

Research Article

Technical Assessment of Existing Irrigation Schemes for Micro-hydro Power Generation Potential in Jimma, Buno Bedelle, and Ilubabor Zones, South-Western Oromia

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Abstract

The energy created by the force of water can provide a more sustainable, non-polluting alternative to fossil fuels, with other renewable energy sources including wind, solar, tidal, geothermal, and bioenergy. Micro hydropower, which is hydro energy on a 'small' scale, provides hydro-mechanical and hydroelectricity to small communities. The purpose of this study is to conduct technical assessments of the micro-hydropower potential of generating hydroelectric and hydro mechanical power from existing irrigation schemes in Southwestern Oromia. From three zones, 14 schemes from Jimma Zone, 14 schemes from Buno Bedele Zone, and 3 schemes from Ilubabor Zone were selected; all of these schemes had the potential for irrigation and were functional, out of 13 woreda, 31 irrigation schemes were assessed. Among the analyzed schemes, the maximum Hydraulic power potential for micro-hydropower generation at 80% efficiency was 5.14kW at the Gura scheme in the Gechi woreda in the Buno Bedele zone. The maximum discharge and head recorded were 1.027m³/s and 1.4m at the Gura scheme in the Gechi woreda in the Bedele zone, and the Hursa scheme in the Gomma woreda in the Jimma zone. Some of the assessed schemes are not sufficient for micro-hydro power generation, except the Gura scheme in the Gechi woreda in the Buno Bedele zone. However, some of them are possible with technical advances for Pico-hydropower.

Keywords

Assessment, Discharge, Head, Irrigation, Micro-hydropower, Schemes

1. Introduction

Hydropower is one of the most promising types of renewable energy sources [1]. In comparison to other renewable energy sources, it is among the most developed technologies for converting natural water energy to electrical energy [2]. Renewable energy contributed 28.3% of global electricity generation in 2021, while hydropower contributed 19.8% [3]. Hydropower resources can categorize into large (>10 MW),

medium (<10 MW), small (<1 MW), micro (<100KW), and Pico (< 5kW) [1]. In Ethiopia, the installed capacity of SHP up to 10 MW is 12.9 MW, while the potential capacity is estimated at 1,500 MW, indicating that less than 1 percent has been developed [4].

Despite numerous energy sources, the production of energy has been going on for many years to meet the global energy

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demand, but the world is currently facing an energy crisis [5]. Alternative energy sources, such as renewable energy are required to meet the rising energy demand. Micro and Pico-hydropower is one of the energy sources that may be developed, and it can provide affordable rural power even in

areas with low population density [6]. Micro hydropower plants use changes in elevation and discharge to generate electricity from water movements [7]. The approximate range of head, flow, and power applicable to the different turbine types are summarized in the figure below.

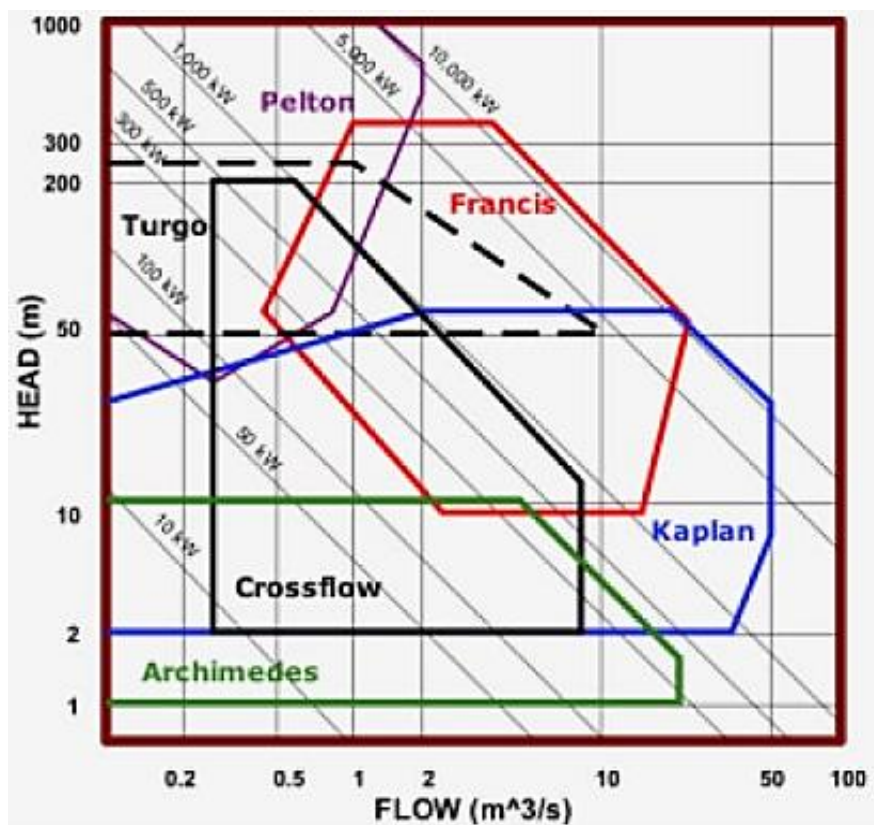


Figure 1. Use of turbine types by head, discharge, and capacity [8].

Irrigation networks have the potential to develop micro hydropower plants if they have water availability indicated by dependable flow in irrigation networks. If irrigation networks have a minimum head of 2 meters, are situated in primary or secondary channels, and produce 5kW to 100kW of electricity, then micro hydropower plants may be developed [9].

Oromia has recently constructed a large number of irrigation canals and dams for irrigation needs, which may be utilized to produce energy or power for agricultural uses. To build a self-sufficient community, irrigation water can be used in the irrigation channels of the micro-hydropower plant. The community senses that this is a self-contained community that is not dependent on the need for fossil fuel or electricity. Agricultural hydropower projects utilize the infrastructure already in place or being constructed for a gravity irrigation system. The systems are becoming more popular in the agriculture community because of their ability to not only save the producer's electric power expenses but also reduce carbon emissions and other greenhouse gases by not burning oil or

natural gas to power the irrigation systems [10]. Therefore, this study aimed to conduct a technical assessment of existing irrigation schemes for micro hydro power generation potential in Jimma, Buno belle, and Ilubabor zones.

2. Materials and Methods

2.1. Study Areas

The study area was in the southwestern Oromia regional state of Ethiopia, in the Jimma, Buno Bedelle, and Ilubabor zones. The study area was located at 7°40' N 36°50' E, 8°27' N 36°21' E, and 8°17' N 35°6' E, with an elevation of 1780 m, 2006.99 m, and 1730 m above sea level, and average annual precipitation of 91.72 mm, 92.37 mm, and 2000 mm, and an annual temperature of 19.07 °C, 15.39 °C, and 20.7 °C, respectively [11].

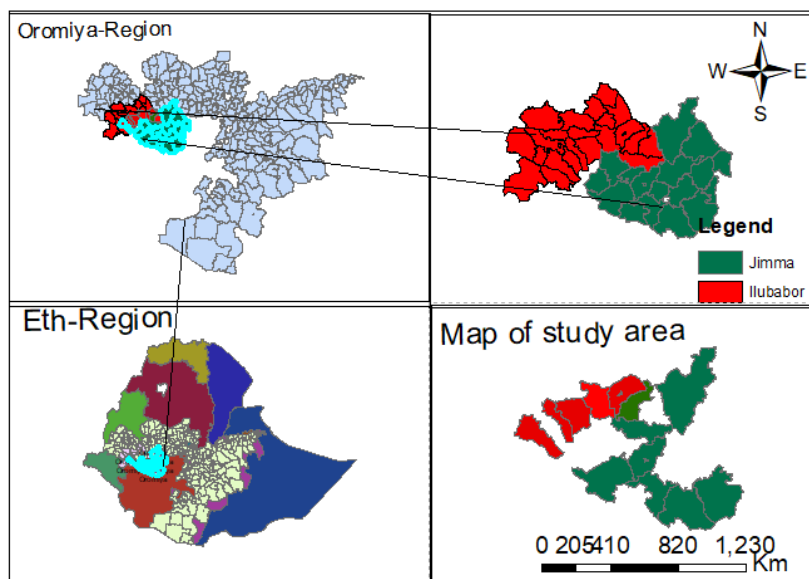


Figure 2. The map of the study area.

2.2. Materials

The instruments, and tools to be used to assess irrigation schemes for micro-hydropower potential for the generation of hydro mechanical and hydroelectricity were:

- 1) Tape
- 2) Bubble level
- 3) GPS
- 4) Meter stick
- 5) Rope
- 6) Stopwatch
- 7) Styrofoam

2.3. Methods

The study was conducted in the Jimma, Buno Bedele, and Ilubabor zones, which have the potential for irrigation schemes. From these zones, 14 schemes from Jimma Zone, 14 schemes from Buno Bedele Zone, and 3 schemes from Ilubabor Zone were selected; all of these schemes had the potential for irrigation and were functional. Therefore, out of 13 woredas, 31 irrigation schemes were assessed. The flow rate through the irrigation schemes varies due to seasonal changes. However, the lowest flow rate was used to assess micro hydropower potential in the Jimma, Buno Bedele, and Ilubabor zones from January 30 to February 30 during the irrigation session.

2.3.1. Flow Rate Measurement

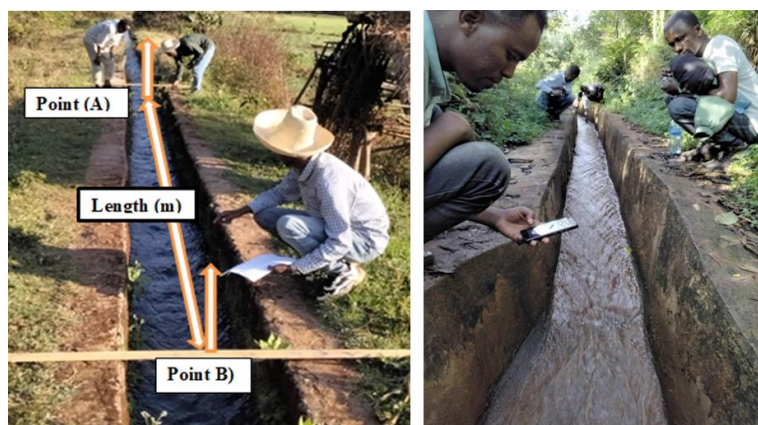


Figure 3. The photo taken during the measurement of the flow rate.

The float method (also known as the cross-sectional method) was used to measure the flow rate by the following procedures:

- 1) Initially, identify the elevated areas where irrigation water flows through the canals.
- 2) Choose a straight section of canal at least ten feet long.
- 3) The shape of the canal along the section is as uniform as possible.
- 4) Place one plank at the upstream end of the selected portion of the canal for marking; these correspond to point A in Figure 2.
- 5) Measure ten meters or more along the canal.
- 6) Place one plank at the downstream end of the selected portion of the canal. These correspond to point B in Figure 2.
- 7) Place the Styrofoam floating object on the center line of the canal at least 2 m upstream of point A, and start the stopwatch when the object starts from point A.
- 8) Stop the stopwatch when the floating object reaches point B and record the time in seconds.
- 9) Repeated six times to determine the average time necessary for the object to travel from point A to point B.
- 10) The object does not touch the canal embankment during

the trial, but if it does the operation must be repeated and the time for the bad trial must not be included when calculating the average time.

- 11) The cross-section within the selected portion of the canal is usually not regular, so the width and depth of the canal need to be measured in several places to obtain an average value.

2.3.2. Head Measurement

The heads were measured using a meter stick, a stopwatch, and a spirit level according to the following procedure:

- 1) Select the place where waterfall height is available through an irrigation canal.
- 2) Place a one-meter stick at the upstream end of the selected portion of the canal. It should be perpendicular to the centerline of the canal.
- 3) Place meter and second-meter stick downstream of the selected portion of the canal. It should be perpendicular to the centerline of the canal.
- 4) Connect the meter and meter and sticks to each other by a rope with a spirit level.
- 5) Reduce the elevation from each other.



Figure 4. The photo taken during head measurement.

2.4. Performance Calculations

2.4.1. Flow Rate

The flow rate was calculated by the following formula:

$$Q = A * V * 0.83 \quad (1)$$

Where Q: The flow rate in m³/s,

V: The average flow velocity in m/s.

The cross-section area in m² and the 0.83 coefficient of friction.

2.4.2. The Measurement of Water Speed

Water speed is the ratio of the distance traveled by a floating object made of Styrofoam to the time required 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 speed of water flow was computed by the following equation.

$$V = S/t \quad (2)$$

Where; S is distance traveled in meters, t is time in second.

2.4.3. 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 (4).

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

Where; A cross-sectional area of wet (m^2) b is width of the wet section cross-section (m) y is the depth of water (m).

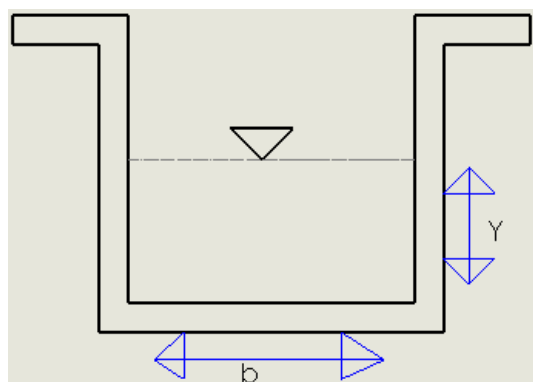


Figure 5. The transverse cross-section of the square canal.

2.4.4. Hydraulic Power Estimation

Hydraulic power generation was computed by eqn (4) [12].

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

Where: ρ is water density (kg/m^3), g is gravitational (m/s^2), Q is the flow rate (m^3/s), η is overall efficiency (0.8) [13].

Measured and calculated Variables

- 1) Head
- 2) Discharge
- 3) Speed of water
- 4) Number of households living around irrigation schemes
- 5) The distance of irrigation schemes from the residential area
- 6) Hydraulic power generation at 80% efficiency

2.5. Data Collection Methods

- 1) The data was obtained by conducting technical assessments of existing irrigation schemes in South Western Oromia
- 2) The speed was determined by timing a float over a certain length of canal (fully straight and free of obstacles)
- 3) The floating method was used to measure the flow rate
- 4) The heads of irrigation schemes were measured using meter sticks, rope, spirit level, and tape

2.6. Data Analysis

According to its applicability, the whole acquired data was examined utilizing software such as basic descriptive statistics and OriginPro 2019b for graphing.

3. Results and Discussions

The assessments of existing irrigation schemes for micro hydro power generation potential in Jimma, Buno Bedele, and Ilubabor Zones were conducted on 14 schemes from the Jimma Zone, on 14 schemes from the Buno Bedele Zone, and 3 schemes from Ilubabor; each of those schemes was functional and had the irrigation potential. Thirty-one irrigation schemes were evaluated among the 13 woreda. The table and figure below display the measured, calculated, and statistically analyzed data from the evaluation of irrigation schemes' potential for producing micro-hydropower.

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.

Zone	Woreda	Irrigation Schemes	Distance from the residential area (m)	No of household (pcs)	Head (m)	Flow rate (m^3/s)	Hydraulic power generation $P_{hyd}(Kw)$	Hydraulic power generation $P_{hyd}(Kw)$ (at 80% efficiency)
Jimma	Omo Nada	Toli colle	250	100	0.033	0.137	0.04435	0.035
Jimma	Omo Nada	Seno	112	150	0.79	0.022	0.17049	0.126
Jimma	Omo Nada	Nada kala	700	200	0.001	0.0385	0.000377	0.0003
Jimma	Omo Nada	Boneya	150	6	0.207	0.0638	0.1295	0.1
Jimma	Dedo	Offole	100	50	0.296	0.0431	0.125	0.1
Jimma	Dedo	Korjo	100	30	0.298	0.0125	0.0365	0.028

Zone	Woreda	Irrigation Schemes	Distance from the residential area (m)	No of household (pcs)	Head (m)	Flow rate (m ³ /s)	Hydraulic power generation P_{hyd} (Kw)	Hydraulic power generation P_{hyd} (Kw) (at 80% efficiency)
Jimma	Dedo	Waro	55	50	0.032	0.112	0.035	0.028
Jimma	Gera	Gicho	100	200	0.47	0.0395	0.182	0.146
Jimma	Gomma	Hida	221	101	0.94	0.1165	1.074	0.86
Jimma	Gomma	Tamsa	50	100	0.037	0.028	0.01	0.008
Jimma	Gomma	Hursa	100	150	1.42	0.2	2.78	2.22
Jimma	S/chokersa	G/kachama	70	2	0.175	0.1828	0.3138	0.24
Jimma	L/sakka	Hursa	5	20	0.622	0.01279	0.078	0.062
Jimma	L/sakka	M/Shomboqo	50	33	0.22	0.0191	0.041	0.032
B/ Bedele	chora	Kodo	300	40	0.96	0.0359	0.338	0.27
B/ Bedele	chora	Nacho	400	20	0.03	0.0167	0.0049	0.0039
B/Bedele	chora	Debaso 2nd	500	130	0.09	0.0148	0.013	0.01
B/Bedele	chora	Xiphacha	600	200	0.03	0.0038	0.0011	0.0008
B/ Bedele	chora	Sota	100	10	0.02	0.0165	0.00323	0.0025
B/Bedele	Bede	Hursa	20	50	0.785	0.0162	0.124	0.099
B/Bedele	Bede	Urgesa	300	50	0.02	0.0532	0.001	0.0008
B/Bedele	Gechi	Gura	112	55	0.65	1.0272	6.376	5.14
B/Bedele	Gechi	Kobba Kala	85	52	0.315	0.0242	0.07478	0.059
B/Bedele	Gechi	Kobba guda	119	80	0.51	0.156	0.78	0.624
B/Bedele	Gechi	H/konbolcha	15	70	0.95	0.164	1.528	1.22
B/Bedele	Gechi	Doriye	200	52	0.1	0.049	0.048	0.038
B/Bedele	Dedesa	Gela	70	80	0.45	0.0653	0.239	0.19
B/Bedele	Dedesa	Gepha	80	56	0.34	0.0362	0.12	0.096
Illubabor	Yayu	Qanqe	50	50	0.46	0.0087	0.03925	0.03
Illubabor	Hurumu	Wanxe	100	60	0.59	0.027	0.156	0.12
Illubabor	Ale	A/qonnor	500	180	0.84	0.0135	0.111	0.088

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 the south-western Oromia in Jimma, Buno bedelle, and Ilubabor 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 equation (4), and according to this determination, the requirement is fulfilled [14].

Figure 6 shows the relationship between irrigation schemes

versus distances from residential areas and the number of households living around the schemes. The schemes' minimum and maximum distances from residential areas were 5m and 700m from the Hursa scheme in Limmu Sakka woreda and Nada Kala in Omo Nada woreda in the Jimma zone respectively. In each of the three zones, the average scheme distance from the residential area was 181.1m. The minimum and maximum numbers of households living around irrigation schemes were 2 and 200 at Gibe Kachama in Saka chokersa woreda and Nada Kala in Omo Nada woreda in the Jimma zones, respectively. In each of the three zones, the average number of households living near the scheme was 78. The long lengths of wire have more resistance than short lengths;

thus, the lengths of wire will cause a larger voltage drop. 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 large distance of the area.

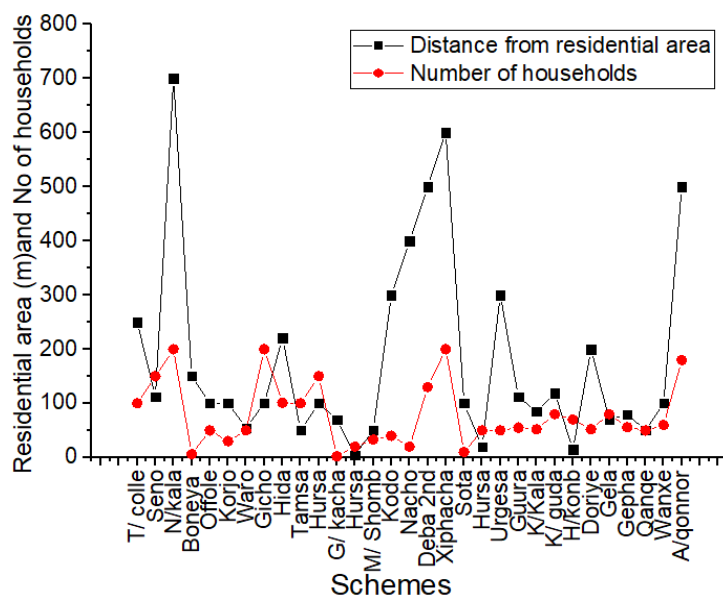


Figure 6. Schemes versus distance from the residential area and number of households.

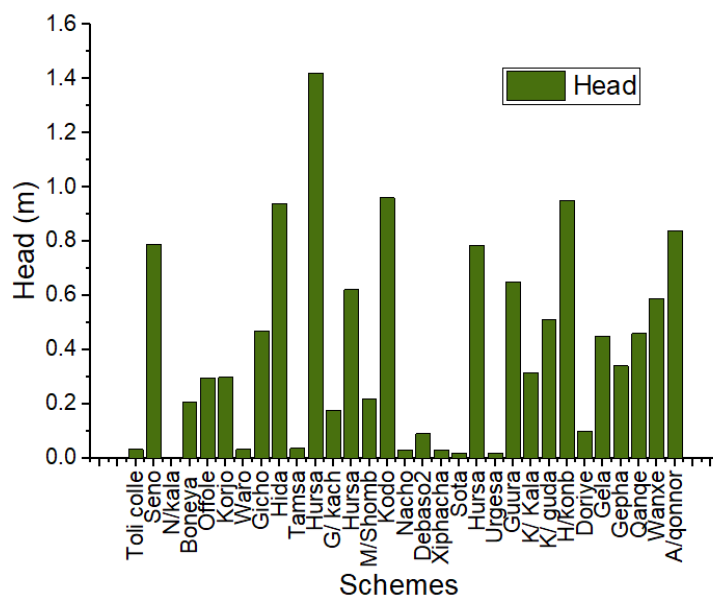


Figure 7. Schemes versus heads.

Figure 7 shows the relationship between irrigation schemes and heads. According to an investigation of the potential of irrigation schemes for micro-hydropower, the Hursa project in the Gomma woreda of the Jimma zone has the highest head of 1.4 m. During the evaluation of irrigation schemes for micro-hydropower in three zones, the average head recorded was 0.41 m. When the head drops below 1.5 m, it is technically possible to develop it for the Archimedean screw and water-wheel turbines [15].

Figure 8 shows the relationship between irrigation schemes and discharge. From the analysis of the assessed irrigation scheme potentials for micro hydropower generation, the minimum and maximum discharge were $0.0038 \text{ m}^3/\text{s}$ and $1.027 \text{ m}^3/\text{s}$ at the Xiphacha scheme in the Chora woreda and the Gura scheme in the Gechi woreda in the Bedele zone, respectively. The availability of water flow in irrigation canals is influenced by the water supply schedule or irrigation application pattern [5].

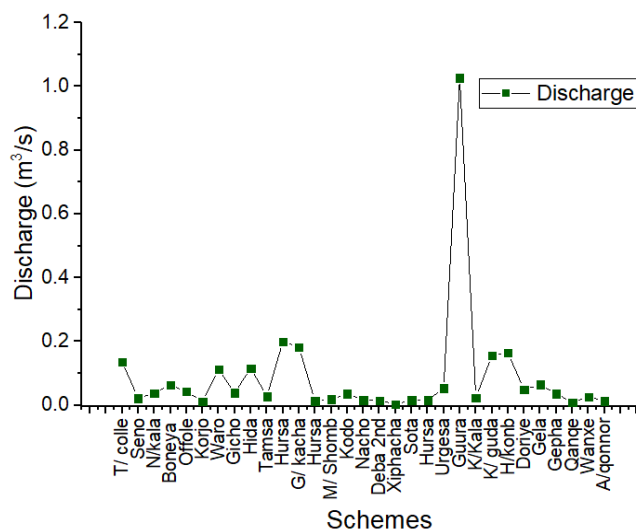


Figure 8. Schemes versus discharge.

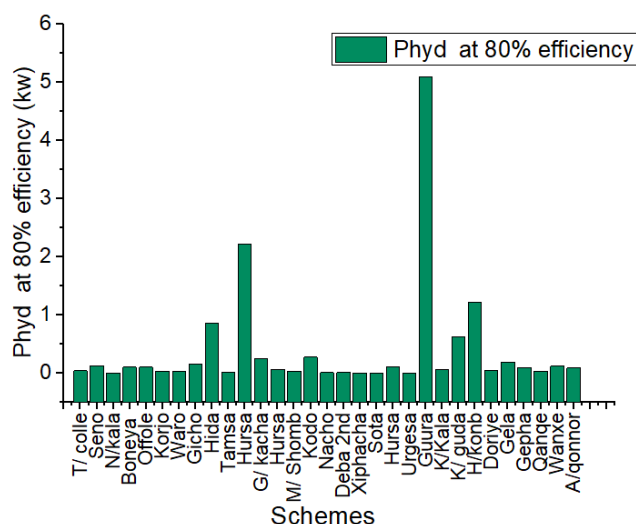


Figure 9. Schemes and hydraulic power at 80% efficiency.

Figure 9 shows the relationship between irrigation schemes and hydraulic power at 80% efficiency. The hydraulic power potentials were estimated using Equation (4), and according to this determination, the requirement fulfilled [14]. The maximum hydraulic power potential obtained was 5.14kW at the Gura scheme in the Gechi district of the Buno Bedelle zone. All except Gura scheme, Hurufa Konbolcha in the Gechi woreda of the Buno Bedele zone, and Hursa schemes in the Gomma woreda in the Jimma zone, the micro-hydropower potential estimated was less than 5kW. With a hydraulic power of 5.14kW, the Gura scheme can produce micro-hydropower. The Hursa scheme's 2.2kW hydraulic power and Hurufa Konbolcha's 1.2kW hydraulic powers can generate Pico hydropower. Micro hydropower plants are defined as having a generation capacity ranging from 5kW to 100kW and Pico hydropower (<5kW) [16].

4. Conclusions and Recommendation

4.1. Conclusions

The study examined and assessed several irrigation schemes in south western Oromia. Based on the head measurement, flow rate, number of households, residential area distance from the schemes, and hydraulic power efficiency of the Schemes were calculated.

The maximum hydraulic power potential obtained was 5.14kW at the Gura scheme in the Gechi woreda in the Buno Bedelle zone. The maximum head recorded was 1.4m at the Hursa scheme in the Gomma woreda of the Jimma zone. The maximum discharge recorded was 1.027 m³/s at the Guura scheme in the Gechi woreda in the Bedelle zone.

4.2. Recommendations

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

- 1) For the assessment of irrigation schemes that to generate micro and Pico hydropower it's possible to use an Archimedes screw turbine and waterwheel turbines.
- 2) The Gura Scheme can generate micro hydropower, and Hursa and Hurufa Konbolcha can generate Pico hydropower in areas with low population density.
- 3) The availability of water flow in irrigation canals is influenced by irrigation season and water supply schedule, Therefore, micro-hydro development in irrigation networks needs to pay attention to the availability of water in the channel.
- 4) Many canals were built without slope. However, some of them have enough water, but due to lack of sufficient elevation. It's not possible to get the required power and discharge, so in the future it is recommended that the canals will be designed by considering Pico, micro and small hydropower.

Abbreviations

MHP	Micro-hydro Power
kW	Kilo Watt
GPS	Geographical Positioning System
Q	Flow Rate
V	Flow Velocity
A	Cross-sectional Area
H	Head
b	Width
y	Depth of Water
S	Distance
t	Time

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Author Contributions

Adem Tibesso: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Abdusalam Aliyi: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review & editing

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Conflicts of Interest

The authors declare no conflicts of interest.

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