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# Evaluation of Small Hydropower plant at Ribb Irrigation Dam in Amhara regional state, Ethiopia

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ABSTRACT:

*Energy is the main requirement for economic growth in any country and also supports the modern economy. The energy sector is considered a vital element in developing countries because it meets energy needs. This article deals with the production of electricity using small hydroelectric power plants for rural applications. The main objective of this study was to assess the potential of the Ribb dam for small hydroelectric plants. Since the height of a proposed site is constant while the available flow is very variable, the flow is very important for the production of hydroelectricity. The flow duration curve is constant from 20% to 50% of the nominal flow, and then decreases as the percentage of the nominal flow increases. The Ribb dam concluded that the average flow of 14.6331m3/s, the smooth head of 70.37 m, and the average nominal power of 5.53 MW would be the most optimal size of a small hydroelectric plant producing a maximum of electricity in the context of future projected flows in the study region. SHP is a promising alternative for the production of cheap and renewable energy in rural or developing areas.*

**Keywords:** Flow Duration Curve (FDC), Ribb Dam, Small Hydroelectricity Power (SHP), Ethiopia

## INTRODUCTION

Electrical energy is becoming an essential commodity for modern life today. All sectors, such as industry, technology, transport, public services or family life, are now entirely dependent on electricity. The dependence on electric power is increasing, which has led to an increase in its demand. Electricity is a fundamental element which is essential to the development of a country [11].

All modern living conditions of mankind quickly depend on electricity. Water, colloquially called “white oil” from Ethiopia, has the enormous uncured ability to inevitably change the capacity of this developing country to industrialization. Ethiopia ranks second in terms of economically feasible hydroelectric production among all African countries, with an approximate capacity of 30,000 MW only for the Democratic Republic of Congo [1].

Energy is one of the main elements of the economic and social growth of Ethiopia. Via our two strategies, we project a high level of hydroelectric production in Ethiopia: between 71 and 87 TWh/year by 2050 in a strict climate change mitigation scenario where the country makes a significant contribution to global efforts to reach the 2oC target set by the Paris Agreement [3]. Although the country’s population and demand for energy is growing rapidly, electricity production and access to it has been one of the lowest in the world [16].

In this case, the power plant can be located at the foot of the dam or at any other suitable place upstream of the collection dam using complete electricity generation irrigation systems subject to temporary irrigation requirements [12]. Hydroelectric power is clean, economical, non-polluting, and a source of sustainable energy for the environment. Hydroelectric power plants help increase the efficiency of the electricity system. Some hydroelectric projects have a long lifespan of more than 50 years and contribute to the overall conservation of rare fossil fuels [17].

One of the renewable energy technologies for electricity and mechanical energy production is the small hydro system (SHP). The SHP system is classified as "thin" according to the capacity of the electricity installed. There is no international agreement on the "small" limit, but most European countries and others accept 10 MW as the upper limit [5]. The systems are further classified within the SHP group as Pico, Medium, Mini and Small Systems [10]. The construction of small hydroelectric projects is a safer choice than a large hydroelectric project to control and use water supplies in a sustainable manner without adverse socio-economic and environmental impact [13]. The development of small hydropower plants will reduce energy imbalances [9].

Small hydropower (SHP) has emerged as an energy source that is accepted as being renewable, easily developed, inexpensive, and harmless to the environment. The general objective of this study is to assess and evaluate the hydroelectric capacity of existing Ribb dams located in the Amhara region of Ethiopia, and to suggest the production of multipurpose water resources for better economic gain. The main objective stated above is further broken down according to the following specific targets to assess the available releases and move towards the production of electricity, estimate the available hydroelectric potential and the energy system that will benefit the economy and society.

**II. Materials and Methods**

Research area, tools and processes used to test and improve existing dams for electricity production.

**2.1 Description of the area of study**

The Ribb dam is located in the river Ribb in South Gondar zone of the National Regional State of Amhara, on the east side of the sub-basin of Lake Tana. The Ribb River, about 130km long, has a drainage area of about 1790 km2 and an annual average discharge 14.6331 m 3/s. There are 685 km2 of the catchment area on the dam site. The axis of the dam is located between the geographic reference grids.UTM E 392174.64, N 1330225.76 and E 390813.45, N 1330018 .02, at altitudes between 1880 m and 1,970 m. The left pinnacle is at an altitude of 1943 m, the middle of the axis of the dam is at an altitude of 1873 m and the right pinnacle is at an altitude of 1966 m. High - Ribb watershed is characterized as a turning point (3.6 percent) of mountain, in the form of corner, and steep - slope. The highest elevation of the watershed is approximately 4,100 m in its southeastern part. The lowest topography is on the dam site, at 1873 m above sea level. The climate of the Ribb basin is characterized by a rainy season from May to September, with monthly precipitation varying from 65 mm in May to 411 mm in July. Average annual precipitation at the top is about 1,400 mm and at the bottom about 1,200 mm. Throughout the year, temperature variations are small (19 0C in December to 23 0C in May), with maximum and minimum temperatures of 30 0C and 11.5 0C, respectively. The wind speed is low, reducing the possible evapotranspiration values between December 95 mm/month and April 140 mm/month. The amount of sunlight is reduced to 6.0 hours in July and 6.5 hours in August.

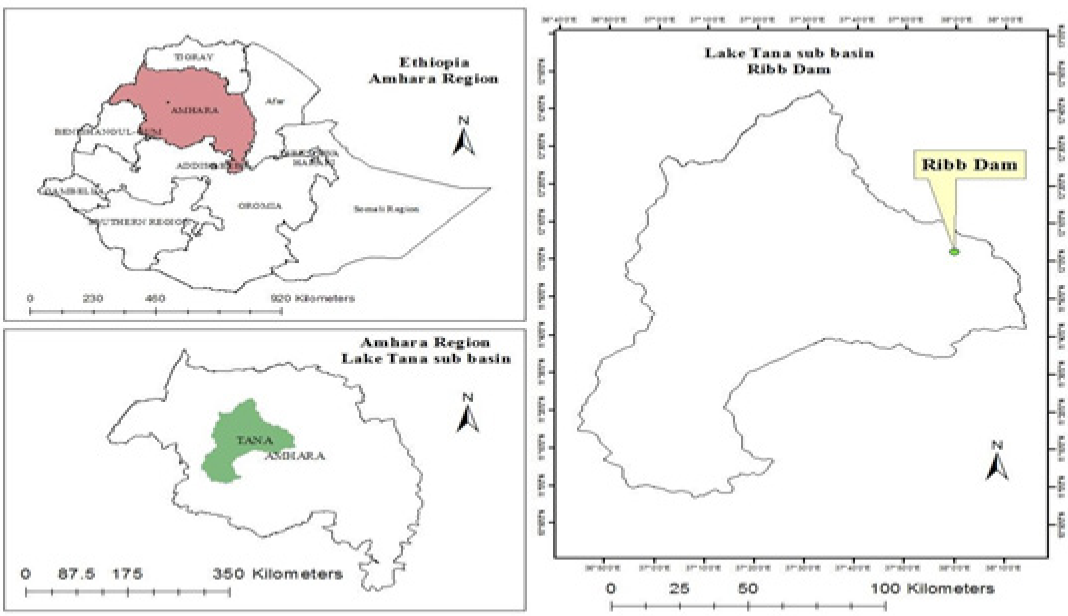


Figure 1.Location map of the study area

### 2.2 Description of input data

Data collection techniques for primary and secondary data were collected from various sources and analyzed using GIS, spread sheet Excel, and Mat lab. The main data come from topographic, hydrological, geological, studies and materials. To understand water discharges, the annual energy production of the proposed site can be estimated, which will be used as input energy to power the hydraulic turbine of the SHP electricity production system. Analyzing the demand for water for hydroelectricity means compiling and analyzing flow data, since the total quantity available on a site is used in the production of electricity. The flow is therefore an important parameter in deciding the potential power that can be derived from any flowing river. The production of hydroelectric power leads to a sustainable climate and a better standard of social life. The results of the study will form the basis for further analysis to support a reasoned decision to further assess the capacity of a site to be served. The electrical energy generated by a small hydroelectric plant would be able to meet the community's needs for irrigation flows. The system used in this research included several stages in the use of irrigation flow for the production of small hydroelectric plants.

Table 1: Yearly/Monthly discharge flow data of Rib River

| Year/Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1998 | 0.707 | 0.318 | 0.258 | 0.175 | 1.288 | 3.856 | 48.36 | 66.479 | 43.012 | 12.401 | 3.983 |
| 1999 | 0.805 | 0.491 | 0.363 | 0.298 | 0.386 | 3.416 | 45.272 | 70.812 | 39.862 | 41.027 | 12.955 |
| 2000 | 5.046 | 0.467 | 0.303 | 0.987 | 0.682 | 2.009 | 40.953 | 72.013 | 35.076 | 16.198 | 5.193 |
| 2001 | 0.803 | 0.481 | 0.492 | 0.427 | 0.531 | 15.312 | 57.551 | 73.215 | 26.7 | 5.056 | 1.844 |
| 2002 | 0.543 | 0.284 | 0.286 | 0.452 | 0.13 | 7.594 | 22.828 | 46.646 | 24.059 | 3.115 | 1.243 |
| 2003 | 0.704 | 0.509 | 0.565 | 0.131 | 0.062 | 3.974 | 44.273 | 65.973 | 44.303 | 8.415 | 4.071 |
| 2004 | 1.619 | 1.32 | 1.016 | 1.767 | 1.188 | 3.732 | 36.825 | 54.914 | 19.645 | 5.796 | 2.601 |
| 2005 | 1.293 | 0.88 | 1.585 | 0.627 | 0.955 | 9.082 | 44.826 | 60.456 | 40.669 | 10.574 | 4.841 |
| 2006 | 2.508 | 1.963 | 0.56 | 0.758 | 4.998 | 10.279 | 48.824 | 77.908 | 52.278 | 15.246 | 8.555 |
| 2007 | 5.686 | 4.834 | 3.594 | 4.967 | 6.626 | 19.706 | 62.154 | 75.24 | 50.145 | 12.459 | 8.041 |
| Average | 1.9714 | 1.1547 | 0.9022 | 1.0589 | 1.6846 | 7.896 | 45.1866 | 66.3656 | 37.5749 | 13.0287 | 5.3327 |

Table 2: Rib Annual maximum, mean and minimum flow data

| Year | Maximum($m^3/s$) | Mean ($m^3/s$) | Minimum($m^3/s$) |
|---|---|---|---|
| 1998 | 70.214 | 15.148 | 0.124 |
| 1999 | 94.544 | 11.841 | 0.106 |
| 2000 | 90.729 | 13.557 | 0.156 |
| 2001 | 86.915 | 15.274 | 0.206 |
| 2002 | 77.117 | 9.034 | 0.066 |
| 2003 | 84.411 | 14.674 | 0.000 |
| 2004 | 89.561 | 11.007 | 0.001 |
| 2005 | 90.818 | 14.933 | 0.000 |
| 2006 | 94.224 | 19.234 | 0.000 |
| 2007 | 95.486 | 21.629 | 2.547 |
| **Average** | **87.4019** | **14.6331** | **0.3206** |

### 2.3 Methodology

The methodology estimating the capacity for energy production and the assessment of economic profitability[4] as follows, although only the first step is considered in this paper. The sites' Power Potential was calculated from a reliable average monthly flow and heads for different time scales. The generation potential energy depends primarily on the available flow and topographical hydraulic head [10].

$P = Q\rho\eta gH$ (1)

Where, p is the power is; ρ is water density, g is gravity, Q is discharged equally to 75% effective flow, and H (m) is the net head [7]. Hydroelectricity is the power generated by flowing water using the potential energy it contains. It is a renewable energy source suitable for rural electrification in developing countries like ours. Conceptually, the equation generally used to determine the output power based on flow and head is [15]. Annual values are between the rates the highest and lowest rate. Second, using the Weibull method, the graduated dataset was converted to probabilities.

$P = m/(n+1)*100\%$ (2)

Or; P = the probability equal to or greater than a given flow (percentage of the duration), m is the estimate of a given flow, and n is the total number o f records.

In general, the flow period curve is very useful in hydrological analyzes, and in particular in hydroelectric studies. The flow length curve (FDC) can be used in the hydroelectric study to calculate the expected power of a planned hydroelectric installation [8]. Two methods can be used to calculate a flow length curve at a calibrated point: the graduated flow method and the class interval method. Dominant runoff processes, including soil storage and drainage capacity, affect flow duration curves where watersheds with large storage have duration curves different from those of small storage basins [6].

**Results and discussion**

The power thus part of the South Gonder Libo Kemkem is in need of power and host communities. On the basis of the available gross head, the estimated hydraulic flows and losses as well as the characteristics of the turbines were determined; the amount of annual energy production was generated from the selected hydroelectric sites. Hydroelectricity is the most important type of renewable and sustainable electricity today [2]. Hydroelectricity is the production of electricity by harnessing the energy of moving water. By converting hydraulic energy into mechanical energy, the latest commercially available technologies produce electricity to trigger a turbine connected to a generator [14].

Annual power = P * 24 hours * 365 days

Annual energy consumption (kWh) is

$E = PHC\_F$ (3)

Where, P = power (kilowatts), H = annual period (8760 hours per year) and C F = plant capacity factor (95% for types of hydroelectric plants). Thus, a potentially good SHP site should have a high head and a high throughput. This implies that a hilly area with free flowing rivers generally generates high resistance. The data obtained on the Ribb dam are the maximum, minimum and average annual flows in Table 2. Multiply the measured power value by a given quantity called the correction factor. In general, for rocky and non-rocky streams, correction factor values of 0.65 and 0.85 are used. However, an average value of 0.75 is generally used for statistical purposes. The efficiencies of penstocks, turbines, and generators are 0.95, 0.90, and 0.85, respectively.

Gross head = 73.3 m, hydraulic loss = 4% of gross head

Net height = gross height - hydraulic loss hydraulic loss = 4/100 × 73.3 = 2.93 m

Net height = 73.3 - 2.93 = 70.37 meters

At maximum discharge (Q = 87.4019 m3/s)

η = 0.95 × 0.90 × 0.85 = 0.73, g = 9.81 square meters / sec,

Power in (kW) = 87.4019 × 70.37 × 0.73 × 9.81 = 44,045.373 kW

Power obtained = P × 0.75 (correction factor) = 44,045.373 × 0.75 = 33,034.0298 = 33.034 MW

Annual production energy (MWh) = P * h * CF = 33.034 * 8760 * 0.95 = 274,909.196 MWh

At average flow (Q = 14.6331 m3/s)

Power in (kW) = 14.6331 × 70.37 × 0. 73 × 9.81 = 7,374,214kW

Available power = 7,374,214 × 0.75 = 5,530.661kW = 5.53MW

The power obtainable at an average discharge of 14.6331 cubic meters / sec is 5,530,661 kW

Annual output energy (kWh) = P * h * CF = 5530.661 * 8760 * 0.95 = 46,026.159 MWh

Minimum discharge (Q = 0.3206 m3/s)

Power in (kW) = 0.3206 × 70.37 × 0.73 × 9.81 = 61.56 kW

Available power = 61.56 × 0.75 = 121.172 kW = 0.12MW

The minimum discharge available power at 0.3206 cubic meter / sec is 121.172 Kw

Annual production energy (kWh) = P * h * CF = 121.172 * 8760 * 0.95 = 1,008.397 kWh

Average annual maximum, minimum and average releases were 87.4019 m3/sec, 0.3206 m3/sec and 14.6331 m3/s respectively.

Average annual total runoff volume = 14.6331 m 3 / s * 60 min * 60 s * 24 h * 365 days = 0.46 x 1 0 9 m 3

Table 3: Average mean flow discharge and power potential of Ribb River

Table 3: Average mean flow discharge and power potential of Ribb River

| Month | Mean Flow Discharge(L/s) | Power potential(kW) |
|---|---|---|
| Jan | 1,971.4 | 993.467 |
| Feb | 1,154.7 | 581.900 |
| Mar | 902.2 | 454.655 |
| Apr | 1,058.9 | 533.623 |
| May | 1,684.6 | 848.938 |
| Jun | 7,896 | 3975.059 |
| Jul | 45,186.6 | 22,771.365 |
| Aug | 66,365.6 | 33,444.318 |
| Sep | 37,574.9 | 18,935.516 |
| Oct | 13,028.7 | 6,565.690 |
| Nov | 5,332.7 | 2,687.364 |
| Dec | 3,883 | 1,956.800 |
| Average | 15,503.28 | 7812.391 |

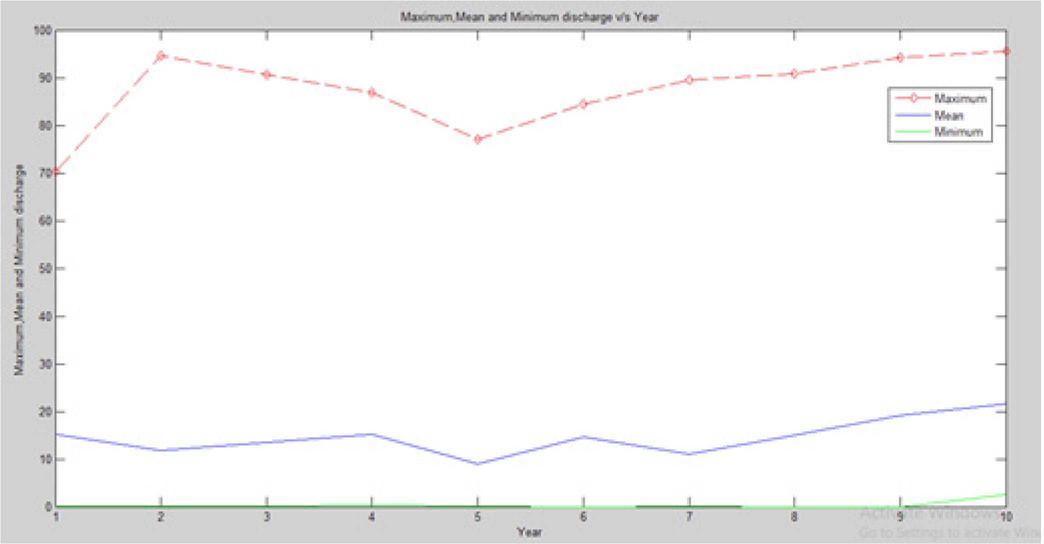


Figure 2: Curve of Maximum, Mean and Minimum flow discharge v/s year

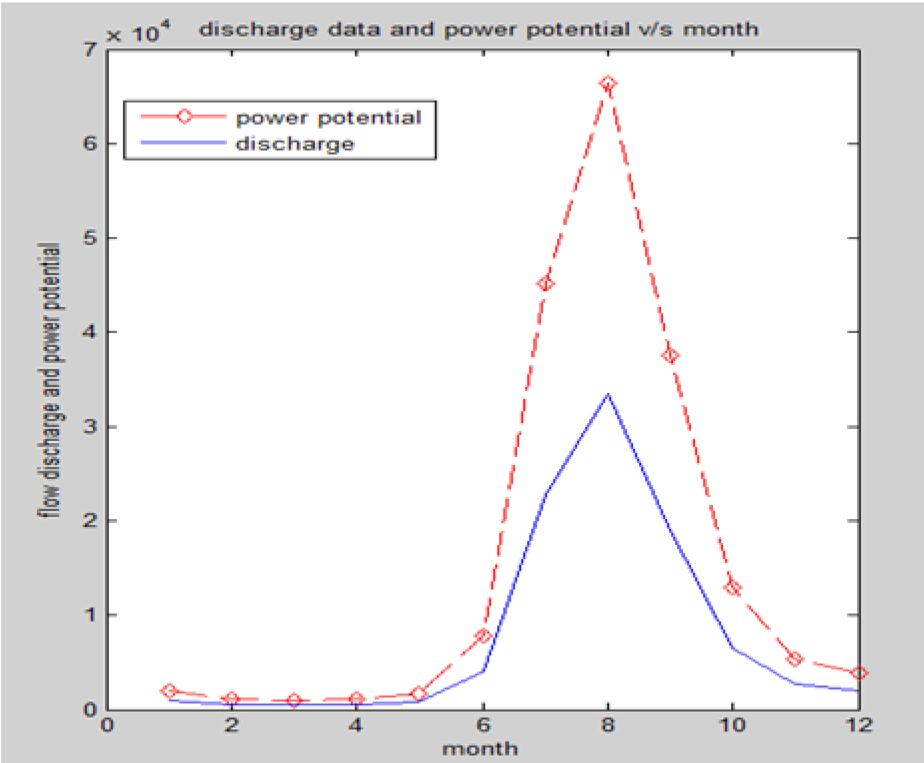


Figure 3: Curve of Power potential and Monthly Flow release

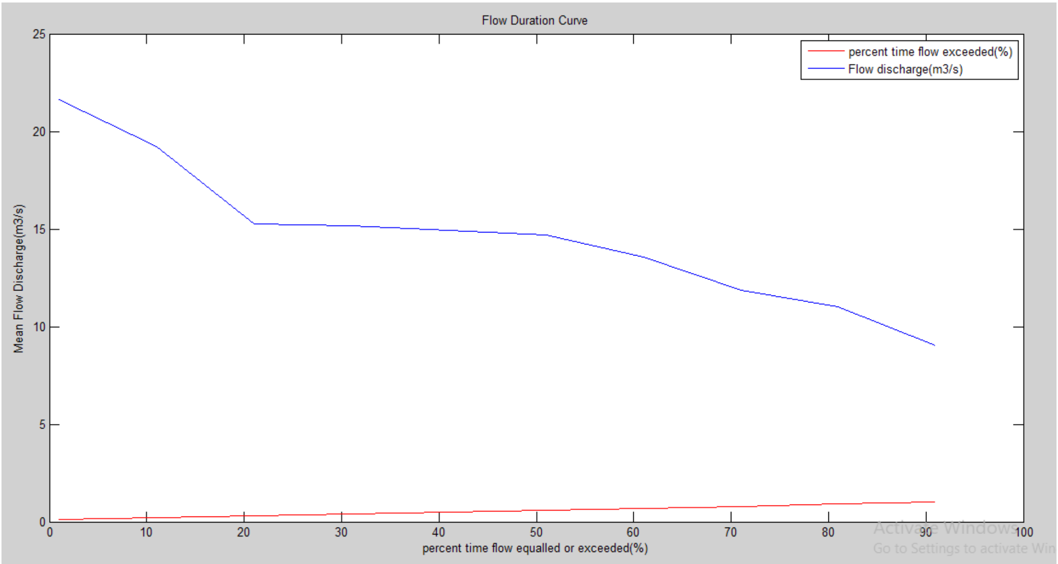


Figure 4: Flow Duration Curve for Ribb River

From figure 3 depicts that the flow duration curve is constant from the nominal flow from 20 to 50%, and then decreases as the percentage of the nominal flow increases. Another way to organize flow data is to plot the flow duration curve (FDC). A FDC shows the proportion of time that the flow is equal to or greater than certain values for a particular point on a river. In general, the flow period curve is very useful in hydrological analyzes, and in particular in hydroelectric studies. The flow duration curve (FDC) can be used in the hydroelectric study to calculate the expected power of a planned hydroelectric installation [8].

A small hydroelectric plant generates energy or energy that depends on flow and head. The head in a small hydroelectric plant is generally constant, as run-of-river plants have a fixed level of upstream water. However, the available speed can be quite variable. Minimum flow is deemed to exceed 100% of the time while the maximum flow exceeds 0% of the time. An efficient flow of 90 percent, therefore, means that the flow is greater than 90 percent of the time, or that the flow reaches this value in 9 out of 10 years. A small run-of-the-river hydroelectric discharge system can be selected from 90 to 50% of reliable flow values anywhere.

From figure 3, it is shown that for the Ribb Dam site, from flow data, month by month, and excess flow over a few months of the year, while there is very little flow over the remaining period. Even after deduction of the minimum requirement downstream, the reliable flow tends to be very low (overflow of 90%), with the exception of the few rainy months of the year. This reality disconcerts the designers of small hydroelectric plants in choosing the optimal design flow. To ensure reliable supply throughout the year, the design flow should be adjusted so low that the power potential of the river would be underutilized. The maximum, minimum, and average discharges for monthly power and electricity were 33.034MW, 0.12MW and 5.53MW, respectively. Annual average electricity production was 46,026.159 MWh.

Hydroelectricity is Ethiopia's main source of energy which can meet the energy needs of the people. Although the country has enormous hydroelectric potential, only a fraction of it has been exploited to date. This is largely due to the capitalistic nature of hydroelectric projects. Today, hydroelectricity is the most important form of renewable and sustainable energy [2]. Small-scale renewable generation could be the most cost-effective way to provide electricity to remote villages that are not connected to transmission lines.

**IV. Conclusion**

River Ribb comes from the southern part of the Gondar zone around Guna Mountain. The coast flows to the west, crossing Libo kemkem Woreda and reaching Lake Tana. There was an irrigation dam, which is expected to grow from approximately 14,460 ha of land from the small's hydroelectric power plants in some cases, feeding directly to small and medium industries such as cement factories or fertilizer. Small hydro in rural areas is widely used for residential lighting, television, radio and telephone services. It also provides energy for small factories, fishing and other important uses. Thus, the Ethiopian government should develop a sustainable electricity capacity with low environmental risk and reduce transport and distribution losses by using good techniques and labor, as well as guarantee a timely and adequate electricity supply.

A river profile was established from the measurement data, with a height of 73.3 m, a head loss 70.37 m and the output power of 5.53 MW was also deducted. This study shows that River Ribb has a potential for the production of small hydropower plants. Small hydropower is both a sustainable and renewable source of electricity. Small hydropower is a well-developed small-scale renewable energy technology that can help meet the needs of regions where there is not significant technological progress and where they can improve the quality of life people by creating jobs, the improvement of the local economy, and improving the community.

Creation of rural and remote areas: deployment potential for the construction of small power plants in remote and mountainous areas. The use of this renewable energy source in these regions allows for economic, social growth and other benefits in regions where small factories such as irrigation, water supply, tourism, fishing and flood prevention are built. Evaluating hydro-project interactions can help assess the future effects of such projects. The result of the study should include a set of recommendations for better planning, development work, and the execution of Ribb Hydroelectric Project dam. Thus, the results of the study will help policy makers and planners, scientists, social workers, organizations, and researcher of programs running, etc. The Ethiopian government has set ambitious targets to become a middle-income country by 2025, which includes targets for power generation and aggressive connections.

## V. Recommendation

This study evaluated the existing Ribb dams for electricity production, and recommends the development of water resources to multipurpose with the inclusion of hydroelectric dams in these systems that can bring the country want the sustainable development. To be effective and efficient in programming rural electrification by developing small hydropower plants, it must be combined with the broader objectives of other rural development programs at local and national levels. Among the various factors that influence the cost of capital, the choice of site and the simple layout are considered among the first. Develop and modernize legacy conventional recording systems for hydraulic data in regular irrigation systems and incorporate modern technology to improve data recording operations.

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