Feasible location identification & potential assessment of micro-hydropower: Gilgel Beles River, Upper Blue Nile Basin, Ethiopia

Semahegn Gebiru

Amhara Design and Supervision Works Enterprise

Mekash Kiflew (✉ mekahydro@gmail.com)

Debre Tabor University <https://orcid.org/0000-0001-7671-4569>

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Abstract

Ethiopia is endowed with huge natural resources especially water resources that is why Ethiopia is the water tower of East Africa. But having the capability of generating a huge amount of electricity Ethiopia is under an energy crisis especially the rural peoples of Ethiopia. To overcome this problem utilization of renewable sources of energy like wind, solar and hydro are the best options. Hence, the objective of this study is to assess and identify the micro hydropower potential of the Gilgel-Beles river which is located in the Amhara and Benishangul Gumuz regions of Ethiopia. For data preparation and analysis, Arc GIS, HEC-GEOHMS, and HOMER software were used. Typical energy demand categories (lighting, radio, television, injera Mitad, stove, water pumps, schools, churches, and health centers) for Alefa Kacha Village were considered. The result showed that there is 88% excess energy from Hp site8 to supply other villages in addition to Alefa Kacha. Based on the estimated total technical ROR hydro potential of Gilgel-Beles River 660.01Kw technical power and 5608.222MWh annual energy was determined. The amount of coal or wood that can be saved per year as a result of the energy produced by the potential Micro Hydropower of Gilgel-Beles River is also determined. Finally, 9 sites were identified and a ranking of hydropower sites has been done for decision-makers to make a reasonable decision as to which sites should be given the top priority for future micro hydropower development.

1. Introduction

Electricity energy glows up our homes, runs all sorts of machinery in industrial facilities, and plays a vital role in making our lives comfortable. Over the years, different methods have been developed to harness electrical energy. Harnessing electrical energy from coal, oil, gas, steam, and water are some common methods that have been in use in previous years. Hydropower energy, Wind energy, Biomass energy, solar energy, and nuclear energy are some of the improvements which have become popular sources of energy in recent years (Panwar et al. 2011).

Hydropower has among the best transformation efficiencies of all known power energy sources (Tamrat, B. 2007). It requires a comparatively high initial capital cost but has a long life with very low operation and maintenance costs (Yüksel, I. 2010). To address the power supply in remote areas of the country on spot hydropower production is better to minimize idle power cable installation from the main power source due to the scarce dwelling pattern of Ethiopia (Yüksel, I. 2010). For villages very far from the national grid where connection to it may not be economical and for which a constant stream flow is available, micro-hydro power systems are the best options for electrification (Abebe Tilahun, 2011).

Rural electrification has the advantage of, raising the income level of the rural population, reduction of firewood consumption and consequently decreasing deforestation and soil degradation, upgrade local industry and creating job opportunities for rural residents, and mitigating population drift towards urban areas (Cook, P. 2011). But, so far, the government of Ethiopia is mainly focused on medium to large-scale hydropower projects rather than constructing micro-hydropower projects, and encouraging private sectors in this area is neglected (Degefu et al. 2015). Providing grid connectivity from the main station to the rural society is not cost-effective (Aggidis et al. 2010).

Due to many factors, the task of extending the grid to the societies to have access to electricity is not easy in the study area. So, the main focus of this study is to assess the micro-hydropower potential assessment on the Gilgel Beles river. This study will identify and pinpoint potential sites on the map using ArcGIS software on River and ranking potential sites. Hence, this research is intended to assess micro-hydropower in the Gilgel-Beles River using the following basic steps. First, by using 12.5m by 12.5m DEM the potential sites are determined by HEC-GEOHMS, and then for three selected sites primary data like head, and location of the micro-hydropower station and secondary data including rainfall and flow data of river collected from the ministry of water and energy office; Secondly, flow estimation of the river; thirdly, deep assessment of hydropower sites will be carried out; fourth, electric load analysis of one selected potential site is evaluated.

2. Materials And Methods

2.1. Description of the study area

The geographical coordinates of the Gilgel Beles River watershed lie between 1223615.18 m to 1245372.67 m North latitudes and 209380.53 m to 266,030.49 m East longitudes. Gilgel Beles river starts downstream of the highlands of Dangila town south and west direction at approximately 2497meter above sea level. The river is part of Abay Basin and it covers big catchment areas ranging from the highlands of Dangila Woreda in Amhara regional state to the lowlands of Pawi woreda of Benishangul regional state at an outlet elevation of 1010m above sea level. The longest flow path distance to the outlet amounts to 50.5 km (Figure 1). Mostly the rainfall in Gilgel-Beles Catchment is concentrated in May to September period with virtual dry from November up to February. The catchment receives an annual average rainfall of 1799.98 mm (Alemayehu et al. 2006).

2.2. Data Collection

2.2.1. Primary Data Collection

During the field survey, primary data is collected through direct measurement (of the head) for three micro hydropower potential sites of Gilgel-Beles river, image to show river channel characteristic and waterfall of selected MHP sites. For the village around Gilgel-Beles river, called Alefa Kacha there is no clean water supply they are seeking for clean water to avoid water-borne diseases and to save their time for fetching water a long distance. To overcome this problem the local people, have an intention on the rural pipe system. Therefore, in this area, 3 surface pumps are assumed to be used to pump the water from the source to the tanker and distributed by gravity to the community. These collected data are used as input data to the HOMER model for simulation.

2.2.2. Secondary Data Collection

The Secondary data collected for this thesis were the flow rate, DEM from earth explorer, the population of some villages in the watershed, road and administrative map of Ethiopia, and land use shapefiles. The flow rate of the river is collected for many years by the Ministry of Water Irrigation and Electricity (MoWIE) of Ethiopia and the Digital Elevation Model file, land use shape, road, and administrative map of Ethiopia are collected from Amhara Design and Supervision Works Enterprise (ADSWE) land-use experts. The flow data consists of more than 33 years of record.

2.3. Material and tools Used and their application

Different tools were used for the preparation and analysis of the collected data.

Google earth engine:- Google earth used to visualize the study area in the office before fieldwork. It is also used to a rough estimate of the head, slope, access road of the study area, dwelling pattern of the area, and population density.

Global mapper:- Generate contour of the watershed by using DEM file of Ethiopia and overlay the streamflow (reach shape file extracted by arc hydro) of Gilgel-Beles river. Then used to chuck out head determined by HEC-GEOHMS river profile tool and sometimes it is used to select the feasible stream reach site for hydropower potential development, which contains a feasible stream reach with a maximum distance of 500m.

ArcGIS:- Was used for the processing of land use, satellite-derived DEM. It was used to generate flow direction map, flow accumulation map, slope map, stream map with the help of extension tools.

Microsoft word and excel:- MS Word and Excel were used for data preparation and analysis.

Arc Hydro:- The ArcGIS Hydro data model delineates geospatial and time-based data on surface water resource features of the landscape (Manual 2020).

HEC-GEOHMS 10.3:- HEC-GEOHMS uses ArcGIS and Spatial Analyst tool to develop several hydrologic modeling inputs. Analyzing digital terrain information transforms the drainage paths and watershed boundaries into a hydrologic data assembly that represents the watershed response to precipitation, manage and process the basin and reach of the watershed by tools (river profile tool, identifying contributing area tool, sub-basin divide tool, add project point tool).

HOMER:- The micropower optimization model, simplifies the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications (Lambert 2004). HOMER's optimization and sensitivity analysis algorithms make it easier to evaluate the many possible system configurations. To use HOMER software, one can deliver the model with inputs, which describe technology options, component costs, and resource availability. HOMER also displays simulation results in a wide variety of tables and graphs that help us compare configurations and evaluate them on their economic and technical merits. It stimulates the achievement of a system by making energy balance calculations for each of the 8,760 hours in a year.

2.4. Hydrologic Data Analysis

For the development of any hydropower scheme, an essential first step is to determine whether there is an appropriate and consistent amount of water to make the scheme economically viable, (Kumar, 2015). European Small Hydropower Association ESHA (2004) also explains that for an ungauged watercourse, where observations of discharge over a long period are not available, it must be involved with the science of hydrologic analysis. Therefore, the relevant hydrological data collected from different sources for the Gilgel-Beles watershed should be checked for its quality before further analysis and simulation are going on. Data quality control involves in this study for estimation of missing data, consistency test, homogeneity test, and trend analysis of flow data in the study area (Figure 2).

2.5. DEM Analysis to generate head

The DEM needs to be processed to generate the stream network and delineate the watershed of the study area, which in this case is the Gilgel-Beles River Basin. Arc Map 10.3 was used for this purpose with Arc Hydro and HEC-GEOHMS Toolsets.

Fill Sinks: If a cell is surrounded by greater elevation cells, the water is locked in that cell and cannot flow. The Fill Sinks function modifies the elevation value to eliminate these difficulties.

Flow Direction: The Flow Direction function (Terrain preprocessing menu) takes a grid ("Hydro DEM" tag) as input, and calculates the equivalent flow direction grid ("Flow Direction Grid" tag). The values in the cells of the flow direction grid indicate the direction of the steepest descent from that cell (Figure 4).

Flow accumulation

Flow direction grid processed before used as input to computes the associated flow accumulation grid that holds the accumulated number of cells upstream of a cell, for each cell in the input grid (Figure 5).

2.5.1. Head determination by using river profile

The river profile is created by extracting elevation values from the terrain model along the streamline. Creating the river profile can be performed using the river profile tool of HEC-GEOHMS (Table 1). These river profiles clearly show the head drop off the channel of the river within a certain distance interval along the river channel (Figure 6 & 7).

The head at hp site8 is the sum of the head available at the position of the waterfall within 200m length (Figure 6) and the head available downstream of the waterfall along 250m length (Figure 7). Thus, adding the head available at two river profiles gives 152.5m with a total waterway length of 450m.

Doing the same thing to all river layers of the watershed the head of all the reach is determined by considering: -

1. The minimum distance between two successive sites should not be less than 1000 meters to ensure that sufficient gap between the infrastructures of one site to the other.
 2. Head greater than or equal to 10 meters, so that adequate power is produced even for minimum flows.
 3. L/H [ratio between waterway length (L) and total head (H)] sites with a smaller L/H value are more advantageous for MHP.
- (Figure 8) displays the relation of the ratio between the gross head (H) and the channel length (L) (L/H) among existing small-scale hydropower sites. As clearly indicated in figure 8, the L/H of micro-hydro is generally not higher than 40 or is an average of 25 (Jemal, 2016).

2.5.2. Contour Line Extraction of Study Area by Global Mapper

The global mapper can generate watershed, contour, and show the river profile by 3D path profile and edit and view the attribute using digitizer tool. For this study, river reach is generated with the arc hydro tool of the GIS and export the file to shapefile and overlay with DEM file in global mapper interface. Extracted contour lines have an interval of 5m and ranging between the minimum elevation at the powerhouse location (at turbine setting) and the maximum elevation at the diversion of intake into the penstock (Figure 9 & 10). These extracted contour lines were used for preliminary feasibility studies of potential hydropower sites to determine hydraulic head drop within the study catchment for estimation of the in-stream power at the site of interest.

Hand-held GPS reading at three MHP potential sites of Gilgel-Beles River was taken to validate the HEC-GEOHMS river profile head determination techniques (Table 2). There is some head difference between GPS reading and the HEC-GEOHMS river profile reading. This sample GPS reading was used to correct the other potential sites by calculating the head difference between HEC-GEOHMS river profile reading and GPS reading. And this head difference is taken as an error of the river profile head determination method. Then after the error magnitude between contour map and total station reading is known, the other six sites head measurement gap in the HEC-GEOHMS river profile head determination method was adjusted using average error values of three GPS readings.

Table 1
HEC-GEOHMS river profile head determination result

Site name	Latitude	Longitude	Elevation @Intake	Elevation @turbine	Available Head(m)
hp site1	36°21'31.56"E	11° 9'31.79"N	1039	1023	16
hp site2	36°32'55.65"E	11° 8'28.90"N	1328.7	1316.4	12.3
hp site3	36°31'5.43"E	11° 8'21.65"N	1310	1292.5	17.5
hp site4	36°30'12.08"E	11° 8'23.78"N	1275.5	1259	16.5
hp site5	36°33'23.16"E	11° 7'49.24"N	1388	1344	44
hp site6	36°24'29.66"E	11° 9'43.72"N	1087.5	1062.5	25
hp site7	36°25'55.99"E	11° 9'3.48"N	1132.5	1108	24.5
hp site8	36°35'49.11"E	11° 6'58.56"N	1770	1617.5	152.5
hp site9	36°22'53.53"E	11°10'32.23"N	1072	1058.2	13.8

Table 2
Handheld GPS reading at 3(three) MHP sites of Gilgel-Beles river and error estimation

Site name		U/S GPS reading	D/S GPS READING	Head from GPS reading	Head from river profile	Error ± (m)
site 8	X	237661	237399			
	Y	1229766	1229549			
	Z	1774	1623	151	152.5	-1.5
site 1	X	211378	211060			
	Y	1234698	1234753			
	Z	1038	1024	14	16	-2
site9	X	213882	213791			
	Y	1236535	1236810			
	Z	1070	1058.2	11.8	13.8	-2
Average						-1.83

The average GPS survey measurement error value from three hydropower sites in this study is -1.83 meters. These average error values are used to adjust the remaining six hydropower sites head drop by subtracting the average error values on the previous head values from the HEC-GEOHMS river profile reading (Table 3).

Table 3
Corrected head after error
adjustment

Site name	Corrected head (m)
hp site1	14
hp site2	10.47
hp site3	15.67
hp site4	14.67
hp site5	42.17
hp site6	23.17
hp site7	22.67
hp site8	151.00
hp site9	11.80

2.6. Streamflow data

To determine the hydropower potential of a site, the availability of recorded streamflow data for a long period is required. But most of these hydropower potential sites may not be at the stream gauge station. Therefore, to transfer the flow data to the point of interest some mathematical equation is utilized. The standard drainage area ratio method is the best technique used for transferring streamflow from gauged sites to ungauged sites (Smakhtin, V.Y., and Masse, B., 2000 and Mohamoud 2010) (eq 1) and (Table 4).

$$Q_u = Q_g (A_u/A_g) \dots\dots\dots 1$$

Where: - Q_u is the estimated daily streamflow at the ungauged or destination site; Q_g is daily streamflow at the gauged site or source site; A_g and A_u are the drainage areas of the gauged and the ungauged sites, respectively.

2.6.1. Contributing Area Calculation at Point of Interest to transfer flow at the ungauged site

To determine the flow rate for each hydropower potential site the area at the point of interest must be first calculated by using HEC-GEOHMS with Arc Hydro tool. HEC-GEOHMS uses the output of terrain preprocessing of the watershed which is done by the Arc Hydro tool to generate the HEC-GEOHMS project. After the project is generated in HEC-GEOHMS Basin Processing, Stream Processing and Watershed Characteristics are done to start a project and taking it through the HEC-GEOHMS process. In the Gilgel-Beles watershed, all hydropower sites are found upstream of the gauging station and the area is determined by Click on a stream section (river layer) in the map to open contributing area (Figure 11).

Table 4
Area ratio of the ungauged site to gauged station

Site name	Contributing area to the ungauged site (km ²)	<i>Contributing area at ungauged site</i> <i>Stream gauged area</i>
hp site1	735.55	0.99
hp site2	478.98	0.65
hp site3	490.82	0.66
hp site4	498.53	0.67
hp site5	451.78	0.61
hp site6	637.45	0.86
hp site7	663.15	0.89
hp site8	412.85	0.56
hp site9	668.78	0.90
Stream gauged station area	741.0779	

2.6.2. Flow-Duration Curve

The long-term flow is converted to a flow duration curve simply by taking all the flow records over many years and assigning them with the maximum figures on the left and the lower figure placed progressively over to the right (JICA 2009). The flow duration curve computation technique in Gilgel-Beles river was organizing the mean monthly flow values throughout the documented duration of 33 years from 1982 to 2014 and streamflow duration curves were prepared for all the identified potential sites by using We bull's method in the Microsoft excel following the next four steps (Kumar, 2015) (eq 2) and (Figure 12).

$$P = \left(\frac{m}{N+1} \right) * 100\% \dots\dots\dots 2$$

Where, P = Probability that a given flow will be equaled or exceeded (% of the time), m = Ranked position on the listing, N = Number of months for the period of record (dimensionless).

2.6.3. Estimation of Discharge for Power Generation

The design discharge may depend on the economic value of the project and the necessity for power generation. For instance, if a scheme has to be constructed in isolated mode the design discharge will be taken at higher dependability (90–95%) as the power has to be generated and distributed to local areas throughout the year, or a maximum period in a year. On the other hand, if the scheme is grid-connected in that case the design discharge may be taken at lower dependability (say 60%, 70%), provided it is economically feasible (ESHA, 2004). The design discharges for this study are considered as 90% of 90% (0.1m³/s) dependable flow and 10 % of 90 % dependable flow has been left for environmental reasons.

2.7. Stream power potential estimation methods

2.7.1. Theoretical power potential estimation method

Theoretical power is the power that is generated using “ideal” hydro system assumptions. The theoretical power (P) available at all selected sites in the Gilgel-Beles stream is estimated using (eq 3), (Mehari, 2017).

$$P_i = \sum_{j=1}^n (g p H_j Q_{ij}) \dots\dots\dots 3$$

Where, H_j= gross head for plant j, i=is index for flow percentiles (30, 40..., 100), j= index for proposed plants = 1, 2, 3 ...n, n=total number of plants, Q_{ij}= discharge at percentile i and plant j, P_i= is power at percentile i for plant j (kw), g =earth gravity (9.81m/s), p= Density of water (1000kg/m³)

2.7.2. Methods of Turbine Type Selection for small Hydropower schemes

Head, Design discharge, and the theoretical power output from design discharge for each site were used to select the turbine applicable to the feasible site (Table 5).

Table 5
Head and Discharge @ Q90 m³/s for Gilgel
Beles river

Site	Head m	Discharge @ Q90 m ³ /s
site1	14.00	0.53
site2	10.47	0.34
site3	15.67	0.35
site4	14.67	0.36
site5	42.17	0.32
site6	23.17	0.46
site7	22.67	0.48
site8	151.00	0.3
site9	11.80	0.48

By considering the available head and discharge for the selected sites cross-flow and Pelton turbines are selected. Pelton turbine is used, when the flexibility of discharge varies 40% up to 100% of the design value (Data 2003).

Table 6
System efficiency of selected sites

Site name	Suggested turbine set	Efficiency of turbine	Efficiency of generator	Efficiency of transformer	Channel efficiency	Penstock efficiency	Efficiency of line	Efficiency of driver system	Efficiency of civil work	System efficiency
site1	Cros-flow	0.77	0.95	0.98	0.95	0.9	0.95	0.97	1	0.5648
site2	Cros-flow	0.77	0.95	0.98	0.95	0.9	0.95	0.97	1	0.5648
site3	Cros-flow	0.77	0.95	0.98	0.95	0.94	0.95	0.97	1	0.5899
site4	Cros-flow	0.77	0.95	0.98	0.95	0.94	0.95	0.97	1	0.5899
site5	Cros-flow	0.77	0.95	0.98	0.95	0.94	0.95	0.97	1	0.5899
site6	Cros-flow	0.77	0.95	0.98	0.95	0.94	0.95	0.97	1	0.5899
site7	Cros-flow	0.77	0.95	0.98	0.95	0.9	0.95	0.97	1	0.5648
site8	pelton	0.82	0.95	0.98	0.95	0.94	0.95	0.97	1	0.6282
site9	Cros-flow	0.77	0.95	0.98	0.95	0.9	0.95	0.97	1	0.5648

2.7.3. Technical power potential estimation method

The technical power potential of the hydropower system is the power output by considering overall system efficiency (Table 6) and (eq 4).

$$P_{\text{net}} = P_{\text{gross}} \times \eta \dots \dots \dots 4$$

Where: P net is the net technical power (KW), P gross is the gross theoretical power (kW), η is the overall efficiency of the hydropower scheme.

Firm capacity:- Is defined as the power that can be delivered by a specific plant during a certain time with at least 90 –95% certainty and an important factor to show hydropower plant power availability is the firm capacity which is the guaranteed amount of power available during a specified period for production or transmission (Mehari 2017).

2.7.4. Annual Energy Production Capacity Estimation Method

The annual power is calculated by assuming 97% of the operational time in a year, 3% time is left for breakdowns, maintenance, and nonoperational periods. This figure is important to note the amount of coal saved annually (Sahu 2015). It is also predicted how many people are served by Gilgel-Beles river hydropower energy (eq 5).

Annual Power generation = $0.97 \times P_p \times 24 \text{ hours} \times 365 \text{ days}$5

2.8. Design and Simulation with HOMER software

HOMER is a free software of micropower optimization model developed by the National Renewable Energy Laboratory in the United States (Kassam, 2010). While designing a power system one needs to choose what components to add, the size and number of the components to be used, which technology concerning price and accessibility from the several accessible technologies (Abebe Tilahun, 2011).

When designing with HOMER it is first necessary to create a new model and add equipment's to be considered to give the new model created with inputs such as the technology options available (wind, solar, hydro, etc.), component cost, and resource availability (for example flow rate, head for hydro resources) and the type of load to be used (primary and deferrable load). In the optimization process, HOMER simulates various diverse system configurations in pursuit of the one that fulfills the practical constraints at the lower life cycle cost.

2.8.1. Load estimation and scheduling

Gilgel-Beles river has many micro hydropower potential sites but to estimate the load profile of one village is considered to simulate with homer software. The selected site is hp site 8 near Alefa Kacha village and the population and relevant data are collected at the Woreda plan and commission team and by asking the local people during the site visit. Homer software will simulate only a microgrid system, the total population of Alefa Kacha village is 7002 people (Central Statistical 2012). By using the number of households in the village and using a typical household utilization that these people may use; this section discusses how the load profile of the village is obtained (Table 7, 8, 9, and 10).

Domestic load: - *Domestic* load refers to household demand as per this research and while calculating energy demand of the base year it was supposed that all the households cannot have all the utilizations listed down at one time and hence some percentage was fixed for computing energy. For example, 40%, 70%, 30%, 7% of the households will have Television, radio, stove, and injera Mitad respectively at the base year (Tolcha, 2016).

Table 7
Domestic load of Alefa Kacha village

No	Power Consumption	Power (watt)	Qty	Load (kW x qty x No. of H. hold)	hr/day	kWh/day
1	lightning	11	3	38.511	5	192.555
2	tv	80	1	93.36	5	186.72
3	radio	5	1	5.835	6	24.507
4	stove	1000	1	1167	2	700.2
5	Injera Mitad	2500	1	2917.5	0.3	61.2675
6	Miscellaneous	5		5.835	24	140.04
Total No. of household		1167				
Subtotal		1305.2895				

Public service loads: - This demand category includes the water requirements of all schools, health centers, public facilities government offices, churches, mosques, Restaurants, etc. (Tables 8).

Table 8
School electric load

School	No	Power Consumption	Power (watt)	Qty	Load (kW x qty x No. of H. Hold x Df=0.7)	Hr/Dy	kWh/day
	1	Class room lighting	15	47	0.4935	3	1.4805
	3	Teachers' residence lighting	11	26	0.2002	5	1.001
	4	Computer and Accessories	60	27	1.134	6	6.804
	5	Miscellaneous	30		0.021	24	0.504
	sub total				1.8487		9.7895

Table 9
Church electric load

Church	No	Power Consumption	Power (watt)	Qty	Load (kW x qty x No. of H. hold x Df=0.5)	Hr/Dy	kWh/day
	1	lighting (4 indoor 4 external lighting)	15	80	0.6	3	1.8
	3	microphone	10	10	0.05	3	0.15
	5	Miscellaneous	30		0.015	24	0.36
	sub total				0.665		2.31

Table 10
health center electric load

health center	No	Power Consumption	Power (watt)	Qty	Load (kW x qty x No. of H. hold)	Hr/Dy	kWh/day
	1	indoor lighting	13	30	0.39	12	4.68
	2	external lighting	36	4	0.144	12	1.728
	3	refrigerator	120	1	0.12	6	0.72
	4	Computers	60	1	0.06	8	0.48
	5	Ceiling fan	40	10	0.4	8	3.2
	7	Television	70	1	0.07	8	0.56
	8	laboratory	1000	1	1	8	8
	9	Miscellaneous	30		0.03	24	0.72
	sub total				1.114		20.088

From the above calculation, the overall total load is 1332kWh/day and the average 55.54kw load will be consumed by Alefa Kacha village domestic and public service demands in the village.

Deferrable loads:- Deferrable load is an electrical demand which could be happened anytime within a certain period, its exact timing is not significant (Tolcha, 2016). To allocate water to the users of rural communities, pumping to the tanker and then distributing it from the reservoir by using gravity is recommended (Tolcha, 2016). To perform this task enough pressure must be consumed at the water reservoir to distribute water by gravity. The community is assumed to use Water pumping systems for water supply. A minimum of 100 liters of water per day per family and 2500 l/day for schools, health centers, and churches are suggested. To accomplish this, 3 pumps of 250 W (with a capacity of 2.38L/s) operating for 4 hours/day are to be installed to supply water for the community, school, health center, and churches. In the rainy season from June to October up to 30%, the deferrable load can be estimated to decrease because water consumption from the pumps is expected to be shared by river and rainwater ponds (Dahmen&Hall 1989).

2.8.2. HOMER model of the systems

While simulation is carried out for the hp site8 with a single hydro case, there is excess electric production. Therefore, no need to consider other energy sources to supply the considered load. River's flow rate data and head drop, Metrological data for 33 years annual average for each month, Primary and deferrable loads, the Equipment cost for them regarding a resource, are the major inputs given to the HOMER software. After all the vital inputs are done to the software, HOMER simulates and gives a list of viable results arranged by net present cost (Figure 13, 14, and 15).

HOMER adds randomness based on the baseline data entered for daily noise and hourly variability. This random variability comes up with more realistic load demand. For this study, the randomness is made 15% daily and 20% hourly (Figure 16).

2.9. Ranking of sites

To simplify a favorable condition for local decision-makers to make a reasonable decision as to which sites should be given the top priority for future micro hydropower development project implementation, ranking of the sites is essential (Jemal, 2016). The analytic hierarchy process (AHP), which was developed by Saaty supports decision-makers to assess a problem in the form of a hierarchy of reference a series of pairwise comparisons of relative criteria. Concisely relative weights are resolute through pairwise comparison. This method can be done by breaking down the unstructured composite recorded problems into parts. Subjective judgments on the relative importance of each part are represented by assigning numerical values (Mehari, 2017).

To rank hydropower potential sites of Gilgel-Beles river power output, head, discharge, the ratio between waterway length (L) and total head (H), accessibility, i.e., distance from the access road, distance to the demand center have been considered.

Energy output

- The ultimate wanted result that is looked for from a hydropower potential river site is the energy produced. To fix the rank a site has concerning the others, the ratio of the energy output of that site to the highest of the energy of all sites is considered. For instance, the power production of the site of hp site1 is 40.88kw and the maximum power production from all the sites is 305.87kw. So, the proportion of power production of hp site1 to that of the maximum power of all sites is $40.88/305.87 = 0.134$. This ratio is added to the ratios of other constraints to fix the ranking value of the site.

Energy output - The ultimate wanted result that is looked for from a hydropower potential river site is the energy produced. To fix the rank a site has concerning the others, the ratio of the energy output of that site to the highest of the energy of all sites is considered. For instance, the power production of the site of hp site1 is 40.88kw and the maximum power production from all the sites is 305.87kw. So, the proportion of power production of hp site1 to that of the maximum power of all sites is $40.88/305.87 = 0.134$. This ratio is added to the ratios of other constraints to fix the ranking value of the site.

Discharge: - The MHP energy production is subject to annual flow distribution which occurs at all days and months throughout the year. Hence, MHP without a reservoir can produce energy only from available water and cannot compensate during dry periods. This parameter is used along with the others to fix the rank of the sites. Like that of the energy output, the ratio of the discharge of a site to that of the discharge of all sites is obtained and added to the other ratios so that the ranking value is computed. The maximum design discharge of the site is $0.53\text{m}^3/\text{s}$ which is obtained at Hp site1. Thus, the discharge ratio is $0.53/0.53\text{m}^3/\text{s} = 1$.

Head: - **Head** is a vertical distance between two points (intake and turbine) and it can also be defined as the pressure created by the elevation difference between intake and turbine. The potential energy which makes the turbine revolve when the water strikes it is as a result of the head above the turbine. Therefore, the head is taken as one of the parameters to assess the rank of the sites. The highest head of the sites under study is found to be about 151m. The head of hp site1 is 14m. This makes the ratio to be about 0.093

L/H [ratio between waterway length (L) and total head (H)]: - The ratio between the total head (H) and the waterway length (L) (L/H) of a site is a key parameter on minimizing the cost of micro hydropower. A site with a smaller L/H value is more advantageous for small-scale hydropower. Therefore, L/H is taken as one of the parameters to estimate the rank of the sites. In this case, the ratio is obtained taking into account the smallest L/H, so the inverse ratio of the L/H of the site to that of the minimum of the whole site is taken to add up with the rest ratio, for hp site1, $L/H=33.93$ & the minimum L/H of all the site is 2.81, so the ratio is $1/ (33.93/2.81) = 0.083$.

Distance from the access road: - Road accessibility proves to be a vital ranking element for potential hydropower sites. It is essential during the whole life cycle of the power plant, for construction, installation of the power plant, maintenance, and dismantling at end of hydropower functional life. In Gilgel-Beles stream, from all selected hydropower sites, hp site 8 has dry season leveled grassland road accessibility which is located near the gravel road from Dangila to Chagni town along the street of Chara and Gisa and hp site1 has the same manner to hp site8 except for hp site1 asphalt road near Gilgel-Beles town. Sites 2, 3, 4, 5, 6, 7, and Site 9 do have not accessibility of road. These sites are far from more than 6km at gravel road with dense forest and very steep slope. The distance of site hp site1 from the nearby road is about 1.3km.

The site which is very near or adjacent to all weathered roads is hp site8 having a distance of 0.978km from the gravel road. The inverse Ratio of this distance of the site of hp site1 to the distances of other respective sites is taken in the evaluation of the rank. For hp site1 the ratio is $1/(1.3/0.978) = 0.747$.

Distance of the site to the demand center: - As much as possible the end-users should be nearer to the hydropower station since expensive transmission lines are not appreciated in MHP installation. The distance of hp site1 from the demand center is about 1.5km. The site which has the shortest distance to the demand center is also hp site1. For hp site1 the ratio is $1/(1.5/1.5) = 1$. The sum of the above five ratios reveals the rank of the site of hp site1(eq 6).

$$R = rE + rQ + rH + rDAR + rDDC + rL/H \dots\dots\dots 6$$

Where: - rE – the ratio of the energy output of a site to the maximum of the energy output of all sites, rQ – the ratio of discharge of a site to the maximum discharge of all sites, rH – the ratio of the head of a site to the maximum of the head of all sites, rDAR – the inverse ratio of the lowest distance of the all sites to the site under consideration (Distance between the site and the nearby road), rDDC – the inverse ratio of the lowest distance of the sites to the site under consideration (distance between the site & the demand center), rL/H:- the inverse ratio of the lowest L/H(ratio between waterway length (L) and total head (H))to that of a site.

3. Results And Discussion

3.1. Head, contributing area, and reach the length of selected sites

The head with drop head greater than 10m, head (H) to waterway length (L) ratio along the stream less than 40, and feasible stream reach length less than 500m are considered to select the head of the reach for potential hydropower (Table 11).

Table 11
head, contributing area and reaches a length of selected sites

Site name	Latitude	Longitude	Available Head(m)	Distance(m)	L/H	Area Km ²
hp site1	36°21'31.56"E	11° 9'31.79"N	14	375	33.93	735.55
hp site2	36°32'55.65"E	11° 8'28.90"N	10.47	250	23.89	478.98
hp site3	36°31'5.43"E	11° 8'21.65"N	15.67	125	7.98	490.82
hp site4	36°30'12.08"E	11° 8'23.78"N	14.67	150	10.23	498.53
hp site5	36°33'23.16"E	11° 7'49.24"N	42.17	375	8.89	451.78
hp site6	36°24'29.66"E	11° 9'43.72"N	23.17	225	9.71	637.45
hp site7	36°25'55.99"E	11° 9'3.48"N	22.67	325	14.34	663.15
hp site8	36°35'49.11"E	11° 6'58.56"N	151.00	450	2.81	412.85
hp site9	36°22'53.53"E	11°10'32.23"N	11.80	259	21.95	668.78

3.2. Flow-Duration Curve

This is also a planning tool to decide the size of the turbine to be installed indicating the required variable flow performance of the turbine and the plant factor constraints which will result from any specific choice of turbine size (JICA 2009).

The flow duration curve developed for the Gilgel-Beles river is shown below to select the design discharge at Q_{90} for micro hydropower scheme development of all potential sites with discharge value greater than or equal to 0.1m³/s (Mehari, 2017) (Figure 17 and 18).

All the flow-duration curves show the comparable characteristic of sharp drop at the end of FDC. This indicates that the dependable flow decreases sharply with growth in the demanded degree of trustworthiness. This affects the choice of applicable installation capacity of the power plant due to low flow during the dry season. Discharge for maximum power with a maximum period in a year may be generated power efficiently is the design discharge. The design discharge may depend on the economics and the requirement for power generation. For this study, minimum flows data are taken at 90% time exceeded to assure of the smallest kWh. The flow at Q_{90} of hydropower potential site Gilgel-

Beles is shown in (Table 12). The design discharges for the study are considered as 90% of 90% dependable flow and 10 % of 90 % dependable flow has been left for environmental reasons.

Table 12
Discharge Available for Power Generation

Site Name	Q ₉₀ m3/s	Discharge Available for Power Generation (m3/s)
hpSite1	0.59	0.53
hpsite2	0.38	0.34
hpsite3	0.39	0.35
hpsite4	0.40	0.36
hpsite5	0.36	0.32
hpsite6	0.51	0.46
hpsite7	0.53	0.48
hpsite8	0.33	0.30
hpsite9	0.53	0.48

3.3. Estimation of Power Potential of the identified Sites

Results from the hydrological analysis, topographical data, and efficiencies of various MHP structures were used to quantify the power potential generation (Table 13).

Table 13
Theoretical Power Potential and Technical Power Potential (kW) of all Gilgel-Beles river

Site name	Head(m)	Discharge Available for Power Generation (m3/s)	Theoretical Power Potential(kw)	System efficiency	Technical Power Potential(kw)
hpSite1	14	0.53	72.38	0.56	40.88
hpsite2	10.47	0.34	35.24	0.56	19.90
hpsite3	15.67	0.35	54.05	0.59	31.88
hpsite4	14.67	0.36	51.40	0.59	30.32
hpsite5	42.17	0.32	133.90	0.59	78.99
hpsite6	23.17	0.46	103.80	0.59	61.23
hpsite7	22.67	0.48	105.66	0.56	59.68
hpsite8	151.00	0.30	486.88	0.63	305.87
hpsite9	11.80	0.48	55.32	0.56	31.25
Total					660.01

A perusal of (Table 13) clearly shows that the overall power potential for 9 potential sites in the Gilgel-Beles river is 660.01 KW. Thus, in Gilgel-Beles River According to the Classification of Hydro Power plant one site (hp site8) fall under Mini Hydropower (more than 100 KW but less than 1 MW) with a total potential of 305.87 KW and the rest 8(eight) sites under micro-Hydropower (more than 10 kW but less than 100 kW) with a total potential of 354.14 KW (ESHA 2004 and Kumar 2015).

3.4. Annual Energy Generation

The total annual energy output of all sites is calculated using equation 3.10 to show Gilgel-Beles river hydropower potential annually (Table 14).

Table 14
annual power generation

Site name	Head(m)	Discharge Available for Power Generation (m3/s)	Theoretical Power Potential(kw)	System efficiency	Technical Power Potential(kw)	Annual Energy generation (MWh)
site1	14	0.53	72.38	0.56	40.88	347.39
site2	10.47	0.34	35.24	0.56	19.90	169.12
site3	15.67	0.35	54.05	0.59	31.88	270.93
site4	14.67	0.36	51.40	0.59	30.32	257.62
site5	42.17	0.32	133.90	0.59	78.99	671.21
site6	23.17	0.46	103.80	0.59	61.23	520.32
site7	22.67	0.48	105.66	0.56	59.68	507.08
site8	151.00	0.30	486.88	0.63	305.87	2599.04
site9	11.80	0.48	55.32	0.56	31.25	265.50
Total					660.01	5608.222

A perusal of results in (Table 14) shows that the entire annual energy generation from 9 potential sites Gilgel-Beles River will be 5608.22MWh. Based on local load estimation done in section 3.8.2 for Alefa Kacha village 5608.22MWh will serve 13452 households having the same load profile as Alefa Kacha village without considering deferrable load. If the housed hold demand satisfied their energy demand from thermal power plants (wood, coal, and other gas-emitting sources), the system would produce a considerable number of gases. Based on an investigation performed by M.Mittal the average power generated per ton of coal in Indian thermal power plants is 2640 KWh (Sahu, 2015), (eq 7).

$$\text{Thus, the amount of coal saved} = \frac{5608222 \text{ KWh}}{2640 \text{ KWh}} = 2124.33 \text{ ton} \text{-----} 7$$

Therefore, a minimum of 2124.33 tons of coal or wood can be kept per year as a result of the power produced by the potential MHPs. This renewable hydro resource reduces the emission of greenhouse gases produced by the burning of coal or wood. Coal contains more carbon and some amounts of other components, such as hydrogen, sulfur, oxygen, and nitrogen. Consequently, the burning of coal produces greenhouse gases of carbon dioxide, sulfur dioxide, and oxides nitrogen. As a result of reducing the consumption of 2124.33 tons of coal, the emission of this gas could be minimized (Table 15).

Table 15
Greenhouse gas emission per KWh
production in thermal power plants
(Sahu, 2015)

S.no	Gas	Emission per kWh
1	CO ₂	1.1 kg/KWh
2	SO ₂	8 g/KWh
3	NO _x	2.1 g/kWh

Emission of CO₂=5608222*1.1kg/KWh=5165831Kg=5165.831ton,

Emission of SO₂=5608222*0.008kg/KWh=44865.77Kg=44.866ton

Emission of NO_x=5608222*0.0021kg/KWh=11777.265Kg=11.778ton

Therefore 2124.33 tons of coal emits 5165.8 tons of CO₂, 44.866 tons of SO₂, 11.778 tons of oxides of nitrogen. Hence if 5608222 kWh of coal is replaced by a renewable source of energy then corresponding quantities of greenhouse gas emission can reduce 2124.33 tons of coal. Consequently, this can reduce the rate of widespread air pollution.

3.5. HOMER Simulation results and discussion

After the HOMER simulation, the simulation result indicates that hp site8 can Supply the nearby villages of Alefa Kacha kebele safely and constantly without any additional sources. The hydro turbine output is 4,018,758kWh/yr while the total primary and deferrable load is 483,123 kWh/yr which leads to surplus electricity of 3,535,821kWh/yr which is around 88% of the production capability (Figure 19 & 20).

3.6. Ranking Results of Potential Sites in Gilgel-Beles River

The ranking of sites by considering criteria like head, discharge, power, L/H ratio, distance to the access road, and distance to the demand center hp site8 ranks first and the whole result is shown in (Table 16 & 17).

Table 16
Ranking criteria's

Hp sites	Power	Head	Discharge(m ³ /s) @Q90	L/H	DAR in km	DDC in km	Demand center
site1	40.88	14.00	0.53	33.93	1.309	1.5	Gilgel Beles town
site2	19.90	10.47	0.34	23.89	7.962	6.9	Gisa Kansen
site3	31.88	15.67	0.35	7.98	6.615	3.5	Gumade
site4	30.32	14.67	0.36	10.23	6.732	7	Dek town
site5	78.99	42.17	0.32	8.89	6.304	8	Gisa Kansen
site6	61.23	23.17	0.46	9.71	6.642	3.5	Kutir Hulet &Dek Werkager
site7	59.68	22.67	0.48	14.34	6.495	6.7	Genet Maryam town
site8	305.87	151.00	0.3	2.81	0.978	3.2	Tiru Birhan,tirgi sima and Alefa Kacha
site9	31.25	11.80	0.48	19.07	4.757	1.7	Menjare
	305.87	151.00	0.53	2.81	0.978	1.5	
max				min			

Table 17
Ranking results of hydro potential sites

Hp sites	power	Head	Discharge(M3/S) @Q90	L/H	DAR in km	DDC in km	Rank	Demand center
site1	0.13	0.09	1.00	0.08	0.75	1.00	3.06	2 Gilgel Beles town
site2	0.07	0.07	0.64	0.12	0.12	0.22	1.23	9 Gisa Kansen
site3	0.10	0.10	0.66	0.35	0.15	0.43	1.80	7 Gumade
site4	0.10	0.10	0.68	0.28	0.15	0.21	1.51	8 Dek town
site5	0.26	0.28	0.60	0.32	0.16	0.19	1.80	6 Gisa Kansen
site6	0.20	0.15	0.87	0.29	0.15	0.43	2.09	4 Kutir Hulet & Dek Werkager
site7	0.20	0.15	0.91	0.20	0.15	0.22	1.82	5 Genet Maryam town
site8	1.00	1.00	0.57	1.00	1.00	0.47	5.03	1 Tiru Birhan, Tirgi Sima and Alefa Kacha
site9	0.10	0.08	0.91	0.13	0.21	0.88	2.30	3 Menjare
Nb: DDC* stands for distance to demand center, DAR * distance from the access road								

4. Conclusion

In this study, feasible location of MHP of Gilgel-Beles River is assessed and for Alefa Kacha village near hp site8 load estimation and simulation by homer software and ranking of 9 identified potential sites is performed. Potential heads along the river are found out using the ArcGIS software extension HEC-GEOHMS River profile tool. The flow rate at these locations is also calculated by the area ratio method. From these two factors, the hydropower potential available at those feasible locations is also estimated. FDC for all hp sites has been established to

find out Q_{90} . This Q_{90} is used as the design discharge in the determination of technical power potential. Based on the estimated total technical ROR hydro potential of Gilgel-Beles River 660.01Kw technical power and 5608.222MWh annual energy is determined for 90% flow.

Identified hydropower sites are classified based on their install capacity, so there are one mini and eight micro-scale run-off hydropower potential sites available in the Gilgel-Beles River. For Alefa Kacha village with input data to HOMER, model simulation is carried out. As discussed in section 4.6, the simulation results indicate that the generated energy from hp site 8 can supply more than 7 villages having the same load as Alefa Kacha village. The reduction in wood consumption may minimize greenhouse gases emission from the thermal power plants. Ranking of the site is done based on power output, head, discharge, L/H ratio, and distance from the demand center and access road. As shown in section 4.7 hp site8 is ranked first and the other sites ranked properly for decision-makers.

Declarations

Conflict of interest: We (Authors) must state that we have no known personal relationships that may have influenced the work disclosed in this paper.

Ethical statement: The authors state that the research was conducted according to ethical standards and we declare that this manuscript is original, has not been published before, and is not currently being considered for publication elsewhere.

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Figures

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Figure 19

hydro turbine energy production, consumption, and excess electricity

Figure 20

Hourly primary load, hydropower production, deferrable load, and excess electricity