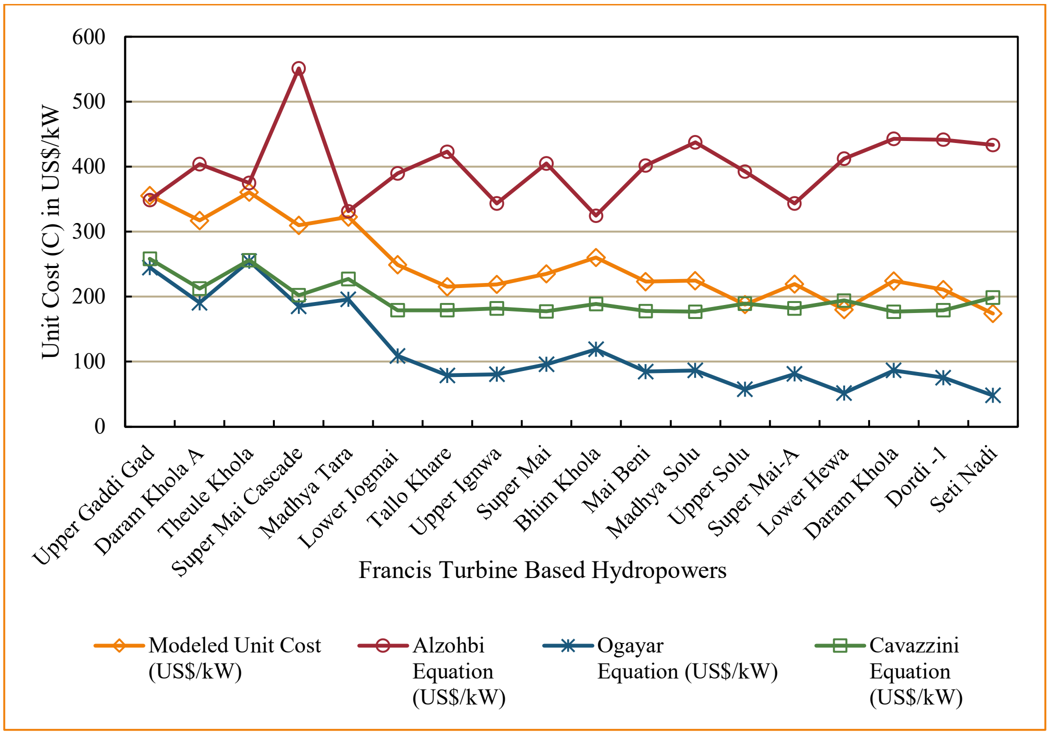

Figure 4.14: Francis Unit Modeled Cost Vs. Referenced Past Equation's Cost

Analyzing the result obtained for the Francis unit above, Cavazzini's equation was found to be relatively fits the newly developed correlation in this research than others. Deviations in the modeled cost were observed mainly due to the installed capacity range, operating conditions and country of origin. There are so many other factors like quality of water, the requirement of spare parts, transportation cost, etc. that are different than Nepal. Ogayar's equations were developed by considering the relatively small hydropower project with an installed capacity of less than 2,753kW and that gave higher deviations than Cavazzini's equation.

Table 4.5: Validation of Research Output with Secondary Data for Francis Units

S.N.	Project Name	Net Head (H) m	Installed Capacity (P) kW	Design Flow Rate (m3\sec)	Modeled Unit Cost (US$/kW)	Alzohbi Equation (US$/kW)	Alzohbi Equation % Deviation	Ogaryar Equation (US$/kW)	Ogaryar Equation % Deviation	Cavazzini Equation (US$/kW)	Cavazzini Equation % Deviation
1	Upper Gaddi Gad	95.00	1550	2.02	355.52	348.48	-2.00%	245.17	-45.00%	258.5	-38.00%
2	Daram Khola A	83.30	2500	3.60	317.2	404.07	21.00%	190.74	-66.00%	212.45	-49.00%
3	Theule Khola	81.00	1500	2.06	360.69	374.84	4.00%	254.84	-42.00%	256.12	-41.00%
4	Super Mai Casc	47.35	3000	7.50	309.88	551.12	44.00%	185.06	-67.00%	202.43	-53.00%
5	Madhya Tara	119.09	2200	2.20	322.92	331.3	3.00%	195.79	-65.00%	227.23	-42.00%
6	Lower Jogmai	123.49	6200	5.72	249.03	389.71	36.00%	109.08	-128.00%	179.31	-39.00%
7	Tallo Khare	128.00	11000	11.00	215.55	423.04	49.00%	78.76	-174.00%	179.19	-20.00%
8	Upper Ignwa	186.92	9700	6.19	219.14	343.36	36.00%	80.53	-172.00%	181.89	-20.00%
9	Super Mai	123.93	7800	7.50	235.14	404.88	42.00%	95.87	-145.00%	177.61	-32.00%
10	Bhim Khola	165.25	4960	3.48	260.29	324.69	20.00%	119.11	-119.00%	189.12	-38.00%
11	Mai Beni	135.02	9510	8.02	223.05	401.74	44.00%	84.87	-163.00%	177.93	-25.00%
12	Madhya Solu	113.46	9500	10.00	224.63	437.66	49.00%	86.82	-159.00%	177.12	-27.00%
13	Upper Solu	177.06	18000	12.99	188.22	392.72	52.00%	57.35	-228.00%	189.61	1.00%
14	Super Mai-A	186.30	9600	6.39	219.73	343.31	36.00%	81.03	-171.00%	182.08	-21.00%
15	Lower Hewa	170.95	21600	15.15	180.1	412.46	56.00%	52.02	-246.00%	194.13	7.00%
16	Daram Khola	111.20	9600	10.30	224.22	442.83	49.00%	86.53	-159.00%	177.07	-27.00%
17	Dordi -1	121.00	12000	11.72	211.38	441.58	52.00%	75.55	-180.00%	179.43	-18.00%
18	Seti Nadi	163.00	25000	18.00	173.98	433.15	60.00%	48.22	-261.00%	198.58	12.00%

Table 4.5 shows the percentage error calculated by comparing the modeled cost with simulated cost proposed by the previous researchers.

4.4 EM Cost Estimation Nomogram

Considering the equations generated in this research, a cost forecasting nomogram has been developed. The graph has been plotted in MATLAB considering net head 50 m to 800 m for Pelton-based hydropower and 30 m to 300 m for Francis-based hydropower in a single graph. Power considered for both types has been taken from 1,000 kW to 25,000 kW. The Nomogram has been plotted with H on the x-axis and P on the y-axis with a cost variation of 180 US$ /kW to 400 US$/kW with a 10 US$/kW interval for easy use. The blue line and red line denote the unit cost for Pelton and Francis Based EM equipment for the hydropower project respectively. The developed Nomogram is shown in Figure 4.15.

To estimate the electromechanical cost for Pelton or Francis-based hydropower project, net head and installed power are to be used as input parameters. The following sequence is required to be followed for the cost forecast.

- Plot the vertical line of the net head (H) on the x-axis with the meter as a unit over the Nomogram.
- Plot the horizontal line of installed capacity (P) on the y-axis with kW as the unit of measurement over the Nomogram.
- Find the intersect point and interpolate the cost value by considering the above and below unit cost line. That gives the desired unit cost of hydropower EM equipment in US$/kW.

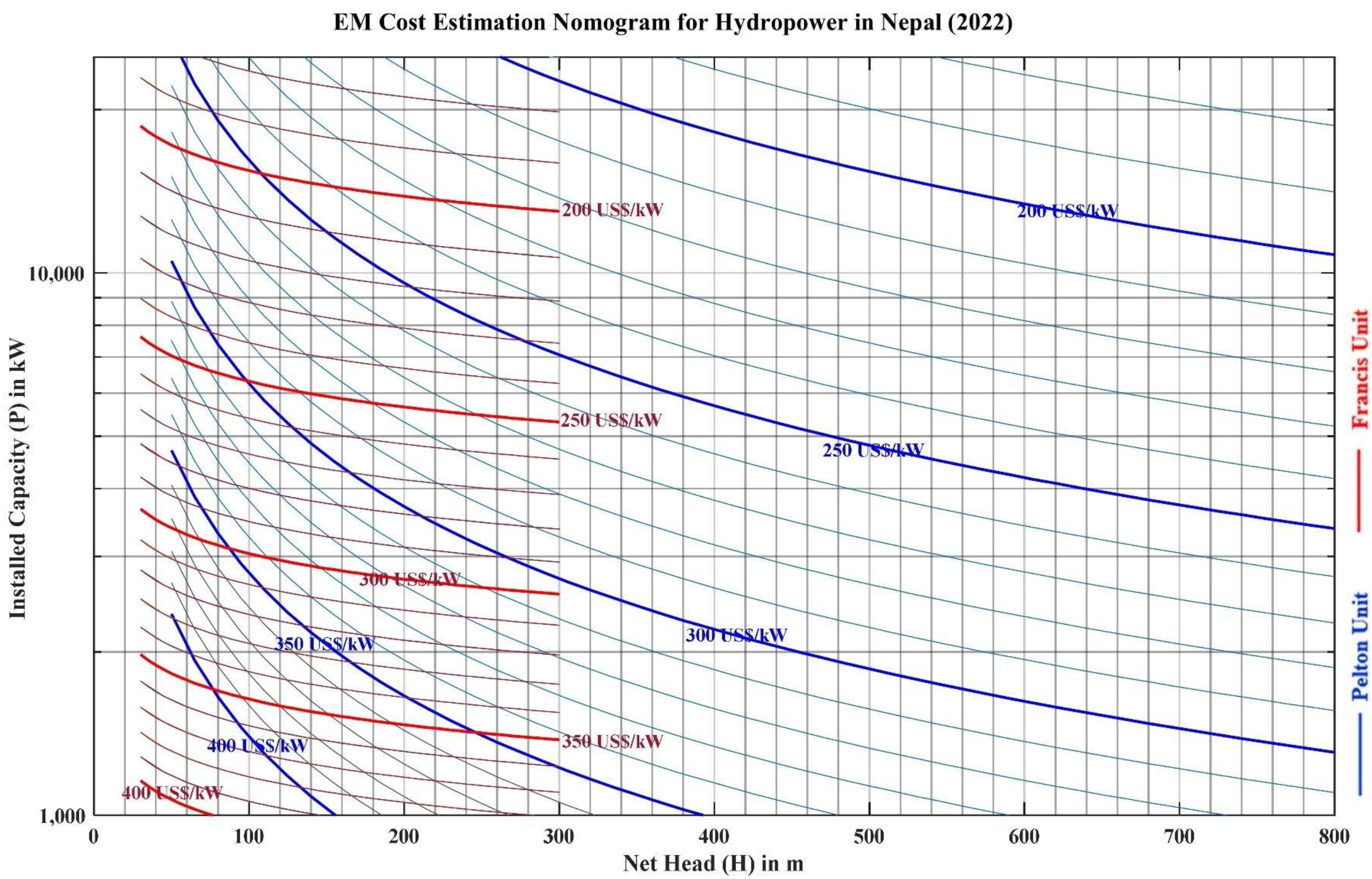

Figure 4.15: Nomogram Graph for EM Cost Forecasting

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this research, the relationship of installed capacity vs. the unit cost of EM equipment, as well as net head vs. unit cost of EM equipment, were studied separately for both Pelton and Francis-based hydropower plants of 18 samples each. During regression analysis of both Francis and Pelton-based hydropower EM unit cost data, high negative correlations were obtained for P vs. C plots whereas moderate negative correlations were obtained in the case of H vs. C plots. Further, Pelton and Francis-based hydropower were combined and made 36 sample sizes to generalize the scenario. P vs. C and H vs. C linear correlations were plotted and analyzed. That also gave the same scenario as given by the Pelton and Francis-based hydropower. From the above facts and analyzing the value of R^2 and RMSE obtained, it can be concluded that the unit cost by relating only to the installed capacity or net head would not give a real scenario of the unit cost variation.

In multivariate regression analysis, the value of R^2 obtained was 78.94% with an error mean of 0.2%, SD 6.9% and MAPE 5.81% for Pelton based hydropower. Similarly, for Francis-based hydropower, a relatively good value of R^2 was found with an error mean of 0.5% SD 10.2 and MAPE 8.12%. In both cases, the value of MAPE were found to be < 10% which means the modeled equation provides an excellent accurate estimation. Modeling was also done by combining the Pelton and Francis-based hydropower and concluded that the generalized modeled equation generates the unrealistic contradictory data.

EM Cost estimation nomogram for both Pelton and Francis-based hydropower has been derived and plotted for the net head range of 50m to 800m for Pelton and 30m to 300m for Francis-based hydropower with an installed power range of 1,000kW to 25,000kW in a single graph. However, installed power and net head are not only the factors that affect the unit cost of the EM equipment but other parameters such as the number of generating units, turbine axis, speed of rotation, the extent of control and automation system to be installed, location of hydropower, type of switchyard proposed (AIS or GIS), voltage level in transmission lines, turbine manufacturer's goodwill, country of origin, currency inflation, etc. also holds the minor impact.

5.2 Recommendations

- This nomogram will be very useful for the initial cost estimation of EM equipment for hydropower project financial analysis in the feasibility stage and for the DDA purposes.

- The estimation accuracy of the nomogram would be increased if the turbine axis and number of turbine units can be incorporated into the nomogram. Hence, the proposed equation be expanded to accommodate those minor variables in further research.

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ANNEXURE A: MATLAB CODE FOR 3D MESH & SCATTERPLOT

Mesh and Scatterplot for Pelton Based Hydropower

```
clear

clc

close all

% for scatterplot

P=[4500 4550 5000 9050 14300 6000 7000 3000 13600 7500
4000 6400 8500 8800 6600 21300 8630 3750];

H=[233.18 211.67 248.18 527.46 486.5 321.81 434.21 153.81
375.9 439 190 273.19 236.2 276.89 299.81 347.25 217.8
427];

C=[255.17 263.23 256.93 212.94 183.08 259.00 250.04
334.08 205.00 255.18 317.29 281.44 256.00 223.07 275.02
214.67 250.32 267.61];

figure

scatter3(H,P,C, 'filled')

% for 3d mesh plot

P=1000:500:25000;

H=50:15:800;

[P,H]=meshgrid(P,H);

C=exp(8.0467).*P.^(-0.1920).*H.^(-0.1444);

hold on

mesh(H,P,C, 'facealpha',0.5);

hold off

zlabel({'Unit EM Cost (C'')','in US$/kW'});

ylabel({'Installed Capacity (P)','in kW'},'Rotation',-13);

xlabel({'Net Water Head (H)',' in
m'},'HorizontalAlignment','center',...
```

```
    'Rotation',20);
```

Mesh and Scatterplot for Francis Based Hydropower

```
clear

clc

close all

% for scatterplot

P=[9700 9510 6200 1500 11000 18000 4960 9600 12000 9500 21600 7800
9600 3000 2500 2200 25000 1550];

H=[186.92 135.02 123.49 81.00 128.00 177.06 165.25 111.20 121.00
113.46 170.95 123.93 186.30 47.35 83.30 119.09 163.00 95.00];

C=[235.00 223.58 269.87 350.00 238.80 208.74 224.75 189.24 185.57
220.18 192.30 235.00 206.70 302.49 355.00 280.34 176.55 424.13];

figure

scatter3(H,P,C, 'filled')

% for 3d mesh plot

P=1000:500:25000;

H=50:5:200;

[P,H]=meshgrid(P,H);

C=exp(7.8842).*P.^(-0.2494).*H.^(-0.0392);

hold on

mesh(H,P,C, 'facealpha',0.5);

hold off

zlabel({'Unit EM Cost (C'')','in US$/kW'});

ylabel({'Installed Capacity (P)','in kW'},'Rotation',-13);
```

```
xlabel({'Net Water Head (H)',' in
m'},'HorizontalAlignment','center',...

    'Rotation',20);
```

Mesh and Scatterplot for Hydropower in General

```
clear

clc

close all

% for scatterplot

P=[4500 4550 5000 9050 14300 6000 7000 3000 13600 7500 4000 6400 8500
8800 6600 21300 8630 3750 9700 9510 6200 1500 11000 18000 4960 9600
12000 9500 21600 7800 9600 3000 2500 2200 25000 1550];

H=[233.18 211.67 248.18 527.46 486.5 321.81 434.21 153.81 375.9 439
190 273.19 236.2 276.89 299.81 347.25 217.8 427 186.92 135.02 123.49
81.00 128.00 177.06 165.25 111.20 121.00 113.46 170.95 123.93 186.30
47.35 83.30 119.09 163.00 95.00];

C=[255.17 263.23 256.93 212.94 183.08 259.00 250.04 334.08 205.00
255.18 317.29 281.44 256.00 223.07 275.02 214.67 250.32 267.61 235.00
223.58 269.87 350.00 238.80 208.74 224.75 189.24 185.57 220.18 192.30
235.00 206.70 302.49 355.00 280.34 176.55 424.13];

figure

scatter3(H,P,C, 'filled')

% for 3d mesh plot

P=1000:500:25000;

H=50:15:800;

[P,H]=meshgrid(P,H);

C=exp(7.7652).*P.^(-0.2571).*H.^(0.0031);

hold on

mesh(H,P,C, 'facealpha',0.5);
```

```
hold off

hold off

zlabel({'Unit EM Cost (C'')','in US$/kW'});

ylabel({'Installed Capacity (P)','in kW'},'Rotation',-13);

xlabel({'Net Water Head (H)',' in
m'},'HorizontalAlignment','center',...

    'Rotation',20);
```

ANNEXURE B: QUESTIONNAIRE FOR REPEARCH

Institute of Engineering

Department of Mechanical and Aerospace Engineering

Pulchowk Campus

Master of Science in Renewable Energy Engineering

Questionnaire for Research Purpose

The information is strictly confidential matter and used only for the academic purpose.

Informer's relation with Project:		
Name of the Organization		
Address and Date:		

Project Information:

Name of the Project:		Remarks:
Project Location:		
Province:		
Developer's Name and Address:		
Installed Capacity:		in MW
No. of Generating Unit:		in Numbers
Design Discharge per unit:		in Cubic m per second
Rated Net Head:		in meter
EM Manufacturer/Supplier:		
Type of Turbine		
Proposed Speed of Turbine		in RPM
Axis of Turbine:		
Country of Origin:		
Date of Contract Signing:		
Cost of Electromechanical Equipment:		in € or US$ or INR
US$ Exchange rate with respect to Contract Signing Date		
Cost Equivalent to US$		
Unit Cost		in US$/kW
Issues and Comments:		

ANNEXURE C: PROVINCEWISE SMALL HYDROPOWERS IN NEPAL

DEVELOPED BY DOMESTIC IPP'S

(POPULATION SIZE)

PROVINCE - 1

S.N.	Developer	Project	Location	Capacity (kW)
1	Arun Valley Hydropower Development Co. (P.) Ltd.	Piluwa Khola Small	Sankhuwasabha	3000
2	Himal Dolkha Hydropower Company	Mai Khola	Ilam	4500
3	Barun Hydropower Development Co. (P.) Ltd.	Hewa Khola	Sankhuwasabha	4455
4	Joshi Hydropower Development Company Limited	Upper Puwa -1	Illam	3000
5	Sanima Mai Hydropower Limited	Mai Khola	Ilam	22000
6	Sanima Mai Hydropower Ltd.	Mai Cascade	Ilam	7000
7	Panchakanya Mai Hydropower Ltd.	Upper Mai	Ilam	9980
8	Panchthar Power Company Pvt. Ltd.	Hewa Khola A	Panchthar	14900
9	Sanvi Energy pvt. Ltd.	Jogmai	Ilam	7600
10	Mai Valley Hydropower Private Limited	Upper Mai C	Ilam	5100
11	Dibyaswari Hydropower Limited	Sabha Khola	Sankhuwasabha	4000
12	Puwa Khola-1 Hydropower P. Ltd.	Puwa Khola-1	Ilam	4000
13	Shibani Hydropower Co. Pvt. Ltd.	Phawa Khola	Taplejung	4950
14	Molung Hydropower Company Pvt. Ltd.	Molung Khola	Okhaldhunga	7000
15	Himal Dolkha Hydropower Company Ltd.	Mai sana Cascade	Ilam	8000
16	Super Mai Hydropower Pvt. Ltd.	Super Mai	Illam	7800
17	Eastern Hydropower Pvt. Ltd.	Pikhuwa Khola	Bhojpur	5000
18	Mountain Hydro Nepal Pvt. Ltd.	Tallo Hewa	Panchthar	22100
19	Rairang Hydropower Development Company Ltd.	Iwa Khola	Taplejung	9900
20	Arun Kabeli Power Ltd.	Kabeli B-1	Taplejung,	25000
21	Terhathum Power Company Pvt. Ltd.	Upper Khorunga	Terhathum	7500
22	Upper Solu Hydroelectric Company Pvt. Ltd	Solu Khola	Solukhumbu	23500
23	Sagarmatha Jalabidhyut Company Pvt. Ltd.	Super Mai 'A'	Illam	9600
24	Mai Khola Hydropower Pvt. Ltd.	Super Mai Cascade	Illam	3800
25	Rawa Energy Development Pvt. Ltd.	Upper Rawa	Khotang	3000
26	Taksar-Pikhuwa Hydropower Pvt. Ltd.	Taksar Pikhuwa	Bhojpur	8000
27	Reliable Hydropower Company Pvt. Ltd.	Khorunga Khola	Terhathum	4800
28	Beni Hydropower Project Pvt. Ltd.	Upper Solu	Solukhumbu	18000
29	Dudhkoshi Power Company Pvt. Ltd.	Rawa Khola	Khotang	6500

30	Doval Hydropower Company Pvt. Ltd.	Junbesi Khola	Solukhumbu	5200
31	Maya Khola Hydropower Co. Pvt. Ltd.	Maya Khola	Sankhuwasabha	14900
32	River Falls Hydropower Development Pvt. Ltd.	Down Piluwa	Sankhuwasabha	9500
33	Numbur Himalaya Hydropower Pvt. Ltd.	Likhu Khola A	Solukhumbu	24200
34	Dipsabha Hydropower Pvt. Ltd.	Sabha Khola A	Sankhuwasabha	9990
35	Menchhiyam Hydropower Pvt. Ltd.	Upper Piluwa Khola 2	Sankhuwasabha	4720
36	Upper Hewa Khola Hydropower Co. Pvt. Ltd.	Upper Hewa Khola Small	Sankhuwasabha	8000
37	Siddhi Hydropower Company Pvt. Ltd.	Siddhi Khola	Ilam	10000
38	Samling Power Company Pvt. Ltd.	Mai Beni	Ilam	9510
39	Orbit Energy Pvt. Ltd.	Sabha Khola B	Sankhuwasabha	15100
40	Him Star Urja Co. Pvt. Ltd.	Buku Kapati	Okhaldhunga	5000
41	Sanvi Energy Pvt. Ltd.	Jogmai Cascade	Ilam	6000
42	Asian Hydropower Pvt. Ltd.	Lower Jogmai	Ilam	6200
43	Three Star Hydropower Company Ltd.	Sapsup Khola	Khotang	6600
44	People's Power Limited	Puwa-2	Ilam	4960
45	Chirkhuwa Hydropower Pvt. Ltd.	Upper Chirkhuwa	Bhojpur	4700
46	Gaurishankar Power Development Pvt. Ltd.	Middle Hongu Khola B	Solukhumbu	22900
47	Unitech Hydropower Co. Pvt. Ltd.	Upper Phawa	Taplejung	5800
48	Arun Valley Hydropower Development Co. Ltd.	Kabeli B-1 Cascade	Panchthar	9940
49	Lower Irkhuwa Hydropower Co. Pvt. Ltd.	Lower Irkhuwa	Bhojpur	13040
50	Apex Makalu Hydro Power Pvt. Ltd.	Middle Hongu Khola A	Solukhumbu	22000
51	Mabilung Energy Pvt. Ltd.	Upper Piluwa Khola -3	Sankhuwasabha	4950
52	Ingwa Hydro Power Pvt. Ltd	Upper Ingwa khola	Taplejung	9700
53	Sisa Hydro Electric Company Pvt. Ltd.	Sisa Khola A	Solukhumbu	2800
54	Chirkhwa Hydropower Pvt. Ltd.	Lower Chirkhwa	Bhojpur	4060
55	Sabha Pokhari Hydro Power (P.) Ltd.	Lankhuwa Khola	Sankhuwasabha	5000
56	IDS Energy Pvt. Ltd.	Lower Khorunga	Terhathum	5400
57	Super Hewa Power Company Pvt. Ltd.	Super Hewa	Sankhuwasabha	5000
58	Baraha Multipower Pvt. Ltd.	Irkhuwa Khola B	Bhojpur	15524
59	Himali Hydro Fund Pvt. Ltd.	Sona Khola	Taplejung	9000
60	Arati Power Company Ltd.	Upper Irkhuwa	Bhojpur	14500

61	Mount Everest Power Development Pvt. Ltd.	Dudhkunda Khola	Solukhumbu	12000
62	Palun Khola Hydropower Pvt. Ltd.	Palun Khola	Taplejung	21000
63	Mid Solu Hydropower Company Pvt. Ltd.	Mid Solu Khola	Solukhumbu	9500
64	Apolo Hydropower Pvt. Ltd.	Buku Khola	Solukhumbu	6000
65	Phedi Khola Hydropower Company Pvt. Ltd.	Phedi Khola (Thumlung)	Bhojpur	3250
66	Kabeli Hydropower Company Pvt.Ltd.	Kabeli-3	Taplejung	21930
67	Union Mewa Hydro Ltd.	Mewa Khola	Taplejung	23000
68	Habitat Power Company Pvt. Ltd	Hewa Khola "A"	Panchthar	5000
69	Maa Shakti Engineering & Hydropower Pvt. Ltd.	Luja Khola	Solukhumbu	23550
70	Sankhuwasabha Power Development Pvt. Ltd.	Super Sabha Khola	Sankhuwasabha	4100
71	Hilton Hydro Energy Pvt. Ltd.	Super Kabeli	Taplejung	12000
72	Snow Rivers Pvt. Ltd.	Super Kabeli A	Taplejung	13500
73	Hydro Connection Pvt. Ltd.	Rauje Khola	Solukhumbu	17712
74	Milke Jaljale Hydropower Pvt. Ltd.	Puuer Piluwa Hills	Sankhuwasabha	4990
75	Orbit Energy Pvt. Ltd.	Sabha Khola C	Sankhuwasabha	4196
			Total Installed Capacity (kW)	739,907

BAGMATI PROVINCE

S.N.	Developer	Project	Location	Capacity (kW)
1	National Hydro Power Company Ltd.	Indrawati- III	Sindhupalchowk	7500
2	Chilime Hydro Power Company Ltd.	Chilime	Rasuwa	22100
3	Sanima Hydropower (Pvt.) Ltd.	Sunkoshi	Sindhupalchowk	2500
4	Alliance Power Nepal Pvt.Ltd.	Chaku Khola	Sindhupalchowk	3000
5	Unique Hydel Co. Pvt. Ltd.	Baramchi	Sindhupalchowk	4200
6	Thoppal Khola Hydro Power Co. Pvt. Ltd.	Thoppal Khola	Dhading	1650
7	Synergy Power Development (P.) Ltd.	Sipring Khola	Dolakha	9658
8	Laughing Buddha Power Nepal (P.) Ltd.	Middle Chaku	Sindhupalchowk	1800
9	Aadishakti Power Dev. Company (P.) Ltd.	Tadi Khola	Nuwakot	5000

10	Ankhu Khola Jal Bidhyut Co. (P.) Ltd.	Ankhu Khola-1	Dhading	8400
11	Nepal Hydro Developer Pvt. Ltd.	Charanawati	Dolakha	3520
12	Laughing Buddha Power Nepal Pvt. Ltd.	Lower Chaku	Sindhupalchowk	1800
13	Bhairabkunda Hydropower Pvt. Ltd.	Bhairab	Sindhupalchowk	3000
14	Mailung Khola Hydro Power Company (P.) Ltd.	Mailung Khola	Rasuwa	5000
15	Bojini Company Private Limited	Jiri Khola	Dolakha	2200
16	Electro-com and Research Centre Pvt. Ltd.	Jhyadi Khola	Sindhupalchowk	2000
17	Khani Khola Hydropower Company Pvt. Ltd.	Tungun-Thosne	Lalitpur	4360
18	Khani Khola Hydropower Company Pvt. Ltd.	Khani Khola	Lalitpur	2000
19	Garjang Upatyaka Hydropower (P.) Ltd.	Chake Khola	Ramechhap	2830
20	Mandu Hydropower Ltd.	Bagmati Khola Small	Lalitpur	22000
21	Manakamana Engineering Hydropower Pvt. Ltd.	Ghatte Khola	Dolakha	5000
22	Shiva Shree Hydropower (P.) Ltd.	Upper Chaku A	Sindhupalchowk	22200
23	Hira Ratha Hydropower Pvt. Ltd.	Tadi Khola	Nuwakot	5000
24	Energy Engineering Pvt. Ltd.	Upper Mailung A	Rasuwa	6420
25	Himalaya Urja Bikas Co. Pvt. Ltd.	Upper Khimti	Ramechhap	12000
26	Mathillo Mailung Khola Jalabidhyut Ltd.	Upper Mailung A	Rasuwa	14300
27	Sanjen Jalavidhyut Company Limited	Sanjen (Upper)	Rasuwa	14800
28	Gelun Hydropower Company Limited	Gelun	Sindhupalchowk	3200
29	Suryakunda Hydroelectric Pvt. Ltd.	Upper Tadi	Nuwakot	11000
30	Salankhu Khola Hydropower Pvt. Ltd.	Salankhu Khola	Nuwakot	2500
31	Moonlight Hydropower Pvt. Ltd.	Balephi A	Sindhupalchowk	22140
32	Universal Power Company Ltd.	Lower Khare	Dolakha	11000
33	Betrawoti Hydropower Co. Pvt. Ltd.	Phalankhu Khola	Rasuwa	13700
34	Himalaya Urja Bikas Co. Pvt. Ltd.	Upper Khimti II	Ramechhap	7000
35	Consortium Power Developers Pvt. Ltd.	Khare Khola	Dolakha	24100
36	Singati Hydro Energy Pvt. Ltd.	Singati Khola	Dolakha	25000
37	Buddha Bhumi Nepal Hydropower Co. Pvt. Ltd.	Lower Tadi	Nuwakot	4993
38	Chandeshwori Mahadev Khola MH. CO. Pvt. Ltd.	Chulepu Khola	Ramechhap	8520
39	Suri Khola Hydropower Pvt. Ltd.	Suri Khola	Dolakha	6400
40	Chauri Hydropower Pvt. Ltd.	Chauri Khola	Ramechhap	6000
41	Miulti Energy Development Pvt. Ltd.	Langtang Khola	Rasuwa	20000

42	Sano Milti Khola Hydropower Pvt. Ltd.	Sano Milti	Ramechhap	3000
43	Rasuwa Hydropower Pvt. Ltd	Phalanku Khola	Rasuwa	5000
44	Him River Power Pvt. Ltd.	Liping Khola	Sindhupalchowk	16260
45	Yambling Hydropower Pvt. Ltd.	Yambling Khola	Sindhupalchowk	7270
46	Gorakshya Hydropower Pvt. Ltd.	Super Ankhu Khola	Dhading	23500
47	Makar Jitumaya Hydropower Pvt. Ltd.	Upper Suri	Dolakha	7000
48	Balephi Jalbidhyut Co. Ltd.	Balephi	Sindhupalchowk	23520
49	Sewa Hydro Ltd.	Lower Selang	Sindhupalchowk	1500
50	Nyam Nyam Hydropower Company Pvt. Ltd.	Nyam Nyam Khola	Rasuwa	6000
51	Saptang Hydro Power Pvt. Ltd.	Saptang Khola	Nuwakot	2500
52	Himalayan Water Resources and Energy Development Co. Pvt. Ltd.	Upper Chauri	Kavrepalanchowk	6000
53	Jalshakti Hydro Company Pvt. Ltd.	Ilep (Tatopani)	Dhading	23675
54	Him Parbat Hydropower Pvt. Ltd.	Sagu Khola	Dolakha	20000
55	Kalinchowk Hydropower Pvt. Ltd.	Sangu (Sorun)	Dolakha	5000
56	Integrated Hydro Fund Nepal Pvt. Ltd.	Upper Brahamayani	Sindhupalchowk	15150
57	Perfect Energy Development Pvt. Ltd.	Middle Trishuli Ganga	Nuwakot	19410
58	Sajha Power Development Pvt. Ltd.	Lower Balephi	Sindhupalchowk	20000
59	Sindhujwala Hydropower Ltd.	Upper Nyasem Khola A	Sindhupalchowk	21000
60	Ruby Valley Hydropower Company Ltd	Menchet Khola	Dhading	7000
Total Installed Capacity (kW)				592,576

GANDAKI PROVINCE

S.N.	Developer	Project	Location	Capacity (kW)
1	Butwal Power Company Ltd.	Andhi Khola	Syangza	9400
2	Khudi Hydropower Ltd.	Khudi Khola	Lamjung	4000
3	Gandaki Hydro Power Co. Pvt. Ltd.	Mardi Khola	Kaski	4800
4	Bhagawati Hydropower Development Co. (P.) Ltd.	Bijayapur-1	Kaski	4410
5	Nyadi Group (P.) Ltd.	Siuri Khola	Lamjung	4950
6	United Modi Hydropwer Pvt. Ltd.	Lower Modi 1	Parbat	10000
7	Radhi Bidyut Company Ltd.	Radhi Khola	Lamjung	4400

8	Chhyangdi Hydropower Ltd.	Chhandi	Lamjung	2000
9	Sayapatri Hydropower Private Limited	Daram Khola A	Baglung	2500
10	Daraudi Kalika Hydro Pvt. Ltd.	Daraudi Khola A	Gorkha	6000
11	Madi Power Pvt. Ltd.	Upper Madi	Kaski	25000
12	Mount Kailash Energy Pvt. Ltd.	Thapa Khola	Myagdi	13600
13	Mandakini Hydropower Limited	Sardi Khola	Kaski	4000
14	Union Hydropower Pvt. Ltd.	Midim Karapu	Lamjung	3000
15	Sikles Hydropower Pvt. Ltd.	Madkyu	Kaski	13000
16	Barahi Hydropower Pvt.ltd	Theule Khola	Baglung	1500
17	Bindhyabasini Hydropower Development Co. (P.) Ltd.	Rudi Khola A	Lamjung and	8800
18	United Idi Mardi and R.B. Hydropower Pvt. Ltd.	Upper Mardi	Kaski	7000
19	Bindhyabasini Hydropower Development Co. (P.) Ltd.	Rudi Khola B	Lamjung	6600
20	Ghalemdi Hydro Limited	Ghalemdi Khola	Myagdi	5000
21	Himalayan Hydropower Pvt. Ltd.	Namarjun Madi	Kaski	11880
22	Civil Hydropower Pvt. Ltd.	Bijayapur 2 Khola Small	Kaski	4500
23	Manang Trade Link Pvt. Ltd.	Lower Modi	Parbat	20000
24	Water and Energy Nepal Pvt. Ltd.	Badi Gad	Baglung	6600
25	Liberty Hydropower Company Ltd.	Upper Dordi A	Lamjung	25000
26	Middle Modi Hydropower Ltd.	Middle Modi	Parbat	15100
27	Madhya Midim Jalbidhyut Co. Pvt. Ltd.	Middle Midim	Lamjung	3100
28	Tangchhar Hydro Pvt. Ltd.	Tangchhahara	Mustang	2200
29	Dordi Khola Jal Bidyut Company Ltd.	Dordi-1 Khola	Lamjung	12000
30	Research and Development Group Pvt. Ltd.	Rupse Khola	Myagdi	4000
31	Hydro Empire Pvt. Ltd.	Upper Magdi	Myagdi	20000
32	Dhaulagiri Kalika Hydro Pvt. Ltd.	Darbang-Myagdi	Myagdi	25000
33	Upper Syange Hydropower Pvt. Ltd.	Upper Syange Khola	Lamjung	2400
34	Myagdi Hydropower Pvt. Ltd.	Ghar Khola	Myagdi	14000
35	Richet Jalbidhyut Company Pvt. Ltd.	Richet Khola	Gorkha	4980
36	Diamond Hydropower Pvt. Ltd.	Upper Daraudi-1	Gorkha	10000
37	Chhyangdi Hydropower Limited	Upper Chhyangdi Khola	Lamjung	4000
38	Daram Khola Hydro Energy Limited	Daram Khola	Baglung	9600
39	Madhya Tata Khola Hydropower P. Ltd.	Madhya Tara Khola Samll	Baglung	1700
40	Aashutosh Energy Pvt. Ltd.	Chepe Khola Small	Lamjung	8630
41	Him Consult Pvt. Ltd.	Rele Khola	Myagdi	6000
42	Parbat Paiyun Khola Hydropower Co. Pvt. Ltd.	Seti Khola	Parbat	3500

43	Vision Lumbini Ltd.	Seti Nadi	Kaski	25000
44	Samyukta Urja Pvt. Ltd.	Thulo Khola	Myagdi	21300
45	Bhujung Hydropower Pvt. Ltd.	Upper Midim	Lamjung	7500
46	Ridge Line Energy Pvt. Ltd.	Super Chepe	Gorkha	9050
47	United Modi Hydropwer Ltd.	Lower Modi 2	Parbat	10500
48	Upper Richet Hydropower Pvt. Ltd.	Upper Richet	Gorkha	2000
49	Seti Khola Hydropower Pvt. Ltd.	Seti Khola	Kaski	22000
50	North Summit Hydro Pvt. Ltd.	Nyadi Phidi	Lamjung	21400
51	Him Parbat Hydropower Pvt. Ltd.	Sagu Khola-1	Dolakha	5500
52	Annapurna Bidhyut Bikas Co. Pvt. Ltd.	Landruk Modi	Kaski	86590
53	Madame Khola Hydropower Pvt. Ltd.	Madame Khola	Kaski	24000
54	Thulo Khola Hydropower Pvt. Ltd.	Upper thulo Khola-A	Myagdi	15000
55	Super Ghalemdi Hydropower Pvt. Ltd.	Super Ghalemdi	Myagdi	9140
56	Amar Jyoti Hydro Power Pvt. Ltd.	Istul Khola	Gorkha	1506
57	Sushmit Energy Pvt. Ltd.	Kunaban Khola	Myagdi	20000
58	Shikhar Power Development Pvt. Ltd.	Bhim Khola	Baglung	4960
59	Bikash Hydropower Company Pvt. Ltd.	Upper Machha Khola Small	Gorkha	4550
60	North Summit Hydro Pvt. Ltd.	Hidi Khola	Lamjung	6820
61	Mount Rasuwa Hydropower Pvt. Ltd.	Midim 1 Khola	Lamjung	13424
62	Dudhpokhari Chepe Hydropower Pvt. Ltd.	Dudhpokhari Chepe	Gorkha	8800
63	Champawati Hydropower Pvt. Ltd.	Chepe Khola A	Lamjung	7000
64	Barpak Daraudi Hydropower Pvt. Ltd.	Middle Super Daraudi	Gorkha	10000
65	Ambe Hydropower Pvt. Ltd.	Upper Burundi	Parbat	3750
66	Dhaulagiri CEM Engineering Pvt. Ltd.	Madhya Daram Khola A	Baglung	3000
67	Bhalaudi Khola Hydropower Pvt. Ltd.	Bhalaudi Khola	Kaski	2645
68	Kalika Construction Pvt. Ltd.	Upper Daraudi B	Gorkha	8300
69	Kalika Construction Pvt. Ltd.	Upper Daraudi C	Gorkha	9820
70	Super Khudi Hydropower Pvt. Ltd.	Upper Khudi	Lamjung	21210
			Total Installed Capacity (kW)	738,915

LUMBINI PROVINCE

S.N.	**Developer**	**Project**	**Location**	**Capacity (kW)**
1	Butwal Power Company Ltd.	Jhimruk Khola	Pyuthan	12000
2	Ridi Hydropower Development Co. (P.) Ltd.	Ridi Khola	Gulmi	2400

3	Ruru Hydropower Project (P) Ltd.	Upper Hugdi Khola	Gulmi	5000
4	Nama Buddha Hydropower Pvt. Ltd	Tinau Khola Small	Palpa	1665
5	Jumdi Hydropower Pvt. Ltd.	Jumdi Khola	Gulmi	1750
			Total Installed Capacity (kW)	22,815

KARNALI PROVINCE				
S.N.	**Developer**	**Project**	**Location**	**Capacity (kW)**
1	Bhugol Energy Development Compay (P). Ltd.	Dwari Khola	Dailekh	3750
2	Dolti Power Company Pvt. Ltd.	Padam Khola	Dailekh	4800
3	Rara Hydropower Dev. Co. Pvt. Ltd.	Upper Parajuli Khola	Dailekh	2150
4	Lohore Khola Hydropower Co. Pvt. Ltd.	Lohore Khola	Dailekh	4200
5	Rapti Hydro and General Construction Pvt. Ltd.	Rukumgad	Rukum	5000
6	Mount Nilgiri Hydropower Co. Pvt. Ltd.	Rurubanchu-1	Kalikot	13500
7	Upper Lohore Khola Hydropower Co. Pvt. Ltd.	Upper Lohore	Dailekh	4000
8	Ruru Hydroelectric Company Pvt. Ltd.	Rurubanchu Khola-2	Kalikot	12000
			Total Installed Capacity (kW)	49,400

SUDURPASHCHIM PROVINCE				
S.N.	**Developer**	**Project**	**Location**	**Capacity (kW)**
1	Api Power Company Pvt. Ltd.	Naugadh gad Khola	Darchula	8500
2	Salmanidevi Hydropower (P). Ltd	Kapadi Gad	Doti	3330
3	Api Power Company Pvt. Ltd.	Upper Naugad Gad	Darchula	8000
4	Bungal Hydro Pvt. Ltd.	Upper Sanigad	Bajhang	10700
5	Kalanga Hydro Pvt. Ltd.	Kalangagad	Bajhang	15330
6	Makari Gad Hydropower Pvt. Ltd.	Makarigad	Darchula	10000
7	Omega Energy Developer Pvt. Ltd.	Sunigad	Bajhang	11050
8	Shaileshwori Power Nepal Pvt. Ltd.	Upper Gaddigad	Doti	1550
9	Khechereswor Jal Vidhyut Pvt. Ltd.	Jadari Gad Small	Bajhang	1000
10	Jal Urja Pvt. Ltd.	Naugad	Darchula	1000
			Total Installed Capacity (kW)	70,460

ANNEXURE D: PLAGIARISM TEST REPORT

Formulation of Electromechanical Cost Estimation Nomogram for Small

ORIGINALITY REPORT

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SIMILARITY INDEX

PRIMARY SOURCES

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