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Research Article

Assessment of Head for Hydropower Potential Using DEM, Google Earth, and GPS in the Furfuro Watershed, Ethiopia

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Abstract

Energy is vital for social progress and economic success in all nations. Ethiopia, with its abundant water resources and ideal geography, holds significant potential for hydropower development. However, comprehensive data on the hydropower potential of many perennial rivers remains inadequate. To unlock Ethiopia's vast hydropower potential and establish a foundation for a clean, sustainable energy future, accurate and reliable head data is crucial. The goal of this study was to assess the potential head of the Furfuro River, which is located in the Rift Valley Basin, Ethiopia, using Geographic Information System (GIS), Digital Elevation Model (DEM), Google Earth, and hand Global Position System (GPS). The hydropower potential of the site was analyzed by measuring the gross head using GPS and Google Earth. The potential head was calculated from the longitudinal river profile, and the performance was evaluated using Nash-Sutcliffe efficiency (NSE) and coefficient of determination (R^2) and the values were (0.997 and 0.994, respectively). By overlaying the DEM and stream network using GIS, the study identified four potential hydropower sites in the Furfuro River, all on streams of orders 4 and 5 with heads exceeding or equal to 8 meters. The findings of this study highlight the effectiveness of using DEM, Google Earth, and hand GPS for assessment of optimal heads for hydropower potential sites.

Keywords

Digital Elevation Model, Geographic Information System, Google Earth, Global Position System, Head Drop, Hydropower, Renewable Energy

1. Introduction

Renewable energy is becoming more popular as a way to meet the growing demand for energy and address the challenges of climate change [1]. Hydropower is a renewable energy source that uses the force of flowing water to produce

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electricity. It is a safe and dependable energy source that can reduce greenhouse gas emissions and fight climate change [2]. Hydropower is an important green energy source; it generates around 16% of the world's electricity. Water movement can produce energy in the form of hydropower. The snow or rain that create streams and rivers comes from mountains or hills. Hydropower became a source of electricity in the late 19th century. In 1879, the first hydroelectric power plants were built at Niagara Falls. In 1881, Niagara Falls started harnessing hydropower. The first hydroelectric power plant in the world started running in 1882 along the Fox River near Appleton, Wisconsin [3].

Hydropower is the production of electricity through the use of moving water's energy [3]. It is a reliable and renewable energy source that supports the goals of the country's environmental and energy policies. Hydropower is one of the most significant renewable sources for the production of electricity. It derives from water that is flowing downhill a river's course, either from rivers or streams, due to the force of gravity [4]. The kinetic energy that is linked to this flowing water is released due to the friction between the water and the rocks and silt in the riverbeds. Hydropower is produced by using the kinetic energy of the moving water to drive turbines [5].

Ethiopia has the second-highest hydropower potential in Africa (only the Democratic Republic of the Congo has a higher potential) [6], with a potential capacity of up to 45,000 MW [7]. The hydropower operation began with the first Aba Samuel dam, ordered in 1932 and with an installed capacity of 6.6 MW [8].

The lack of accurate and reliable information on the resources is one of the key requirements for the development of water resources in the nation [9]. Although Ethiopia has abundant water resources and a topography that is suitable for the development of hydropower, there is a lack of data on the majority of perennial rivers and their hydropower potential. It is easy to plan, make legislation, and put plans for the development of hydropower into action when there is accurate information on headwater in perennial rivers.

In the Furfuro River catchment of Ethiopia's Rift Valley sub-basin, residents rely on unsustainable and harmful energy sources like cow dung and kerosene for cooking and heating. These resources are expensive, time-consuming to acquire, and detrimental to health [7]. Additionally, traditional farming practices constrain economic opportunities for women and children. This study aims to assess optimal hydropower potential in the study area DEM, Google Earth, and GPS, seeking a clean and affordable energy solution for the community. The development of hydropower on the Furfuro River has the potential to provide a clean and affordable source of energy for people in the catchment. However, to develop hydropower effectively, it is essential to have accurate information on the river's potential head.

Assessing hydropower potential requires the determination of two key factors: head drop (H) and river discharge (Q). Head drop, the elevation difference between a river's upstream and downstream points, can be manually calculated from topographic maps or automatically derived from the Digital Elevation Model (DEM) using GIS software [10].

2. Materials and Methods

2.1. Study Area Description

The Furfuro River is a perennial river located in the Wulbareg Woreda Silte zone. The coordinates of the river are Latitude 7°40′0″ to 7°54′45″N and Longitude 37°58′50″ to 38°18′38″E (Figure 1). It originates from the high Silte Plateau and flows down to merge with the Dijo River, eventually flowing into Lake Shala. Furfuro River Catchment is located in the Rift Valley sub basin, covering an area of around 202.04 km^2. It extends up to 30 km with a river basin, which is the largest river basin area in the Silte zone. It is located at a distance of 170 km from Addis Ababa.

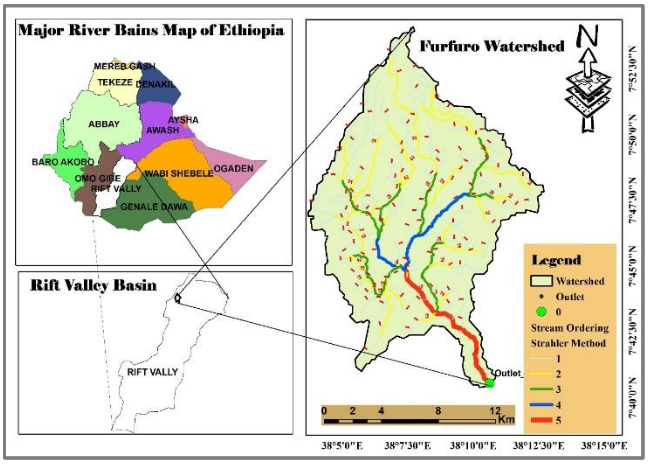

Figure 1. *Location map of Furfuro Watershed.*

2.1.1. Topography

Furfuro Watershed consists of rugged and undulating topographies, which vary in altitude from 1862 m above sea level up to 2669 m above sea level (a.m.s.l) (Figure 2).

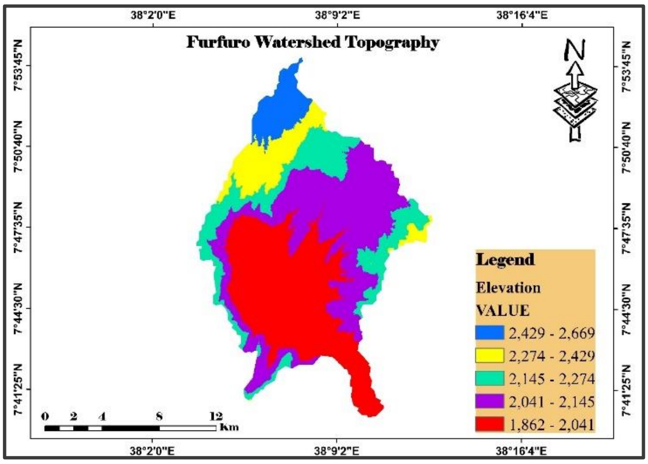

Figure 2. Topography of Furfuro watershed.

2.1.2. Digital Elevation Model (DEM)

The DEM was used to delineate the Furfuro watershed and divide it into sub-watersheds. Flow accumulation, stream link, stream order, and slope were calculated from DEM. The digital elevation model (DEM) is one of the inputs for the SWAT model. The DEM was used to delineate the Furfuro watershed and divide it into sub-watersheds. Flow accumulation, stream link, stream order, and slope were developed from DEM. For this study, the high-resolution grid DEM of 12.5 m by 12.5 m, shown in (Figure 3).

2.2. Criteria for Identification of Hydropower Potential Sites

For site selection and potential head for hydropower site identification, the following criteria were established [4].

2.2.1. Order of Stream

Stream ordering was used to identify reaches within the Furfuro River network with adequate flow for hydropower siting. Stream order is a river classification technique that classifies a stream network into reaches and indicates the magnitude of flow within those reaches [11]. Among the different stream ordering methods, such as the Shreve, Horton, and Strahler methods, the Strahler method was chosen due to its extensive application and simplicity [12].

This method assigns a higher stream order when two streams of equal order meet; for example, the adjoining of two first-order streams creates a second-order stream, and so on. Consequently, higher stream order generally results in a greater magnitude of flow [13]. To ensure that there is sufficient flow available for hydropower generation, only 5th and 4th order streams are considered for the selection of sites to ensure a sufficient amount of water flow.

The fill tool in ArcGIS was used to process the DEM and eliminate any depressions. The direction of flow and flow accumulation were then computed. A 4,000-cell threshold was used to create flow accumulation using ArcMap's raster calculator. The Furfuro River's stream network was then generated and ordered using the stream order tool and the output from the raster calculator, as shown in (Figure 4).

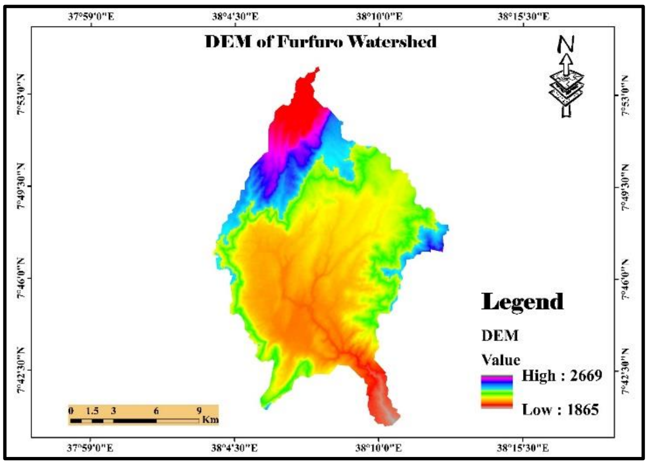

Figure 3. DEM of the study area.

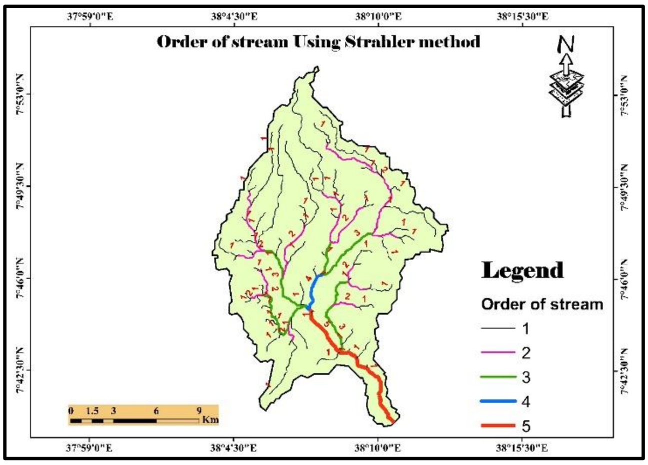

Figure 4. Stream order by the Strahler method.

2.2.2. Head Availability

A crucial factor in evaluating hydropower potential is potential head, which may be calculated either by measurement or by utilizing Google Earth and topographic maps [14]. Direct measuring is time-consuming while being precise. On the other hand, utilizing elevation data to create topographic maps that are generated from DEM data offers a more user-friendly method of determining gross heads [15].

Head availability is measured by superimposing the DEM and stream network on top of a GIS, beginning at the catchment's primary outflow. There should be at least eight meters of head at each possible location. The hydraulic head for that particular place is raised periodically until the distance restrictions are satisfied if the 1000 m condition is not met [16], as shown in (Figure 5).

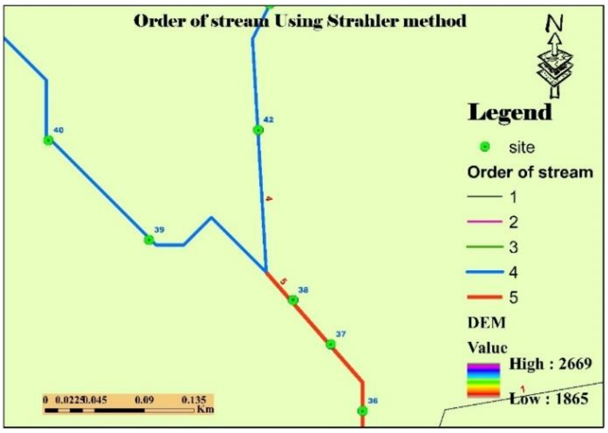

Figure 5. 5th and 4th order streams along the Furfuro River.

2.2.3. Minimum Interval Between Sites

The minimum distance between two consecutive hydropower sites should not be less than 1000 meters to allow the river ecosystem to recover between sites [17].

2.2.4. Environmental Constraints and Ongoing Development Projects

Areas of religious sites and national parks or wildlife reserves are excluded from consideration. Existing projects within the study area, other than ongoing ones, are also considered. for site selection.

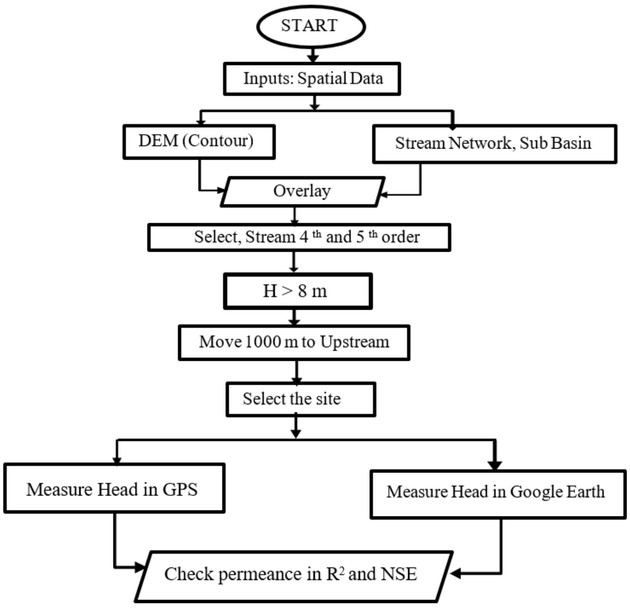

Figure 6. Methodology for Assessment of Head for Using DEM, Google Earth, and GPS.

Table 1. Ground truth data for LULC obtained from field surveys.

	Trees				Built up area		
No	Lat	Long	Elevation (m)	No	Lat	Long	Elevation (m)
1	7 °44 ′43.85	38 °7′27.5	1969	1	7 °44 ′8.23	38 °7′24.47	2003
2	7 °44 ′49.3	38 °7′24.3	1972	2	7 °44 ′45.4	38 °7′31.05	1981
3	7 °44 ′51.47	38 °7′27.79	1976	3	7 °44 ′52.62	38 °7′34.78	1991
4	7 °44 ′53.48	38 °7′27.28	1979	4	7 °44 ′53.08	38 °7′35.27	1988
5	7 °44 ′53.36	38 °7′27.28	1985	5	7 °44 ′25.01	38 °7′30.03	1962
6	7 °44 ′51.85	38 °7′26.81	1974	6	7 °44 ′10.99	38 °7′27.49	1972
7	7 °44 ′32.67	38 °7′29.89	1972	7	7 °44 ′41.25	38 °7′26.45	1994
	Agricultural land				Range land		
No	Lat	Long	Elevation (m)	No	Lat	Long	Elevation (m)
1	7 °44 ′54.34	38 °7′28.22	1980	1	7 °44 ′42.48	38 °7′27.63	1971
2	7 °44 ′55.48	38 °7′29.23	1986	2	7 °44 ′50.75	38 °7′2525	1979
3	7 °44 ′55.82	38 °7′30.52	1982	3	7 °44 ′52.29	38 °7′27.11	1971
4	7 °44 ′55.58	38 °7′33.2	1986	4	7 °44 ′52.22	38 °7′29.04	1977
5	7 °44 ′12.28	38 °7′38.41	1981	5	7 °44 ′53.41	38 °7′28.63	1984
6	7 °44 ′12.35	38 °7′32.29	1996	6	7 °44 ′22.29	38 °7′43.55	1968
7	7 °44 ′12.15	38 °7′32.9	1997	7	7 °44 ′14.86	38 °7′34.16	1974

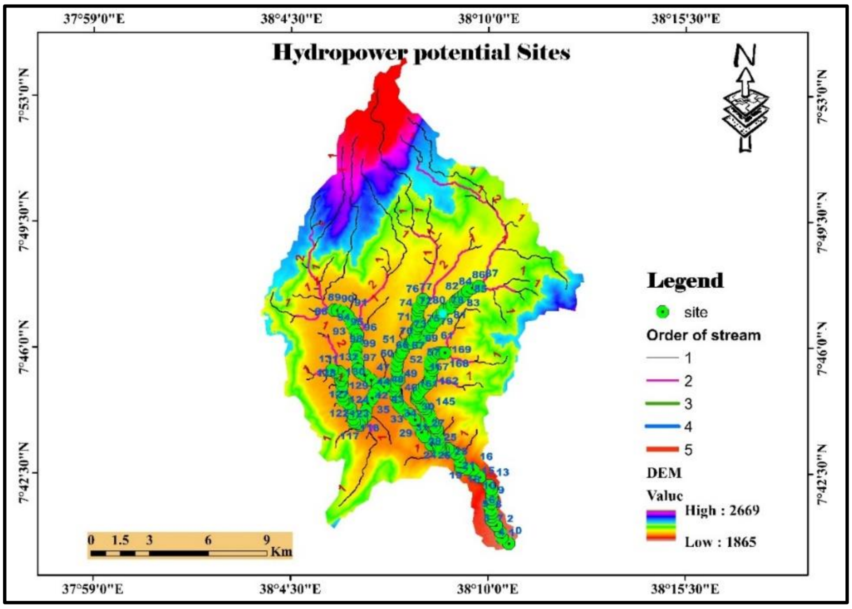

Figure 7. *DEM derived contour map of a sample area for feasible sites.*

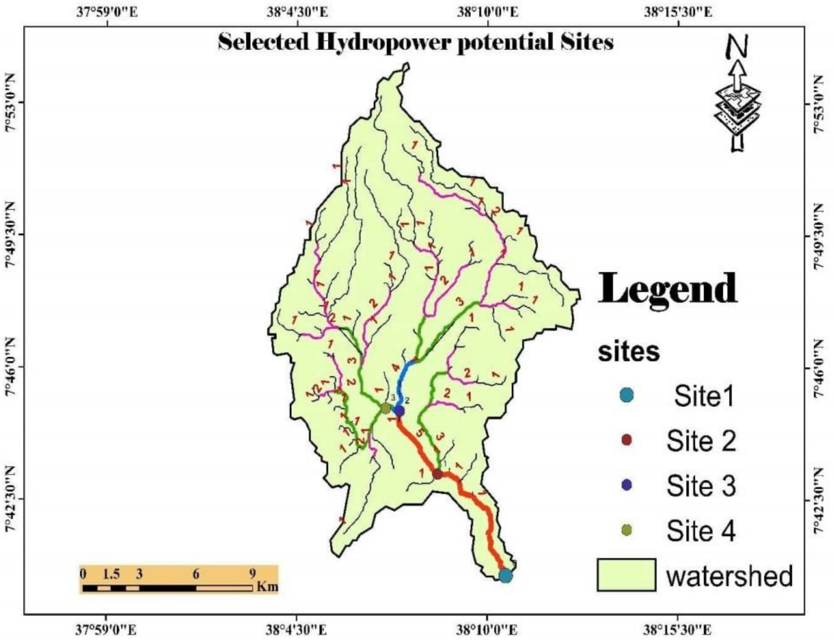

Figure 8. *Map of the selected hydropower potential sites.*

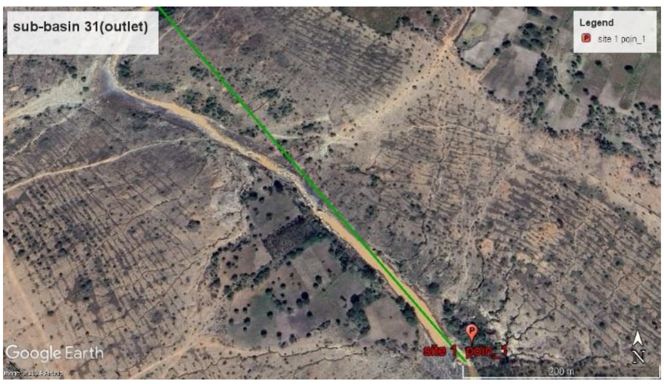

Figure 9. *The distance between site 1 and 2.*

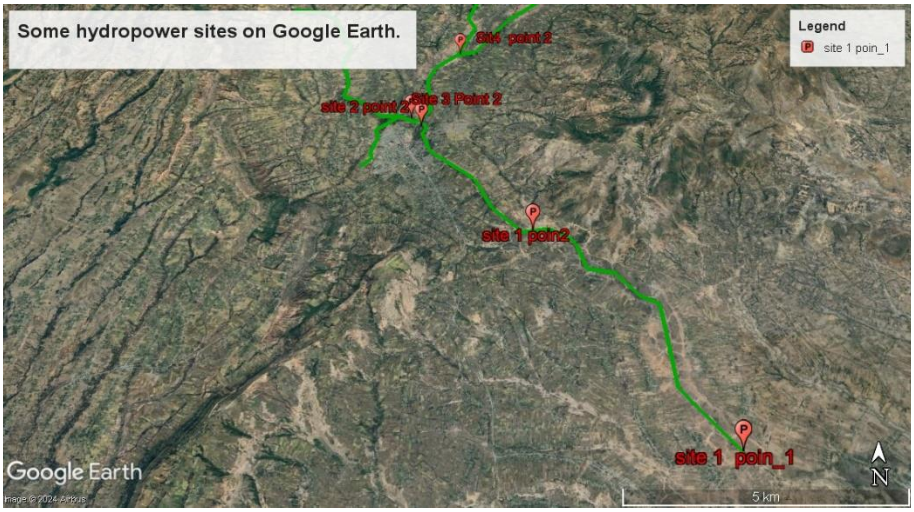

Figure 10. *Selected site in Google Earth.*

Figure 11. *Measure Head in GPS at selected site.*

3. Results and Discussion

The results and discussion include the head drop estimation, the estimation of the potential hydropower for a selected site, and an accuracy assessment for the elevation at the most convenient hydropower locations.

Accuracy Assessment of Elevation

Four accessible locations within the research area were used to gather GPS and DEM readings in order to evaluate the accuracy of the elevation data obtained from Google Earth. The difference between Google Earth data, DEM data, and GPS readings was considered a potential measurement error. The applicability of spatial analysis in ArcGIS was evaluated using real-world geographic information from the study area. To check the performance of elevation information to predict reality, the accuracy of both geographical location and elevation needs to be considered.

Table 2. *Geographical location from DEM and Google Earth Pro, and GPS of the study area.*

		DEM			Google earth pro		GPS	
sites	**points**	**Latitude**	**Longitude**	**Elevation in (m)**	**Elevation in (m)**	**Head drop**	**Elevation in (m)**	**Head drop**
1	poin1	38 °10'38"	7 °40'32"	120	1880	86	1881	84
	point2	38 °8'43"	7 °43'11"		1966		1965	
2	Point 1	38 °8'43"	7 °43'11"	50	1966	18	1965	19
	poin2	38 °7'23"	7 °44'50"		1984		1984	
3	point 1	38 °7'23"	7 °44'50"	8	1984	0	1984	2
	point 2	38 °7'15"	7 °44'58"		1984		1986	
4	Point 1	38 °7'15"	7 °44'58"	49	1984	18	1986	17
	point2	38 °7'53"	7 °46'10"		2002		2003	

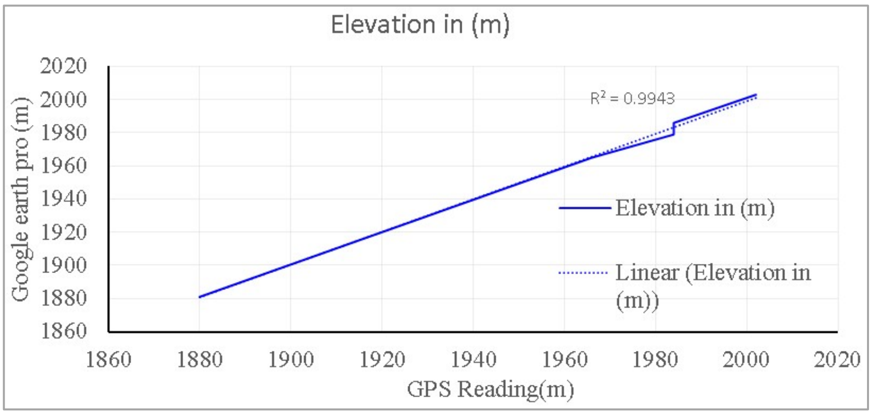

Figure 12. *Comparisons between Google Earth Pro and GPS using R-squared (R^2).*

Table 3. *Comparisons between Google Earth Pro and GPS using Nash-Sutcliffe Efficiency (NSE).*

sites	**Google earth pro**	**GPS**	**(Hgep-Hgps)^2**	**(Hgps-$\overline{Hgps}$)^2**
1	86	84	4	2862.25
2	18	19	1	132.25
3	0	2	4	812.25
4	18	17	1	182.25

sites	Google earth pro	GPS	$(Hgep\text{-}Hgps)^2$	$(Hgps\text{-}\overline{Hgps})^2$
	Sum		10	3989
	NSE			0.997

$$NSE = 1- \frac{\sum(Hgep-Hgps)2)}{\sum(Hgps-\overline{Hgps})2} \quad (1)$$

Where, NSE-Nash-Sutcliffe Efficiency, Head Drop in Google Earth Pro, Head Drop measured GPS, mean of measured GPS.

The head drop measured using Google Earth Pro, the GPS R-squared, and Nash-Sutcliffe Efficiency (NSE) (R^2= 0.994 and NSE = 0.997), respectively, are plotted against the corresponding head drop extracted from field measurements.

4. Conclusions

This study evaluated the hydraulic head for hydropower potential of the Furfuro River basin using DEM, Google Earth, and GPS. Hydropower potential was estimated based on the potential head drop and the discharge. Further research should be conducted on the Furfuro River to assess its technical and economic feasibility for hydropower development. To assess whether the Furfuro River is economically and technically feasible for the construction of hydropower, more study needs to be done on it. The current study only provides a head estimation of hydropower potential.

Abbreviations

DEM	Digital Elevation Model
GIS	Geographical Information System
GPS	Global Position System
LULC	Land Use Land Cover
MoWE	Ministry of Water and Energy
NSE	Nash-Sutcliffe Efficiency
PBIAS	Percent of Bias
R^2	Coefficient of Determination

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Author Contributions

Amsayaw Genet Engida: writing - original draft, writing review and editing, conceptualization investigation, methodology, data curation and analysis, procedural Framework, Model parameterization.

Abebe Tadesse Bulti: Supervision, Validation, overall guidance, Writing, reviewing, and editing.

Temesgen Zelalem Addis: Conceptualization.

Tensay Kifle Habtemariam: Data collection and review

Aynadis Ejargew Molla: Methodology

Data Availability Statement

Data can be acquired upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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Research Fields

Amsayaw Genet Engida: Hydropower, Hydrology, Reservoir Operation, Surface Water, Groundwater, Irrigation

Abebe Tadesse Bulti: Hydropower, Hydrology, surface water, groundwater, climate change, reservoir operation

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Tensay Kifle Habtemariam: Hydropower, Hydrology, Water Quality, Renewable Energy, Water Supply

Aynadis Ejargew Molla: Hydropower, Water Supply, Hydrology, Water Quality, Irrigation