Abyssinia Journal of Engineering and Computing Abyss. J. Engg & Comput., Vol.3, No.2, 2023, 42-57

Evaluation of the Hydroelectric Power Potential in the Beshilo Sub-basin of the Abay River, Ethiopia

Girum Metaferia Affessa [a*], Tewodros Desale Meselaw [b], Asalf Shumete Eshete [a], Dagmawie Negash Agonafire [a]

[a] Department of Hydraulic & Water Resource Engineering, KIoT, Wollo University Ethiopia.
[b] Department of Water Resource and Irrigation Engineering, KIoT,, Wollo University, Ethiopia.

DOI: https://doi.org/10.20372/ajec.2023.v3.i2.900

ISSN : 2788-6239 (Print)
ISSN: 2788-6247 (online)

*Corresponding Author: girumm121@gmail.com

ABSTRACT

Ethiopia boasts significant hydropower potential, but the country faces a daunting energy challenge, as a majority of its population relies on traditional energy sources. The scarcity of power not only leads to an unappealing living environment but also exposes the populace to the adverse effects of climate change resulting from associated environmental impacts. Many villages lack electricity due to power shortages, emphasizing the need for an energy policy that prioritizes addressing the power deficit. Consequently, assessing additional hydropower potential becomes crucial. This study focuses on evaluating the hydropower potential of the Beshilo River and identifying potential sites using an integrated approach involving Geographic Information System (GIS) and the hydrological model Soil and Water Assessment Tool (SWAT). The SWAT model utilized long-duration real-time hydrometeorological datasets for hydrological data simulation and parameterization. Given the absence of recent recorded data for the Beshilo River, a flow transfer method, specifically the area ratio method, was employed in this study. Daily flow data facilitated the identification of potential hydropower sites within the watershed. The study successfully characterized the entire catchment into various sub-catchments, allowing for the identification of hydropower potential zones and suitable site locations for hydropower stations along the stream network. The model calibration and validation demonstrated a strong correlation between simulated and observed datasets, with R2 and ENS values indicating good model performance (≥0.70). Results revealed a substantial hydropower potential in the lower course of the Beshilo River, with corresponding values at 90%, 75%, and 50% of dependable flow being 2320.26 KW, 8899.63 KW, and 42750.01 KW, respectively. In the middle part of the river, potential values at these percentages were 1395.86 KW, 5369.44 KW, and 21561.83 KW, while in the upper part, they were 529.74 KW, 2074.81 KW, and 12757 KW, respectively

.Keywords: Beshilo river, Digital elevation Model, Geospatial data layers, Hydrological modeling, Hydropower, SWAT

1. INTRODUCTION

Reliable and affordable energy source is the key factor to attain sustainable development in the globalized world. In Ethiopia, the growth of population, increased economic activities and industrialization demands sustainable energy sources. Therefore, looking for alternative renewable energy resources has got special attention and hydropower is among one of the reliable energy resources. Hydropower is a reliable energy source that holds for 60% of renewable energy sources [1].

Ethiopia has a huge amount of energy sources. The gross hydropower potential of the country is estimated as 45,000 MW, which constitutes 20 % of Africa's total technical feasible potential. Ethiopia utilizes less than 5% of its potential so far. It has currently injected huge amounts of money into energy infrastructure for electricity generation from hydropower and other renewable energy sources such as wind, solar and geothermal energy. Currently per capita consumption of the country remains relatively low at 200 kWh/year; this is below the world average of 220 kWh/year [2]. Hydropower's growth is critically coupled with innovation that can enable hydropower resource opportunities to be economically competitive and environmentally sustainable in the context of other low carbon energy options. Keys to improved competitiveness are continued technical innovation to reduce capital and operating expenses, improved understanding and market valuation of system wide grid reliability and stability services and recognition and valuation of social benefits from avoiding power sector air pollution and greenhouse gas emissions [3].

According to a 25-year master plan, EEPCO (Ethiopia electric power corporation) focused on the development of medium and large hydropower plant even though country has Substation Rivers and streams suitable for small scale hydropower development which has an estimated potential 1500 to 3000 MW for micro, mini and small hydropower. If the potential is exploited and put into operation, it could provide a considerable contribution to the energy mix of the country by meeting the power deficit in the national grid and electrifying remote rural areas [4].

However, site selection and developing a hydropower site selection is not a simple task. The assessment of Hydropower potential (HPP) sites for development represents a relatively high proportion of overall projects. There are many aspects which have to be taken into consideration, covering many disciplines ranging from business, engineering, financial, legal and administration. These will all be necessary at the different development stages from first choosing a site until the plant goes into operation and hiring a range of experienced expertise in every discipline is required to conduct such assessment [5].

Therefore, the main use of studying water resources for power potential is important for optimal utilization of the water resources, to enhance the development of a nation and to secure the sustainable development of water resources. From this study, East Amhara especially the new expanding towns and new established industries in the area are more beneficiary.

Beshilo river catchment is very mountainous area, it is better to use the water in this river for Hydropower potential development rather irrigation, the reason why we assess the hydropower potential of the Beshilo river catchment.

2. MATERIALS AND METHODOLOGY

Beshilo river catchment is a tributary of Abbay River, it drains the Abbay River Basin on its upper reach in the north east boundary and found at the junction between the Awash River Basin (ARB) and Abbay River Basin. It starts with the water divide between these basins with mountains and extends with plateau of wet land of the Gerado area and then with very rough mountainous

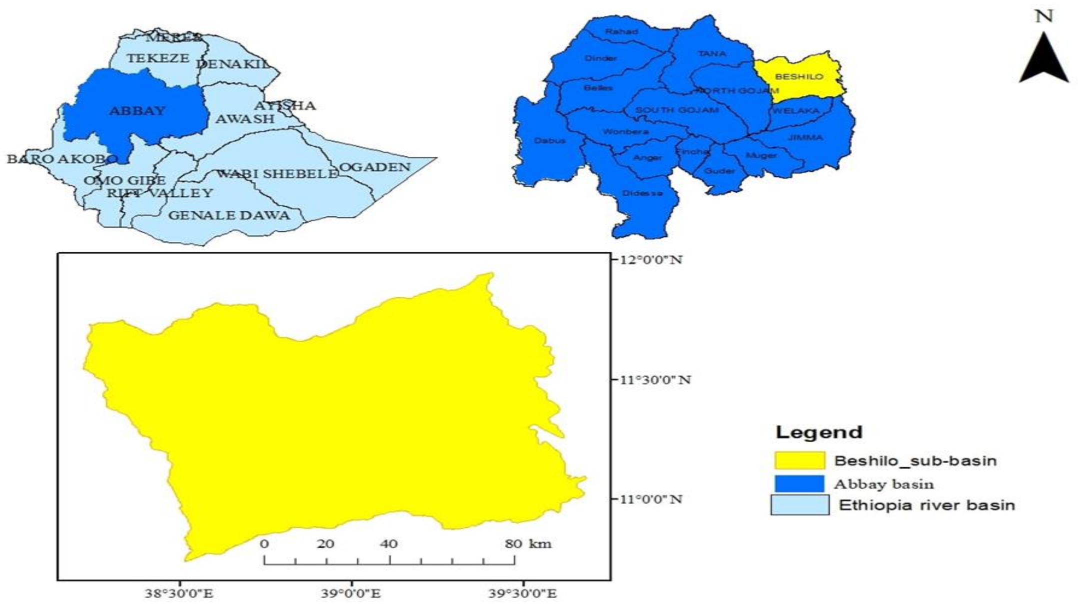

Fig 1. The geographic region of the Beshilo River watershed

regions till, all perennial and intermittent rivers within the study area flows to join the main Beshilo River. The Beshilo River catchment covers an area of 13,242.5 km^2. It originates in the northeastern part of the Abbay River basin in the South Wollo zone, flows southward, and eventually converges with the Abbay River, as depicted in Figure 1

2.1 Climate conditions in the study location

The climate within the catchment exhibits a range from sub-humid to sub-tropical conditions. Annual rainfall in the catchment measures 971.88 mm, with the majority concentrated in the substantial rainy period lasting from July to September. Monthly temperatures fluctuate between 7°C and 22°C, reaching maximum values during March to May, while the mean monthly temperature consistently exceeds 20°C. In the study area, the mean monthly minimum and maximum wind speeds are recorded at 1.3 m/s in January and 2.0 m/s in April, respectively. The monthly mean sunshine hours and ratio exhibit variations ranging from 5.5 to 9.5 and 40.1% to 64.3%, respectively. The rainy seasons are characterized by higher humidity and lower sunshine hours.

2.2 Collecting data in the study area

This hydro potential assessment study using GIS application with SWAT2012 requires some specific data for simulation of flow rates. To meet the objectives of this research, different types of data were collected from both primary and secondary data sources including field data. Secondary data such as census records and unpublished official documents and reports were gathered from offices of Agricultural and Rural Development and Land and Environmental Protection respectively. These data can be categorized as spatial thematic map data and discrete data corresponding to discrete location, including, climatic data, Discharge data, soil type and land use/cover data. Data collected included spatial data, hydrological data, and meteorological data. For this study, daily river discharge data, meteorological data, land use land cover data, and soil map were collected from the concerned organization. The daily river discharge data were collected from Ethiopian Ministry of Water Resources and Energy (MWRE) at records Gumera watershed. Digital elevation model (DEM) data for the study were collected from Ethiopian map agency (EMA).

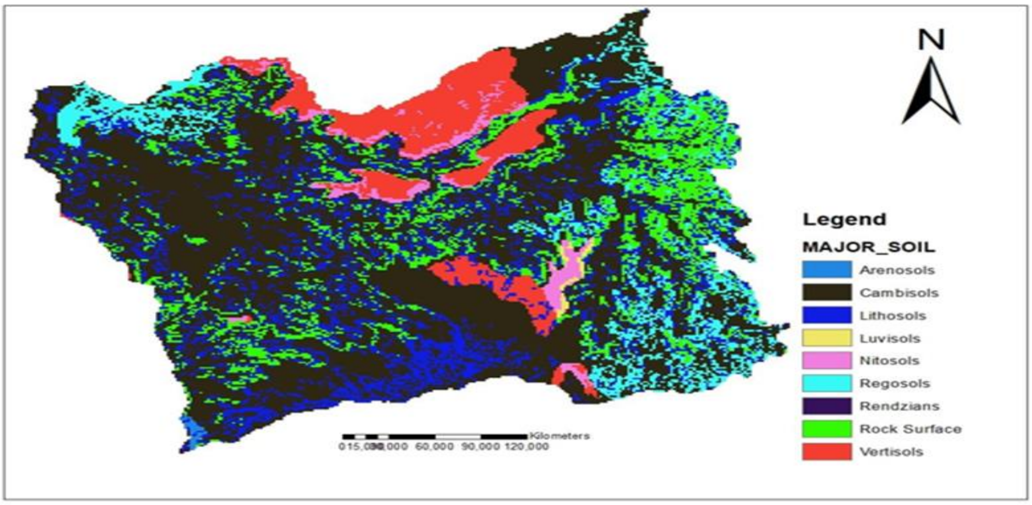

Fig 2. Map detailing the soil composition of the study area

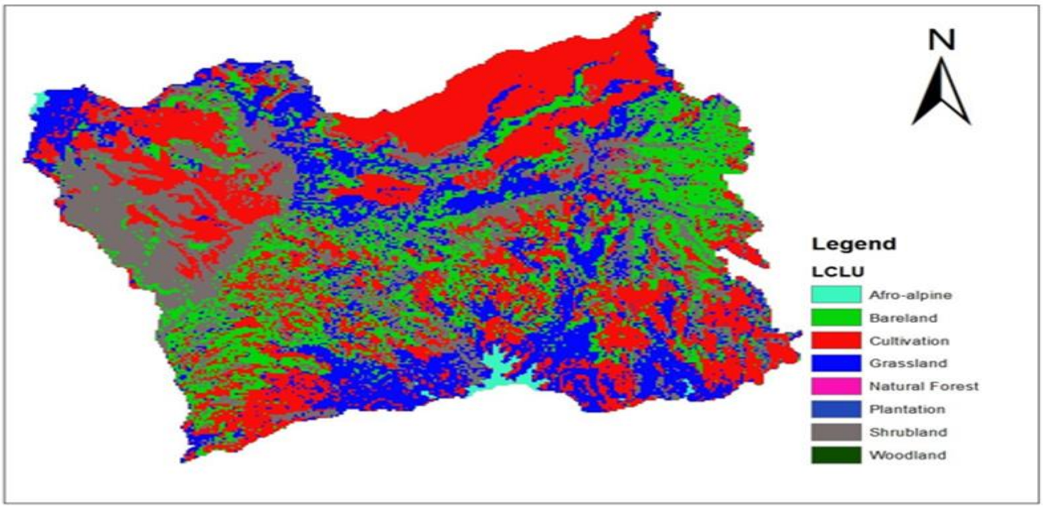

Fig 3. Map depicting the land cover of the study area

Daily meteorological data such as rainfall, minimum and maximum temperature, relative humidity, wind speed and daily sunshine hours were collected from Meteorological Agency of Ethiopia (NMA). Study area and soil composition of study area are shown in Figure 2 and Figure 3 respectively.

2.3 Terrain features and drainage characteristics

Topography: The topography of the Abbay basin signifies two distinct features; the highlands, rugged mountainous areas in the center and western part of the basin and the lowlands in the eastern part of the basin. The topography of the basin ranges from about the lowest about 1124 m.s.l to 4246 m.s.l the highest elevation. 55 % of the total land of the basin has a slope of less than 20 % while the remaining 45 % has greater than 20 percent.

Drainage networks: The whole area of the Basin is intersected by streams, many of which are perennial though highly seasonal in their flow. The primary tributaries of the Basin are the Beshilo River.

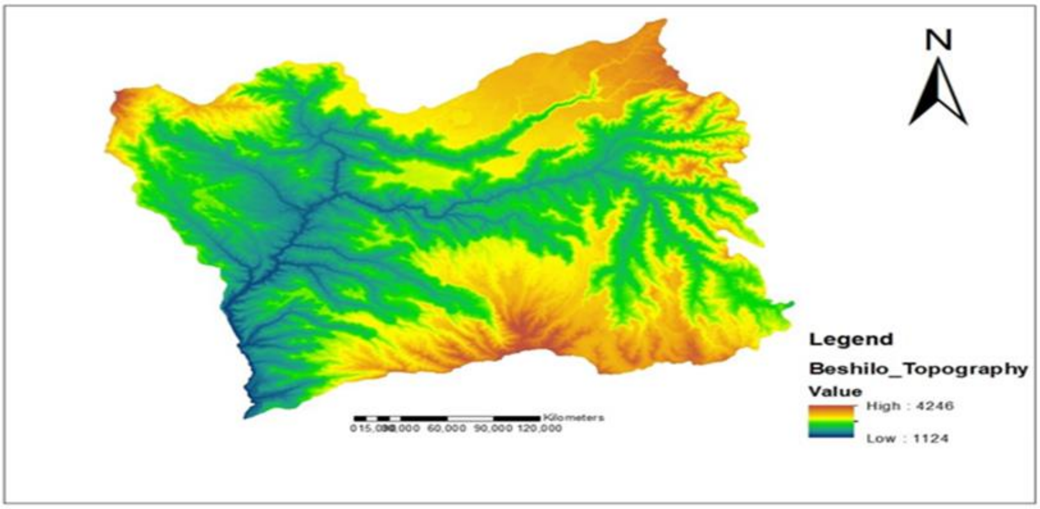

Fig 4. Map illustrating the topography of the study area

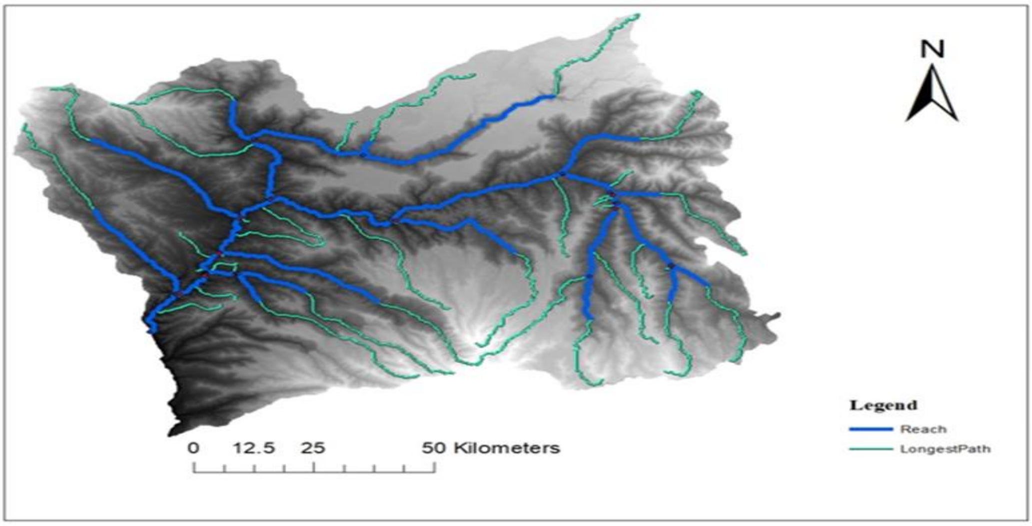

Fig 5. The drainage systems in the study area

2.3.1 Data related to hydrology

Beshilo catchment is one of the major catchments which contributes a significant amount of flow to Abbay River. But the River has not been gauged recently, for this reason the flow data is transferred from the nearest gauging station which has similar watershed characteristics, in this case the nearest catchment is Gumera catchment. The daily streamflow data of Gumera River was obtained from the Hydrology Department of the Ministry of water resources and energy (MWRE). It was used for performing sensitivity analysis, calibration and validation of the SWAT model. Topography and drainage systems in the study area are shown in Figure 4 and Figure 5 respectively.

2.4 Analyzing the data

For the filling of missing rainfall data, there are several methods for estimating missing rainfall data. There are Station average method, normal ratio method, quadrant method, and inverse-distance weighting method, and regression methods.

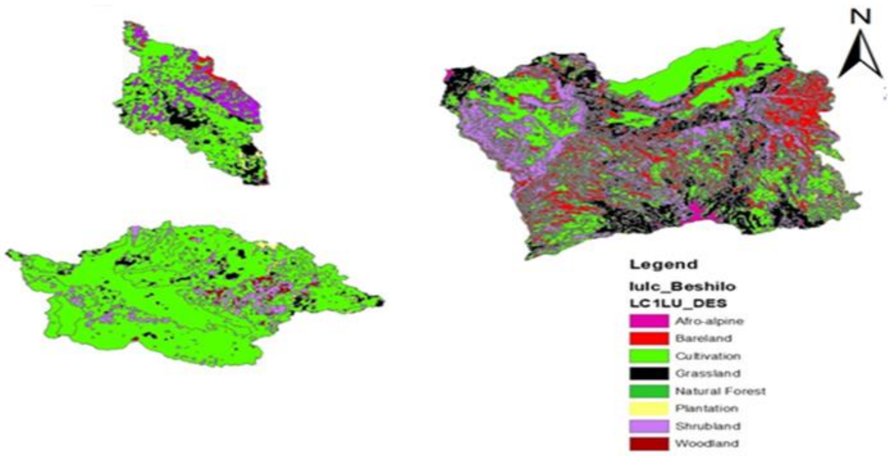

Fig 6. Map illustrating the land use and land cover of the Beshilo, Gumera, and Upper Rib watersheds

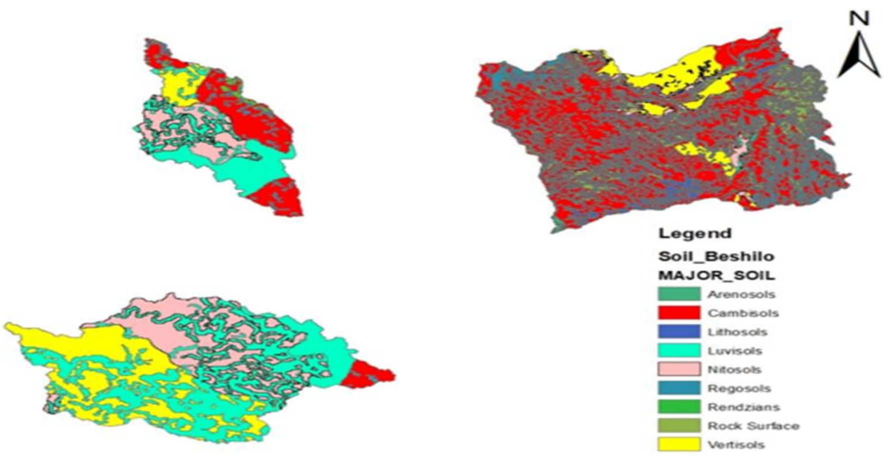

Fig 7. Map delineating the soil types within the Beshilo, Gumera, and Upper Rib watersheds.

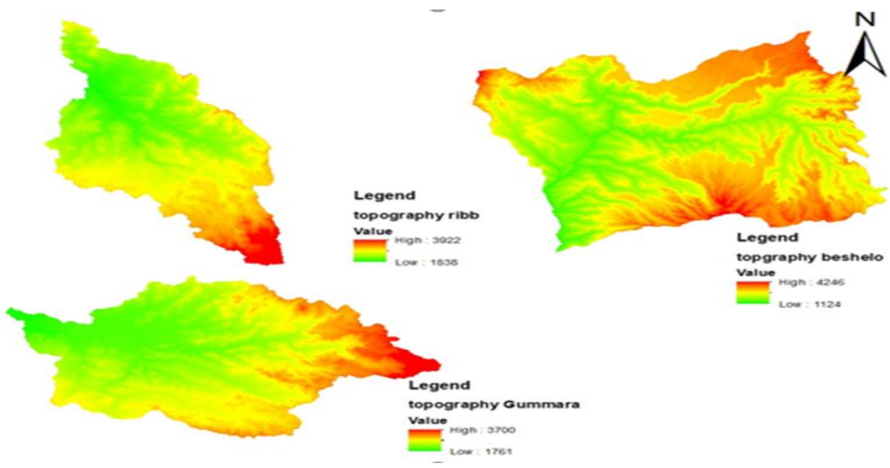

Fig 8. Map illustrating the topography of the Beshilo, Gumera, and Upper Rib watersheds

Therefore, in this study, the normal ratio method was used for filling missing data. Checking Consistency of rainfall stations, the double mass curve technique is employed to regulate precipitation records to require account of non-representative factors like a change in location or exposure of gauge. The accumulated totals of the gauge in question are compared with the corresponding totals for a representative group of the nearby gauge. Identifying sites and determining flows at selected sites have been the requirements for assessing hydropower potential on Beshilo River in the Abay basin. It was examined through simulations using the SWAT and daily climatic data. DEM, digital stream, Land Use Land Cover/LULC/, soil type, and climatic data sets were used as inputs to the SWAT model for simulating daily flows at numerous points along the basin's rivers. Figure 6, Figure 7 and Figure represent land cover area, soil traces and tropology of Beshilo, Gumera water shed respectively.

2.4.1. Analysis of hydrological processes

According to Kumar, [6] for the development of any small hydropower scheme an essential first step is to determine whether a sufficient and reliable amount of water is available to make the scheme economically viable. Abebe, [7] states that to estimate water resources as well as hydropower potentials at the sites, hydrologic study needs to be carried out using existing discharge and rainfall data recorded at the gauging stations available for the sub-basin in or nearby the proposed study area. European Small Hydropower Association [8] also states that for an ungauged watercourse, where observations of discharge over a long period are not available, it involves the science of hydrology, the study of rainfall and stream flow, the measurement of drainage basins, catchment areas, evapotranspiration and surface geology for the estimation of discharge. Most of Ethiopia's rivers do not have sufficient historical recorded data. In such a situation, there must be a mechanism of transferring data from the gauged site to the UN - gauged site; to do prediction of streamflow for an un gauged station are developed by different methods. [9]. However, in this study, the Beshilo watershed is not recently gauged, lacking up-to-date data. To obtain the recent flow data, we transfer it from the nearest gauged station, which has undergone an assessment for watershed similarity, considering land use, soil type, topography, and catchment area similarities between the two catchments. For the assessment of hydropower potential, we use the recent flow data transferred from the Gumera watershed. In this study, we identify two nearest gauging stations, Gumera and Upper Rib watershed, as candidates for the Beshilo watershed. We compare them based on catchment characteristics such as topography, land use, soil type, and catchment area. Upon comparing the two nearest watersheds (Gumera and Upper Rib), Gumera watershed emerges as the very nearest station in terms of catchment characteristics for the Beshilo watershed. Consequently, Gumera watershed is selected.

2.4.2. Data transfer from a gauged watershed to an ungauged

This study employs the Area Ratio method, transferring parameter sets from gauged to ungauged watersheds with similar areas, particularly in the upper Blue Nile region. This approach enhances understanding and prediction [10].

2.5 Criteria for Potential Site Identification

a) Available flow: For the selection of the potential sites for hydropower, the following criteria were accepted. The accessibility of proper flow is to be ensured, [11] by considering first streams that have flow accumulation of 2000 cells or more, as determined from the flow accumulation map; and b.as two second-order streams join to become a third-order stream, this will have sufficient runoff for connection of a powerhouse;

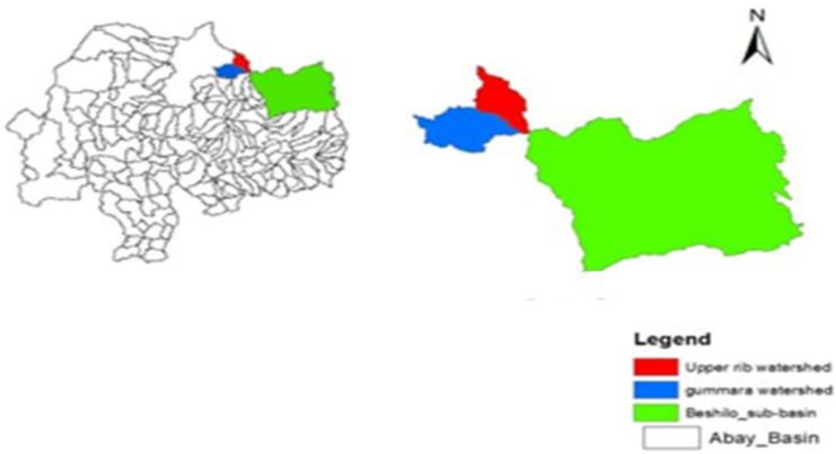

Fig 9. Location of the two closest measured catchments

Thus, the flow accumulation map was studied along with the digitized drainage map to make sure that only streams of third-order or more are considered. Catchment area of the river is shown in Figure 9.

b) Site spacing: The minimum distance between two successive sites should not be less than 1000 meters in ensuring a sufficient gap between the tailrace of one site and the diversion arrangement of the next site. This also ensures that the river ecosystem will have sufficient time to regenerate [12]

c) Head availability: The head availability assessment was done starting from the main outlet of the watershed. The head greater than or equal to 20m, so that sufficient power is generated even for low flows. [13]

2.5.2. Methods for identifying potential sites

Head measurement: To assess potential hydraulic head along the river, computation was started at the main outlet of the watershed and then proceeded in the upstream direction. The gross head (Hmax) is the vertical distance between the upstream water surface level at the stream area and at the tail water level. Topographic survey of measured data and digital elevation model (DEM) were used for identification of potential sites which potentially result in greater head. For this purpose, GIS with field surveying was used.

Preparation of flow duration curve: A flow duration curve is a plot of the discharge against the percent of the time the flow should equal or exceed. After a successful calibration and validation, and determination of the daily or monthly available discharge on each stream using the SWAT model a flow duration curve has been prepared. The daily or monthly discharges for the locations have been arranged in descending order and assigned their respective ranks "m" and the total number of streamflow data available on each individual stream be "N". By using Weibull method, the percentage probability (Pp) of streamflow, to be equaled or exceeded.

2.6. Determination of hydroelectric power potential

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 50%, 70%), provided it is economically feasible. [14] The design discharges for this study are considered as 50%, 75% and 90% of 90% dependable flow.

2.7 Soil and water assessment tool (SWAT) model

Hydrologic modeling was done using the Soil and Water Assessment Tool (SWAT) model. It's a semi-distributed model that may be applied to model the impact of land management activities on water, sediment, and nutrients at a watershed scale. It requires a certain input file which includes; weather, hydrological and spatial data. Geographical system (GIS) is employed as an auxiliary and a preprocessor to the SWAT modeling process. ArcMap interface of ArcGIS 10.3 may be used for managing and processing spatial data that were used as a SWAT input file during a project. Spatial data including digital elevation model (DEM), thematic map layers of land use/cover, and soil data are necessary data to perform hydrological water balance analysis of a basin in SWAT. SWAT-CUP is an interface that was developed for SWAT. Using this generic interface, any calibration/uncertainty or sensitivity program can easily be linked to SWAT. This is often demonstrated by the program linking GLUE, Parasol, SUFI2, and MCMC procedures to SWAT. During this particular study, it absolutely was preferred to use sequential uncertainty fittings (SUFI2). Its automated model calibration requires that the uncertain model parameters are systematically changed, the model is run, and also the required outputs (corresponding to measured data) are extracted from the model output files. The best function of an interface is to produce a link between the input/output of a calibration program and also the model.

3. RESULTS AND DISCUSSION

3.1 Estimation of stream flow for an ungauged catchment

The study was aimed at developing a simple methodology for flow prediction in ungauged catchment using existing data resources from gauged catchment. The stream flow data transferred from the gauged station by using special proximity with a combination of area and rainfall ratio. Gumera catchment streamflow data was transferred to Beshilo catchment, and the long-term average monthly discharge of the Beshilo catchment was similar to the Gumera that peaked at August and minimum around March and April. Therefore, the flow in figure 3.1 is the Beshilo River flow which is transferred from Gumera watershed.

3.2. Calibration and validation of SWAT-CUP

Model calibration involves adjusting parameters within a specified range to align model output with observed data. Arc SWAT's calibration tool facilitates parameter adjustment via user interference. The SUFI-2 algorithm within SWAT-CUP was employed for parameter calibration. This study validated and calibrated the SWAT model for Beshilo's flow data (2000-2020). Calibration utilized 2002-2012 data, while 2013-2020 data were reserved for validation. Sensitivity analysis, examining the model output's relative changes concerning input variable adjustments, is crucial. Determining the impact of model parameters on output through sensitivity analysis helps streamline the calibration process by identifying key parameters, optimizing model performance, and enhancing its reliability. According to different research, to identify input parameters that have the greatest influence on model output, a careful study of input parameters and their sensitivity is required before calibration. 12 sensitive parameters:
(R_SOL_Z(..).sol,V_ALPHA_BF.gw,R_REVAPMN.gw,R_ESCO.bsn, R_GW_REVAP.gw, R__CH_K2.rte, R_CANMX.hru,R_EPCO.bsn,R_SOL_AWC(..).sol, R_SOL_K(..).sol, R_CN2.mgt and V_GWQMN.gw) were identified as having a significant influence on streamflow control in the catchment. Figure 3.2 shown below the fitted calibration and validation value of observed and simulated flow of Beshilo River. Calibration and validation of observations and simulated flow was depicted in Figure 10.

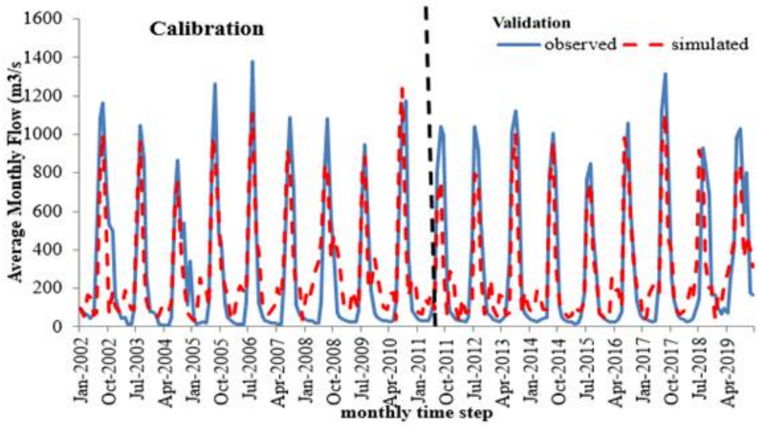

Fig 10. Calibrating and validating the observed and simulated flow of the Beshilo River

3.3 Locating potential sites

The power potential is directly related to both discharge and available head. For a specific location, discharge is primarily influenced by hydrology and catchment characteristics, while head depends on the area's topography. Physical observations, complemented by a field survey, were utilized to pinpoint potential sites within the Beshilo watershed. A site is deemed potential if it exhibits a head greater than 20 meters in the stream and a distance of 1000 meters or more between two sites (Table 1). This determination was made using methods outlined in the identification of potential sites. Head refers to the pressure resulting from the elevation difference between the upper surface of the reservoir and the tail surface water level. Measurement was conducted using surveying instruments during a field visit to identify the maximum reservoir site in the watershed. In this study, we identified potential sites upstream, midstream, and downstream of the watershed. This assessment enhances the identification of more reliable and effective optional sites in the study area. During the assessment, numerous candidate sites were listed, and evaluation was based on the following criteria:

Will the site likely have more than 20 m head? Will the site likely have sufficient discharge? Is the site suitable and economical for construction? Does the site fare well regarding sediment-related issues?

Furthermore, based on these criteria, nine potential sites (three upstream, three midstream, and three downstream) were identified in the catchment, as detailed in Table 1.

Table 1. Potential sites along the Beshilo River

Location	Sites (m)	Latitude (dd,mm,ss)	Longitude (dd,mm,ss)	Max. elevation (m)	Min. elevation (m)	Head (m)	Sub-Basin (No.)
Up stream	Site 7	11° 23' 06"	38° 51' 14"	1476	1426	50	9
	Site 8	11° 22' 22"	38° 56' 51"	1526	1473	53	13
	Site 9	11° 27' 21"	39° 08' 56"	1641	1603	38	17
Mid-stream	Site 4	11° 16' 16"	38° 36' 42"	1324	1296	28	20
	Site 5	11° 22' 59"	38° 39' 07"	1361	1330	31	16
	Site 6	11° 24' 02"	38° 45' 17"	1403	1370	33	11
Down stream	Site 1	11° 03' 01"	38° 28' 52"	1246	1210	36	28
	Site 2	11° 04' 36"	38° 28' 14"	1246	1218	28	35
	Site 3	11° 09' 29"	38° 32' 44"	1276	1250	26	37

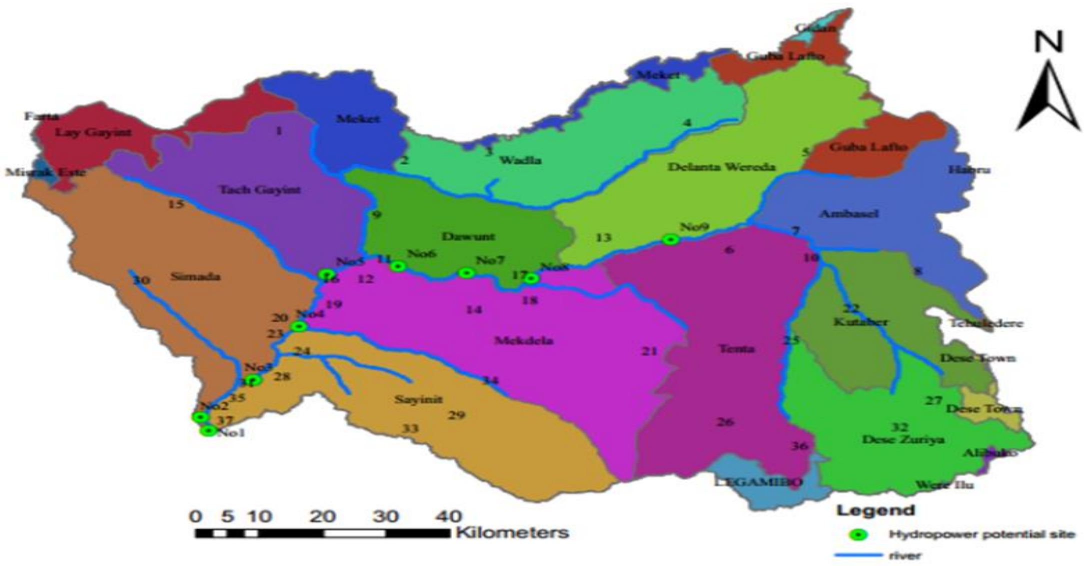

Fig 11. Location of potential sites along the Beshilo River across all weredas.

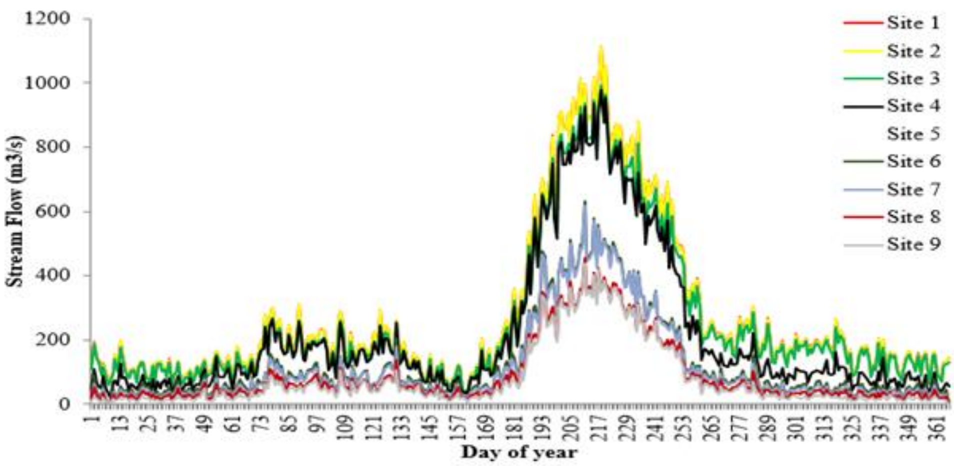

Fig 12. The simulated long-term average streamflow at the preferred site of the Beshilo River

Minimum and Maximum heads were found at Site 3 and Site 8 respectively. Table 1 contains longitude, latitude, maximum and minimum elevation and sub basin numbers for each site. Site selection and stream flow in the sites are shown in Figure 11 and Figure 12 respectively.

3.3.2 Assessment of potential locations

I. Simulated stream flow of Potential sites: Delineation of the watershed, calibration and validation of the SWAT model are the prerequisites for identifying potential sites. After calibrating and validating the model, it was used to estimate daily river flow in each of the potential sites identified using the criteria outlined in the method under section 3.5. In the Beshilo River, nine potential sites (green dots) were identified. After the model calibrating and validating rerun the model by rewriting the best fit parameter on SWAT software. The flow in each potential site was shown on the figure below. At all hydropower sites the stream flow is available for the whole month of the year.

II. Flow Duration Curves: A flow duration curve characterizes the ability of the basin to provide flows of various magnitudes. The shape of a flow-duration curve in its upper and lower regions is particularly significant in evaluating the stream and basin characteristics. The shape of the curve in the high-flow region indicates the type of flood regime the basin is likely to have, whereas, the shape of the low-flow region characterizes the ability of the basin to sustain low flows during dry seasons. Flow probability curves for selected sites from 1 to 9 were shown in Figure 13, Figure 14 and Figure 15 respectively.

3.4 Design discharge for the potential site

During hydropower development, the potential capacity of the proposed site has to be taken into consideration since the river flow is affected by seasonal variations.

Table 2. simulated daily discharge at selected percentile for the selected sites in m^3/s obtained from FDC of each potential site

Name	Flow rate (m^3/sec)		
	dependability level of 0.5	dependability level of 0.75	dependability level of 0.9
Site 1	134.5	28	7.3
Site 2	134.3	27.93	7.3
Site 3	126.1	26.22	7.1
Site 4	87.22	21.72	5.5
Site 5	71.02	18.32	5.1
Site 6	32.05	4.9	1.3
Site 7	28.9	4.7	1.2
Site 8	22.5	3.06	0.87
Site 9	16.62	1.85	0.12

As a result, minimum flow analysis is required to predict dependable capacity; average flow analysis is important for energy output considerations, and maximum flow analysis is critical from design or installed capacity. The design flow is chosen based on the available flow at the site in the watershed; the flow is designed approximately half of the time Q_{50}, Q_{75}, and Q_{90} are thinking about visualizing the flow condition for each of the duration curves created for the site. The meaning of Q_{50} is to be able to discharge in the river 50% of the time. In the sites from 1 to 9, the discharge at 0.5 dependability was shown in Table 2.

3.5 Hydropower potential assessment

To predict dependable or firm plant capacity, minimum flows are required. Long time Series River flows daily data was collected for the computation of water availability. The firm flow of rivers is specified by the flow duration curve, which is typically set by users between 90% and 100% [8]. According to the Ministry of New and Renewable Energy [10]and [14] the hydropower generation is estimated by considering three levels of dependability, 90%, 75%, and 50%. Water availability for hydropower is estimated in this study based on a 90% dependable flow. The 90% of flow denotes the number of rivers flows available 90% of the time, which is the flow that exists during the driest season. However, the installed capacity of a hydropower station increases when there is an increase in flow during a rainy season to meet maximum power generation. The hydropower potential at 90 % dependability, 75% dependability and 50 % dependability are illustrated in Table 3, Table 4 and Table 5 respectively.

4. CONCLUSION

In this study, a comprehensive assessment of the hydropower potential of the Beshilo River was conducted. The identification of hydropower generation potential on the Beshilo River was based on assessments of head, flow rate, and catchment area. Flow transferring methods, specifically the area ratio method, were employed to assess catchment similarity between the Beshilo catchment and neighboring ones. The combination of the SWAT model and ArcGIS proved to be an effective tool for identifying suitable sites for hydropower plants. A total of nine potential sites for run-off river plants in the Beshilo River were identified,

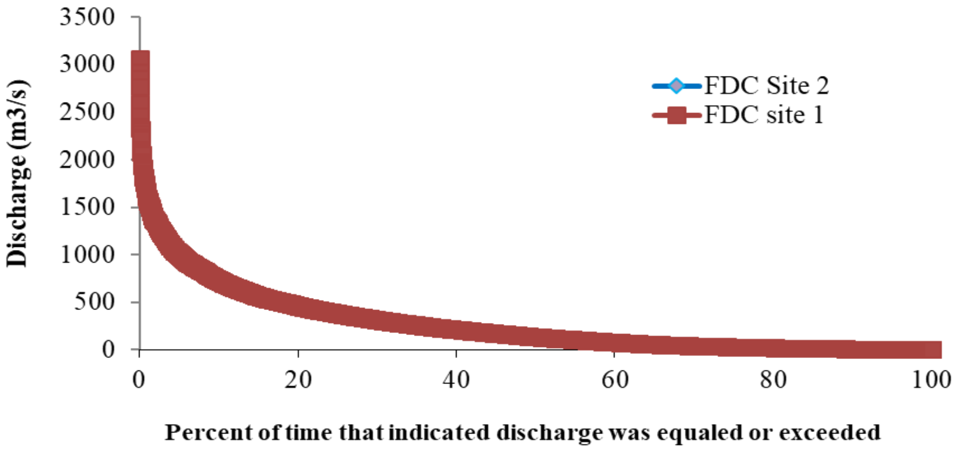

Fig 13. Probability curve for flow exceeding at potential sites 1 and 2

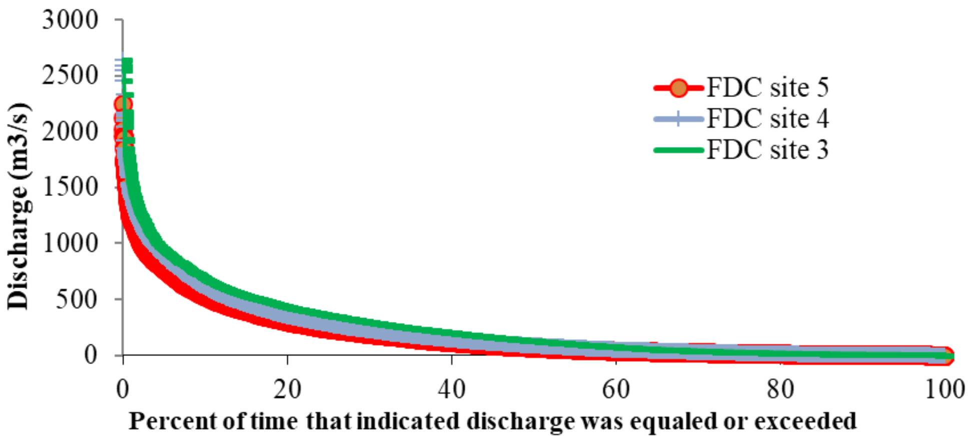

Fig 14. Probability curve for flow exceeding at potential sites 3,4 and

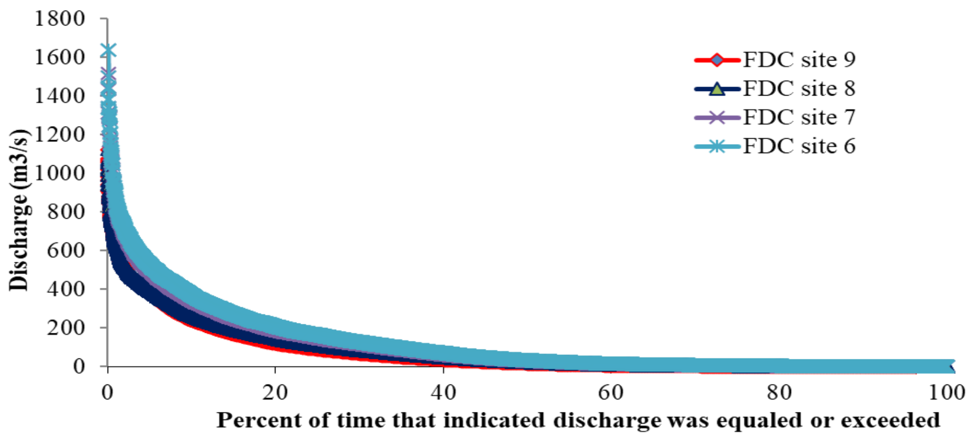

Fig 15. Probability curve for flow exceeding at potential sites 6,7,8 and 9

Table 3. Hydropower potential of the Beshilo River at a 90% reliable flow

Name	Head (m)	Water discharge (m^3/s)	Gravity (m/s^2)	Water density (kg/m^3)	Overall efficiency (%)	Power to be produced (kw)
Site 1	36	7.3	9.81	1000	90	2320.26
Site 2	28	7.3	9.81	1000	90	1804.65
Site 3	26	7.1	9.81	1000	90	1629.83
Site 4	28	5.5	9.81	1000	90	1359.67
Site 5	31	5.1	9.81	1000	90	1395.86
Site 6	33	1.3	9.81	1000	90	378.76
Site 7	50	1.2	9.81	1000	90	529.74
Site 8	53	0.87	9.81	1000	90	407.105
Site 9	38	0.12	9.81	1000	90	40.26
						9866.135 Total kW

Table 4. Hydropower potential of the Beshilo River at a 75 % reliable flow

Name	Head (m)	Water discharge (m^3/s)	Gravity (m/s^2)	Water density (kg/m^3)	Overall efficiency (%)	Power to be produced (kw)
Site 1	36	28.0	9.81	1000	90	8899.63
Site 2	28	27.93	9.81	1000	90	6904.63
Site 3	26	26.22	9.81	1000	90	6018.90
Site 4	28	21.72	9.81	1000	90	5369.44
Site 5	31	18.32	9.81	1000	90	5014.16
Site 6	33	4.9	9.81	1000	90	1427.64
Site 7	50	4.7	9.81	1000	90	2074.81
Site 8	53	3.06	9.81	1000	90	1431.88
Site 9	38	1.85	9.81	1000	90	620.67
						37764.76 Total (kW)

Table 5. Hydropower potential of the Beshilo River at a 50% reliable flow

Name	Head (m)	Water discharge (m^3/s)	Gravity (m/s^2)	Water density (kg/m^3)	Overall efficiency (%)	Power to be produced (kw)
Site 1	36	134.5	9.81	1000	90	42750.01
Site 2	28	134.3	9.81	1000	90	33200.57
Site 3	26	126.1	9.81	1000	90	28946.75
Site 4	28	87.22	9.81	1000	90	21561.83
Site 5	31	71.02	9.81	1000	90	19438.10
Site 6	33	32.05	9.81	1000	90	9337.99
Site 7	50	28.9	9.81	1000	90	12757.90
Site 8	53	22.5	9.81	1000	90	10528.58
Site 9	38	16.62	9.81	1000	90	5576.04
						184097.77 Total (kW)

with a minimum head criterion of 20m and a minimum distance of 1km between consecutive sites. Water availability during the driest season for hydropower was estimated based on a 90% dependable flow. The discharge at each potential site was determined using simulated daily flow data, revealing that potential sites

1 and 2 consistently had the maximum discharge with 90% dependability. The study concluded that the hydrological parameters of most identified locations for potential hydropower plants in the Beshilo River allow for power generation, particularly at site nine. All identified or assessed sites are deemed sufficient for hydro power generation for rural areas. The identified hydropower sites are classified based on their installed capacity, with one micro, three mini, and five small-scale run-off hydropower potential sites along the river. The assessment was conducted at natural ground elevation, and it is noted that the hydropower potential could be further increased through the application of storage structures. The estimated generation from the river is approximately 9.87 MW. If a hydropower plant project is developed, it could provide electricity to surrounding rural communities, addressing energy crises. It is important to note that the engineering geological appraisal conducted for small hydropower sites in this study was limited by resources, time, and financial constraints. Therefore, the results and findings should be considered indicative, and it is strongly recommended to conduct a detailed engineering geological appraisal with actual laboratory testing of rock and soil material before the final development of small hydropower sites.

REFERENCES

[1] S.Tesgera, "Assessment of untapped hydropower potential in existing hydraulic infrastructures", IHE Delft Institute for Water Education, the Netherlands, 2018.

[2] Getenet, "Assessment of hydropower potential of selected rivers in North Shoa Zone, Amhara Regional State, Ethiopia", Am. J. Energy Res., vol. 7, no. 1, pp. 15–18, 2019. doi: 10.12691/ajer-7-1-2

[3] European Small Hydropower Association, "Guide on how to develop a small hydrower plant", Eur. Small Hydropower Assoc., p. 296, 2004. doi:http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.172.1731&rep=rep1&type=pdf.

[4] O.Edenhofer et al., Renewable energy sources and climate change mitigation: Special report of the intergovernmental panel on climate change. 2011.

[5] P.Punys, A.Dumbrauskas, A. Kvaraciejus, and G. Vyciene, "Tools for small hydropower plant resource planning and development: A review of technology and applications," Energies, vol. 4, no. 9, pp. 1258–1277, 2011. doi: 10.3390/en4091258.

[6] Wegene Talelign, "Small hydro power (SHP) potential sites selection and engineering geological appraisal – A study in Ziway lake sub-basin , Central Ethiopia," Addis Abeba University, 2016.

[7] N.Abebe, "Feasibility Study of Small Hydropower Schemes in Giba and Worie Subbasins of Tekeze River, Ethiopia," J. Energy Technol. Policy, vol. 4, no. 8, pp. 8–17, 2014.

[8] S.Gebiru and M.Kifelew, "Feasible location identification & potential assessment of micro- hydropower: Gilgel Beles River, Upper Blue Nile Basin, Ethiopia," Res. Sq., pp. 1–25, 2021.

[9] A. Kumar, "Small hydropower assessment – A solution through Hydra- HP software," no. January 2002, 2002.

[10] Ministry of New and Renewable Energy, "Standards/manuals/ guidelines for small hydro development Project hydrology and installed capacity", no. August, 2013.

[11] Sheka, A.Teklemariam, and M.Adash, "Potential assesment of small hydropower in selected areas of Bench-Maji & Sheka Zones, South Western Ethiopia". IJESC, vol. 9, no. 11, pp. 24153–24159, 2019.

[12] G. A.Caxaria, D.de Mesquita e Sousa and H.M. Ramos,"Small scale hydropower:generator analysis and optimization for water supply systems",

Proceedings, World Renewable Energy Congress, Linköping, Sweden, vol.57, pp.1386 –1393, 2011. doi: 10.3384/ecp110571386.

[13] M.Gergel'ová, Ž.Kuzevičová, and Š.Kuzevič, "A gis based assessment of hydropower potential in hornád basin", Acta Montan. Slovaca, vol. 18, no. 2, pp. 91–100, 2013.

[14] W.Dilnesa,"GIS and hydrological model based hydropower potential assessments of Temcha Watershed," Int. J. Environ. Geoinformatics, vol.9, no.1, pp.97–101, 2022. doi: 10.30897/ijegeo.783157