

Research Article

# Technical Assessment of Existing Irrigation Schemes for Micro-Hydro Power Generation Potential in the Case of West Shewa and East Wollaga, Ethiopia

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## Abstract

The energy generated by the force of water can provide a more sustainable, non-polluting alternative to fossil fuels and other renewable energy sources, including wind, solar, tidal, geothermal, and bioenergy. Micro hydropower is hydro energy on a small scale and provides hydromechanical and hydroelectric power to small communities. This study aimed to conduct technical assessments of the micro-hydropower potential of generating hydroelectric and hydro mechanical power from existing irrigation schemes in West Shewa and East Wollaga, Oromia. From the two zones, 16 schemes from the East Wollaga Zone, and 5 schemes from the West Shewa Zone were selected; all of these schemes had the potential for irrigation and were functional. Out of 8 districts, 21 irrigation schemes were technically assessed. Among the analyzed schemes, the maximum Hydraulic power potential for micro-hydropower generation at 80% efficiency was 14.27 kW at the Chaka Arba scheme in the Wayu Tuka district and 5.95 kW, 5.35 kW, 6.54 kW, 5.4 kW, 5.35 kW, and 6.5 kW at Jalale, Gindo, Indiris, Laga Dabesa, Molo, and Sako schemes of East Wollaga Zone, respectively. The maximum discharge recorded was 1.429 m<sup>3</sup>/s at the Chole 3<sup>rd</sup> scheme in the Toke Kutaye district in the West Shewa zone. Generally, some of the assessed schemes are insufficient for micro-hydro power generation in the West Shewa zone. However, some of them are possible with technical advances for Pico-hydropower and micro-hydropower.

## Keywords

Discharge, Head, Irrigation Schemes, Micro-Hydropower, Technical Assessment

## 1. Introduction

The hydroelectric systems are classified as “hydroelectric” because they use the available head and flow of water to convert that energy into electricity [1]. The turbine is used to rotate a generator that produces either DC or AC electricity. A package of electrical equipment and controls is used to safely transfer that electricity to a local electric load, or in this case, to power electric motors. Hydropower systems require little

maintenance and have low operating costs.

Generally, turbines are highly reliable and durable. The systems are becoming more popular in the agricultural community because of their ability to not only save on electricity production expenses but also reduce carbon emissions and other greenhouse gases by not burning oil or natural gas to power the irrigation systems [2]. These self-sustaining hy-

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dropower systems are not only beneficial to the user but also to the general community as a whole.

According to this method, transforming natural water energy into electrical energy is one of the most advanced when compared to other renewable energy sources [3]. One of the most promising forms of renewable energy is hydropower [2]. Hydropower produced 19.8% of the world's electricity in 2021, while other renewable energy sources produced 28.3%. Large (>10MW), medium (<10MW), small (<1MW), micro (<100KW), and Pico (< 5KW) hydropower resources are the different categories [4].

The small hydropower in Ethiopia is 12.9 MW; the potential is estimated to be 1,500 MW, indicating that less than 1 percent has been developed [5]. The world has been producing energy for many years to fulfill its energy demand despite the availability of various energy sources, but at the moment, there is an energy crisis [6].

The increasing need for energy necessitates the use of alternative energy sources like renewable energy [7]. One energy source that might be developed is micro- and Pico-hydropower, which, even in low-density regions, can offer rural areas inexpensive power [8]. Micro hydropower plants use the movement of water to create energy through variations in discharge and elevation [9].

If irrigation networks have consistent flow, a reliable indicator of water supply, they can support the development of micro hydropower plants. According to [10], micro hydropower plants can be created if irrigation networks have a minimum head of two meters, are located in primary or secondary channels, and generate 5 kW to 100 kW of energy.

Recently, the Oromia region, Ethiopia, has built a significant amount of irrigation canals and dams to meet its demands, which may be utilized to produce energy or power for agricultural uses. The micro-hydropower plant's irrigation canals may be utilized with irrigation water to create a self-sufficient community.

Hydropower projects for agriculture make use of the infrastructure that is being built or is already in place for gravity irrigation systems [11]. Because the systems don't require burning oil or natural gas to power the irrigation systems, they not only cut producers' electric power costs but also lower greenhouse gas emissions and carbon emissions overall [12].

For these reasons, the agriculture community is starting to use the systems more frequently. Therefore, the purpose of this research was to provide a technical evaluation of the current irrigation schemes for the potential to generate micro hydro power in the West Shewa and East Wollaga Zones. As a result, this paper aimed to evaluate the technical and economic feasibility assessment of generating hydroelectric and hydro mechanical power from existing irrigation schemes.

## 2. Materials and Methods

### 2.1. Materials

The instruments and materials that were used for assessment were the following: Tape, Bubble level, Meter stick, Rope, Stopwatch, and Styrofoam

### 2.2. Methods

The investigation was carried out in the areas that may be used for irrigation schemes in west Shewa and east Wollaga. From those zones, 20 schemes from the west Shewa Zone, and 20 schemes from the East Wollega Zone were chosen; every plan had the capacity to be irrigated and was operational. As a result, 21 irrigation systems out of 7 districts were evaluated. Seasonal variations affect the flow rate via the irrigation networks. Nevertheless, from January 30 to March 30 of the irrigation session, the lowest flow rate was utilized to evaluate the potential for micro hydropower in the West Shewa and East Wollaga zones.

#### 2.2.1. Methods for Measuring Flow Rates

The following steps were taken to determine the flow rate using the float technique, also referred to as the cross-sectional method: First, we located the high spots where the irrigation water runs through the canals. Select a straight canal segment that is at least ten meters long, and ensure that the canal's shape is as uniform as feasible across the length. To indicate a section of the canal, place one board at its upstream end; this corresponds to point A in the figure. Track a distance of at least 10 meters along the canal.

At the downstream end of the chosen section of the canal, position a single board. These correspond to point B in the figure. At least two meters upstream from point A, place the floating object on the canal's middle line. Set the stopwatch to begin when the object leaves point A. When the floating item reaches point B, stop the timer and note the time in seconds. To get the average time required for an item to go from point A to point B, repeat step five times.



**Figure 1.** The photo taken during the measurement of the flow rate.

### 2.2.2. Performance Evaluation Calculations

#### 1) Flow rate

The flow rate was calculated using the following formula:

$$Q = A * V * 0.8 \quad (1)$$

Where Q is the flow rate in m<sup>3</sup>/s, and V is the average flow velocity in m/s.

A = cross-sectional area in m<sup>2</sup> and the 0.83 coefficient of friction [2].

#### 2) The Measurement of Water Speed

Water speed is the ratio of the distance a floating Styrofoam object travels to the time it takes to travel that distance. The principle used is that the speed on the surface of the flow in the canal is straight and one-way. The following equation was used to compute the speed of water flow.

$$V = \frac{S}{t} \quad (2)$$

Where S is the distance traveled in meters, and t is the time taken in seconds

#### 3) Canal wet cross-sectional area

In all three zones of the irrigation network, square canals are used. The wet canal's cross-sectional area was measured by taking measurements in the horizontal (width of flow) and vertical (depth of flow) directions in line with the flow cross-section form. A wet cross-section of the canal was calculated by using the following equation:

$$A = b * y \quad (3)$$

Where, A cross-sectional area of wet (m<sup>2</sup>) b is the width of the wet section cross-section (m), y is the depth of water (m).

#### 4) Hydraulic Power Estimation

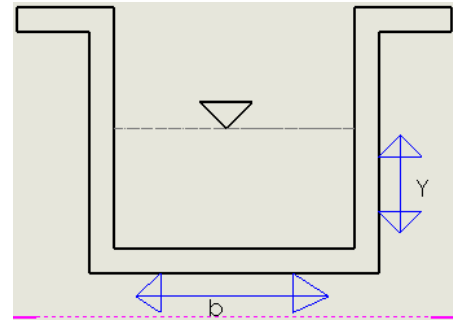
Hydraulic power generation was computed following equation (4).

$$P_{hyd} = p * g * H * Q * \eta \quad (4)$$

Where: is water density (kg/m<sup>3</sup>), g is gravitational (m/s<sup>2</sup>), Q is the flow rate (m<sup>3</sup>/s), and  $\eta$  is the overall efficiency (0.8).

*Measured and calculated Variables*

- Head
- Discharge
- Speed of water
- Number of households living around irrigation schemes
- The distance of irrigation schemes from the residential area
- Hydraulic power generation at 80% efficiency



**Figure 2.** The transverse cross-section of the square canal.

### 2.2.3. Data Collection Methods

The data were collected through technical assessments of existing irrigation schemes in the West Shewa and East Wollaga zones. The flow rate was measured by timing a float as it moved over a specific length of canal (completely straight and free of obstacles). The floating method was used to determine flow velocity. The heads of irrigation schemes were measured using meter sticks, rope, a spirit level, and tape.

### 2.2.4. Data Analysis Method

According to its applicability, the whole acquired data was analyzed using simple descriptive statistics.

## 3. Results and Discussion

**Table 1.** Hydraulic Head, Flow Rate, and Corresponding Power Potential of Selected Schemes.

| Districts   | Site   | Distance from residential area (m) | Number of households | Head (m) | Flow rate (m <sup>3</sup> /s) | HPG (kW) | HPP (kW) at 80% efficiency |
|-------------|--------|------------------------------------|----------------------|----------|-------------------------------|----------|----------------------------|
| Dandi       | Fakare | 500                                | 150                  | 0.1      | 0.2                           | 0.198    | 0.158                      |
|             | Kure   | 420                                | 181                  | 0.12     | 0.17                          | 0.198    | 0.158                      |
|             | Jirma  | 1000                               | 53                   | 0.1      | 0.75                          | 0.743    | 0.594                      |
| Toke kutaye | Chanco | 200                                | 40                   | 0.15     | 0.18                          | 0.278    | 0.222                      |

| Districts   | Site         | Distance from residential area (m) | Number of households | Head (m) | Flow rate (m <sup>3</sup> /s) | HPG (kW) | HPP (kW) at 80% efficiency |
|-------------|--------------|------------------------------------|----------------------|----------|-------------------------------|----------|----------------------------|
| Ejersa Lafo | Chole 3rd    | 151                                | 60                   | 0.3      | 1.42                          | 4.246    | 3.397                      |
|             | Jamjam       | 250                                | 150                  | 0.42     | 0.5                           | 2.080    | 1.664                      |
|             | Oda Guba     | 200                                | 124                  | 0.23     | 0.6                           | 1.367    | 1.093                      |
|             | Lalisa       | 98                                 | 39                   | 0.85     | 0.25                          | 2.105    | 1.684                      |
| Sibu Sire   | Jalale       | 100                                | 100                  | 0.6      | 1.25                          | 7.431    | 5.944                      |
|             | Gindo        | 200                                | 112                  | 0.9      | 0.75                          | 6.687    | 5.350                      |
|             | Ambelta      | 100                                | 100                  | 0.83     | 0.625                         | 5.139    | 4.111                      |
|             | Indiris      | 500                                | 40                   | 1.1      | 0.75                          | 8.174    | 6.539                      |
| Digga       | Gebo         | 150                                | 143                  | 0.7      | 0.6                           | 4.161    | 3.329                      |
|             | Laga dabesa  | 250                                | 150                  | 0.5      | 1.36                          | 6.755    | 5.404                      |
|             | Dimtu        | 180                                | 190                  | 0.3      | 0.48                          | 1.426    | 1.141                      |
|             | Tato         | 200                                | 60                   | 0.9      | 0.6                           | 5.350    | 4.280                      |
| Wayu        | Molo         | 710                                | 40                   | 1.2      | 0.56                          | 6.687    | 5.350                      |
| Tuka        | Sako         | 300                                | 47                   | 1.1      | 0.75                          | 8.174    | 6.539                      |
| Jimma Arjo  | Chaka Arba   | 200                                | 62                   | 1.5      | 1.2                           | 17.835   | 14.268                     |
|             | Nageso       | 201                                | 30                   | 0.98     | 0.2                           | 1.941    | 1.553                      |
|             | Leka Dulacha | kombolcha                          | 21                   | 0.27     | 0.23                          | 0.617    | 0.493                      |

The assessments of existing irrigation schemes for micro hydro power generation potential in West Shewa and East Wollaga zones were conducted. On 5 schemes from the west Shewa Zone, and 16 schemes from the east Wollaga; each of those schemes was functional and had irrigation potential. 21 irrigation schemes were evaluated among the 8 districts.

It demonstrates the irrigation schemes assessed for micro hydropower, as well as the characteristics of the distance from residential areas, the number of households around irrigation schemes, the head, flow rate, and efficiency. The hydraulic power potential was estimated at 80% efficiency of micro-hydro power.

The measured, calculated, and statistically analysed data from the assessment of the potential of irrigation schemes for micro-hydropower generation are shown in Table 1. It demonstrates the irrigation schemes assessed for micro hydropower generation in south-western Oromia in East Wollaga and West Shewa zones, as well as the characteristics of the distance from residential areas, the number of households around irrigation schemes, the head, flow rate, and efficiency.

The hydraulic power potential was estimated at 80% efficiency of micro-hydro power. The hydraulic power was estimated using an equation (4), and according to this determination, the requirement is fulfilled [13]. Table 1: The irrigation schemes assessed for micro hydropower distance from residential areas, the number of households around irrigation

schemes, the head, flow rate, and efficiency.

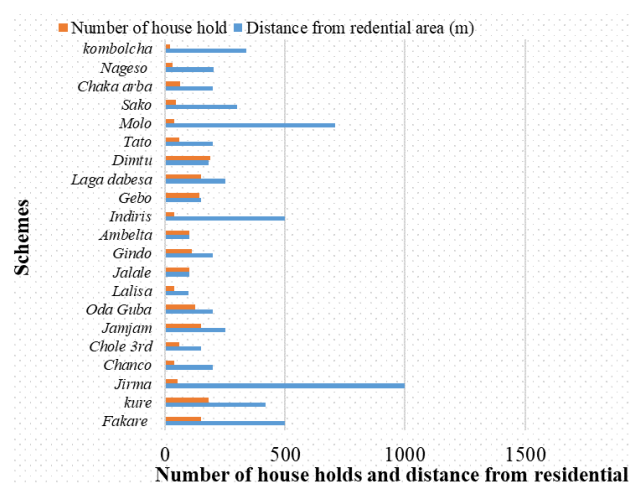


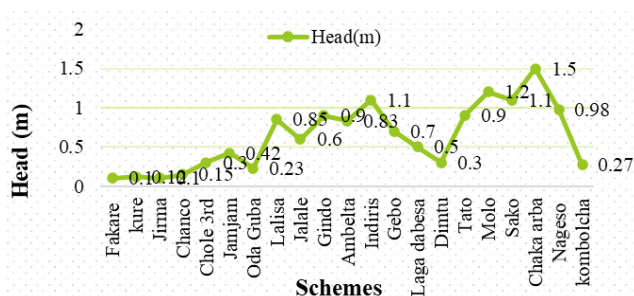
Figure 3. Schemes versus distance from the residential area and number of households.

Figure 3 shows the relationship between irrigation schemes versus distances from residential areas and the number of households living around the schemes. The scheme's minimum and maximum distances from residential areas were 98 m and 1000 m from the Lalisa Scheme in Sibu Sire district

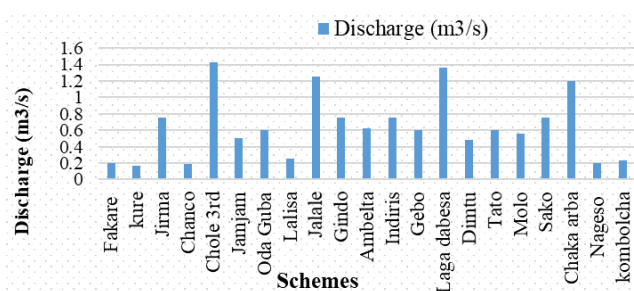
and Jirma in Dandi district, respectively. In each of the zones, the average scheme distance from the residential area was 297 m. The minimum and maximum numbers of households living around irrigation schemes were 21 and 198 at Kombolcha in Leka Dulacha district and Dimtu scheme in Wayu tuka districts, respectively.

In each of the zones, the average number of households living near the scheme was 90. In general, the distance of the schemes from the residential area affects hydroelectricity generation from micro-hydropower because it requires a long wire to supply electricity to the people living in the area. The long lengths of wire have more resistance than short lengths; thus, the lengths of the wire will cause a larger voltage drop.

According to an investigation of the potential of irrigation schemes for micro-hydropower (Figure 4), the Chaka Arba scheme in the Wayu Tuka district has the highest head of 1.5 m. When the head drops below 1.5 m, it is technically possible to develop it for the Archimedean screw and waterwheel turbines.



**Figure 4.** Depicts the relationship between irrigation schemes and heads.



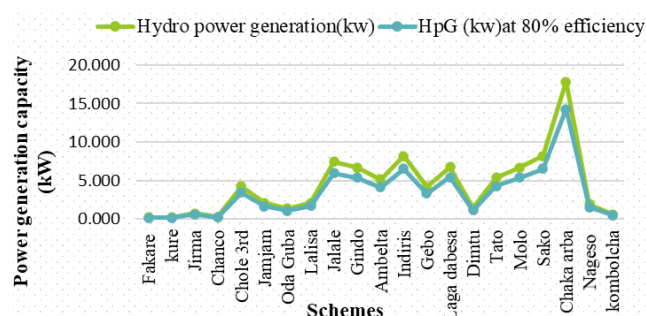
**Figure 5.** The relationship between irrigation schemes and discharge.

From the analysis of the assessed irrigation scheme potentials for micro hydropower generation (Figure 5), the minimum and maximum discharge were  $0.167 \text{ m}^3/\text{s}$  and  $1.429 \text{ m}^3/\text{s}$  at the Kure scheme in the Dandi district and the Chole 3<sup>rd</sup> scheme in the Toke Kutaye district in the West Shewa, respectively. The average discharge from the two zones was  $0.64 \text{ m}^3/\text{s}$ .

Therefore, micro-hydro development in irrigation networks needs to pay attention to the availability of water in the

channel.

The maximum hydraulic power potential obtained was 14.27 kW at the Chaka arba scheme in the Wayu Tuka district of the east Wollaga zone and 5.95 kW, 5.35 kW, 6.54 kW, 5.4 kW, 5.35 kW, and 6.5 kW at Jalale, Gindo, Indiris, Laga dabesa, Molo, and Sako schemes of East Wollaga, respectively. The Chole 3<sup>rd</sup> (3.4 kW), Ambelta (4.1 kW), Gebo (3.23 kW), and Tato (4.28 kW) schemes can generate Pico hydropower. Micro hydropower plants are defined as having a generation capacity ranging from 5 kW to 100 kW, and Pico hydropower (<5 kW) [5].



**Figure 6.** The relationship between irrigation schemes and hydraulic power at 80% efficiency.

## 4. Conclusions and Recommendation

The study examined and assessed several irrigation schemes. Based on the head measurement, flow rate, number of households, residential area distance from the schemes, and hydraulic power at 80 % efficiency of hydropower was calculated. The following conclusion was drawn from the assessments:

The maximum hydraulic power potential and head obtained from the assessment of irrigation schemes for micro-hydro power generation among the schemes studied were 5.14 kW and 1.5 m, respectively, at the Chaka Arba scheme in the Wayu Tuka district of East Wollaga zone. The maximum discharge recorded was  $1.429 \text{ m}^3/\text{s}$  at the Chole 3<sup>rd</sup> scheme in the Toke Kutaye district in the west Shewa zone.

Based on the results and discussion obtained, the following recommendations were made:

- 1) For the assessment of irrigation schemes that generate micro and Pico hydropower, it's possible to use a cross-flow turbine, Archimedes screw turbine, and water wheel turbines.
- 2) The Chaka Arba, Jalale, Gindo, Indiris, Laga Dabesa, Molo, and Sako Scheme can generate micro hydropower, and Chole 3<sup>rd</sup> (3.4 kW), Gebo (3.23 kW), and Tato (4.28 kW) can generate Pico hydropower in areas with low population density.
- 3) The constructed irrigation schemes were not considered for the generation of hydraulic power, but in the future, the design of irrigation schemes will be considered for

the generation of micro hydro power simultaneously.

## Abbreviations

|     |                       |
|-----|-----------------------|
| AC  | Alternating Current   |
| DC  | Direct Current        |
| HPG | Hydropower Generation |
| HPP | Hydropower Potential  |
| KW  | Kilowatt              |

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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