ISSN:2321-1156
International Journal of Innovative Research in Technology & Science(IJIRTS)

ASSESSMENT OF HYDROPOWER POTENTIAL OF UN-GAUGED MYOMBWE RIVER BASED ON HYDROLOGICAL DATA

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Abstract

Assessment of hydropower potential is necessary in evaluating energy generation based on hydrological data for hydropower systems. A study was done at Magunguli waterfalls along the un-gauged Myombwe River with an aim of assessing and analyzing hydropower potential. Hydrological data collections and analysis covered flow rate for gauged Ruaha River and area ratio method to obtain the flow rate for Myombwe River based on catchment area analysed by ArcView GIS. Based on the available resources and data analysis; a hydraulic head of 636 m was realized through GPS techniques, flow rate of 1.979 m^3/s was estimated using area ratio method and flow duration curve. The selected turbine was Pelton turbine which has an efficiency range of 80 - 90%. Based on the hydrological data a Power potential of 9,388.69 kW was realized which is viable for development of mini hydro scheme. To enhance and sustain development of hydropower projects in Tanzania; extensive utilization of acquired data, extended assessment of un-gauge rivers in parallel with impact assessment for the potential hydropower schemes should be done.

Keywords: Hydropower potential, Hydrological data, Ungauged River.

Introduction

Hydrology is the science that encompasses the occurrence, distribution, movement and properties of the waters on the earth and their relationship with the environment within each phase of the hydrologic cycle. Flow duration data are needed to select the hydraulic capacity of the plant and to give the reliability of the plant. Reliability is most important at small hydro sites that are not connected to a national power grid.

Most of waterfalls along the rivers with significant water flow rate have potential for hydropower generation. However, the amount of power generated from waterfalls also depends on the head. Hence, an assessment of the water falls for hydropower generation is the systematic approach of estimating how much power does a particular water fall yield. The evaluated power enables the assessed waterfalls to be categorized as potential pico, micro or mini hydropower site. To date there is still no internationally agreed definition of 'small' hydro; the upper limit varies between 2.5 and 25 MW[1]. Hydropower is a renewable and sustainable energy source to meet global challenges [2] but developing the remaining hydroelectric potential in a sustainable way offers many challenges. Hydropower sites on small watersheds are seldom gauged. Stream flow records are not available.

Mini-hydropower can be applied to sites ranging from a tiny scheme to electrify a single home, to a few hundred kilowatts for selling into the National Grid. Small-scale hydropower is one of the well-developed and trustworthy energy technologies for provision of dirty free power production. Mini-hydropower is in most cases "run-of-river"; in other words any dam or barrage is quite small, usually just a weir, and little or no water is stored. By using mini grids, mini hydropower plants are utilized for rural electrification. However, to ascertain the adequacy of the estimated hydropower, the estimated energy demand of the expected beneficiaries should be known. The rapid economic growth demands more energy generation but the problem arises to provide desired amount of energy in a sustainable manner [3].

The installed capacity of hydropower by the end of 2008 contributed 16% of worldwide electricity supply, and hydropower remains the largest source of renewable energy in the electricity sector [4].Present task for the energy sector is to satisfy the growing demand for electric energy of the community while conserving resources for the benefit of future generation [5].Current figure that is widely quoted in Tanzania is that national access to electricity is 14 per cent of the population, while in the rural areas it is about 6%[6]. There are many regions of Tanzania where the grid is not yet operational, but they have sufficient hydro resources to meet the basic domestic and cottage industry needs of the local populations[7]. Key barriers to the development of Small Hydropower Plants (SHP) in Tanzania are lack of local capacity both design and supplier units, lack of hydrological data for potential sites, un-gauged properties sites and policies[8]. To design a small scale hydropower project at Myombwe stream, hydrological data are required.

Myombwe River has Magunguli waterfall in Mufindi district, Tanzania. The Myombwe River which crosses at Magunguli village is a perennial river, which means the flows are continuous throughout the year. Magunguli waterfall is surrounded by the following villages; Magunguli, Ikiyowela, Isaula, Idete, Nyigo, Ihawaga, Ikimilinzowo, Udumka, Ihomasa, Kilolo, Mtambula, and Ipilimo.These villages are not connected to the national grid. Therefore, the proposed study seeks to assess the suitability of Magunguli waterfalls based on hydrological data for electrification of surrounding villages.

Methodology

Project site

Myombwe river catchment is located in the southern Western part of Tanzania in Mufindi district of the Iringa region Mufindi is situated on a plateau that ranges from 1,500 metres to 2,500 metres above sea level. Significant geological features include numerous steep, rocky hills that punctuate the landscape and the Myombwe River that runs through the Mufindi district southern mountain toward low plateau of Morogoro region. They form the upper catchment of the Great Ruaha River. This river in turn is a main tributary to the Rufiji River, the largest drainage basin in Tanzania covering some 174,800 km^2, or about 18% of the areas of Tanzania Mainland.

Assessing the Hydropower

Potential of Magunguli Water falls

The head (H) in meters and flow rate (Q) in m^3/s was used in to obtain hydropower Potential in Watts of Magunguli waterfalls. The gross head may be estimated, either by field surveying or by using a GPS or by orthographic techniques [9].In this study GPS was adopted to locate the position and elevation of Weir and Sediment Tank. Selection of the Weir site is based on the characteristics of the River. The stretch should be straight, stable and narrow with a gentle slope and should have adequate ponding requirements. Area ratio method maybe used to determine the mean flow rate. This was necessary to the case of Myombwe River because it was not gauged.

Head (H) Measurement

There are two accurate methods for measuring head: direct distance measurement, and water pressure [10]. GPS mobile set of instruments were used to measure the total head (H) of Magunguli waterfalls. AGRMIN GPS map number 62S was used to measure the co-ordinates of the potential sediment tank (STC), and potential power house (PHC). The head was calculated as follows;

$$H = STC - PHC \qquad (1)$$

Hydrological Analysis

The area ratio method was used to analyze the hydrological analysis of the Myombwe River, since the River is not gauged, and nearby there is Little Ruaha River which is gauged.This was necessary for Myombwe River which was not gauged, a condition that necessitated correlation analysis to determine whether the two catchment areas had similar hydrological characteristics. The Karl Pearson's Coefficient was used to determine this relationship.

Area Ratio Method

The area ratio method assumes that, there is a gauged catchment that exists nearby the un-gauged catchment. The two catchments must be hydrological similar in terms topography, land-use, geomorphology and lithology must be similar [11]. The catchment area for the un-gauged stream was obtained using Arcview GIS 9.3 computer software. Digital Elevation Model (DEM) of Tanzania was used to delineate the required area. The mean annual flow (MAF) for the un-gauged catchment area was determined using the following equation

$$M_{ug} = \frac{A_{ug} * M_g}{A_g} \qquad (2)$$

Where Aug = Area of un-gauged catchment (km^2), Mug = mean annual flow of un-gauged catchment (m^3/s), Mg = mean annual flow of un-gauged catchment (m^3/s).

Field Survey Method

A three-point method as outlined in [12] was used to measure the flow rate. Electromagnetic current meter were used to measure velocities at 20% (V20%), 60% (V60%) and 80% (V80%) from the surface of Water River. The mean flow rate (Vm) of the river was then calculated using equation (3). The flow measurements were taken in dry season, during rainy season, and immediately after the rain season.

$$Vm = 0.25 * (V_{0.2} + 2V_{0.6} + V_{0.8}) \quad (3)$$

Cross Sectional Area of the Myombwe River

Measurement of stream flow was made at the place where the axis of river bed is straight and the cross section of the river is almost uniform. The width of the river was measured by using a measuring tape. At this place a width of the river was measured and found to be 20 meters. Cross section area was measured and found to be 20 meters. Cross section area of the stream was measured by first determining the average depth at the river. The sum of depth measurements was determined and it was divided by the number of depth measurements made. Hence average depth (m) calculated. The results was multiplied by the river width to get the cross sectional area. The flow of Myombwe River during dry season, rainy season and immediately after the rain was obtained by using Equation (4)

$$Q = Vm * S \quad (4)$$

where Vm = mean velocity and S = estimated area

Hydrological Correlation Analysis

In order to prove if two catchments have the same hydrology, the correlation analysis was carried out. The average monthly flows (m^3/s) for Little Ruaha and rainfall (mm) for Myombwe village Table 2 and Karl Pearson's coefficient of correlation (r) and Equation 6 were used to compute and check if gauged and un-gauged points are correlated.

$$s = b\left(\frac{h + \cdots + h}{n}\right) \quad (5)$$

Where; b = width, h = depth, and S = estimated area

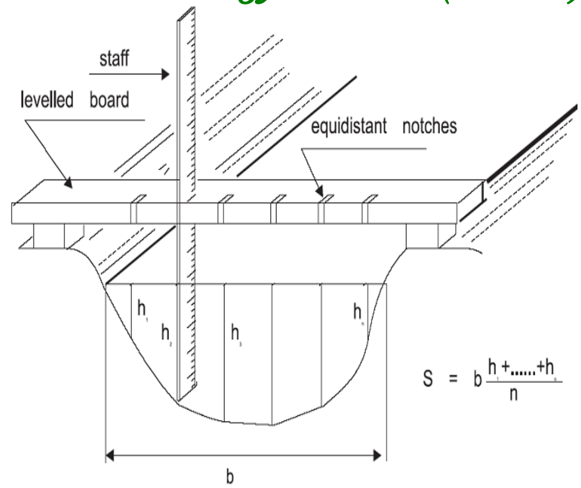

Figure 1: Measuring the cross-sectional area [9]

Table 1: Mean monthly flow of Little Ruaha for 10 years.

Year	Nov	Dec	Jan	Feb	Mar	Apr
2001	0.4	5.2	35.5	49.6	57.9	44.3
2002	2.9	9.1	38.5	36.5	26.4	39.6
2003	5.7	8.5	14.3	13.8	40.9	42.0
2004	5.6	12.0	25.6	26.6	31.2	25.8
2005	1.7	1.8	5.5	17.0	20.7	27.9
2006	2.0	38.5	56.0	58.2	54.6	38.8
2007	4.9	15.8	30.7	58.1	56.7	55.0
2008	3.8	15.2	24.9	28.5	44.8	47.2
2009	6.6	8.0	30.3	30.9	43.4	33.0
2010	2.3	3.8	9.9	14.2	19.4	28.7

Year	May	Jun	Jul	Aug	Sep	Oct
2001	23.2	13.8	9.2	6.9	5.3	4.3
2002	17.9	11.9	9.1	7.4	5.2	4.9
2003	18.0	10.8	8.6	7.0	6.3	5.4
2004	11.7	8.6	7.2	6.3	5.1	3.6
2005	18.0	12.2	9.2	7.8	6.1	3.7
2006	24.7	16.9	11.7	9.7	7.9	6.3
2007	34.1	20.9	13.7	9.7	5.7	3.7
2008	21.8	12.4	9.3	7.1	5.3	3.8
2009	16.1	11.2	8.9	7.2	5.4	3.3
2010	15.3	10.9	8.6	7.1	5.4	4.8

Source: [13]

Table 2: Average Flows and Rainfall Data

Mont	Months Average Flows	Average Rainfall
Jan	27.1182	220.5
Feb	33.3273	112
Mar	39.6018	404
Apr	38.2452	105
May	20.0638	4
Jun	12.9493	-
Jul	9.5467	-
Aug	7.6142	-
Sep	5.7773	-
Oct	4.3882	18
Nov	3.577	41
Dec	11.8028	239.5

Source: [13]

Karl Pearson's Coefficient of Correlation

$$r = \frac{\sum xy}{\sqrt{\sum x^2 \sum y^2}} \quad (6)$$

where x represents monthly average flows for Little Ruaha River, and y represent monthly rainfall data for Myombwe stream. Values of r lie between +1 to -1, where +1 indicates perfect direct correlation, -1 indicates perfect inverse correlation and 0 indicates that no correlation exists between these values.

Estimating a Flow-Duration Curve for Un-Gauged Catchment

A flow duration curve for un-gauged catchment is estimated by using a curve derived for a gauged site along the same stream or in a neighbouring catchment. The flow of Myombwe River was obtained by multiplying the ratio of Myombwe river catchment and flow of neighbouring gauged Little Ruaha catchment. Given the flow of the Myombwe River made possible to plot a flow duration curve which shows percent of time against discharge, for an un-gauged site.

In preparing flow duration curve, stream flow data was arranged in a descending order of stream discharges. A range of values as class intervals is established from the available daily flows data, from the year 2001 to 2010. The plotting position was calculated from Weibull plotting relationship and the results were plotted on a sheet of logarithmic paper. The percentage probability of any flow magnitude Q being equalled or exceeded is given as;

$$P_p = \frac{m}{N+1} * 100\% \quad (7)$$

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

The power generated from hydraulic turbines is a function of the effective head, the flow rate, and the efficiency of the turbine. The equation 8 was used to estimate the power potential at Myombwe River;

$$P = \rho * Q * g * H * \eta \quad (8)$$

Where P is the potential of the Myombwe River, ρ is the water density, g is the acceleration due to gravity, H is the head of the river and η is the efficiency of selected turbine.

Turbine selection

There are various types of turbines. Selection of turbine type depends on the site data; mainly the head and flow discharge. Other technical parameters include efficiency, and cost.

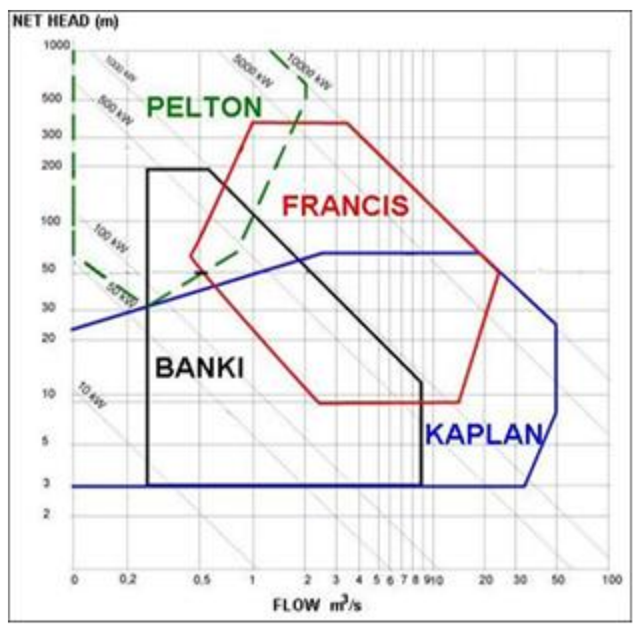

Figure 2: Turbine Selection Chart.
Source (Inforse, 2014)

ISSN:2321-1156
International Journal of Innovative Research in Technology & Science(IJIRTS)

Results and Discussion

From estimation works and methodologies done the results obtained are follows;

Hydropower Potential of Magunguli Water fall

The following information were obtained on the site by using GPS; Potential Sediment Tank: 08 42 332 S, 035 10 397 E, Elevation is 5333 m. Potential Wear: 08 42 281 S, 035 10 371 E, Elevation is 5525 m, Wear Width is 20 m. Potential Power House: 08 42 635 S, 035 10 483 E, Elevation is 4697 m, from these data and formula 1 the results of head obtained was;

H = 5333 m – 4697 m = 636 m

The hydrological data of the river were collected and analysed by using Karl Pearson's methods and results are tabulated in Table 3. This table shows how the correlation analysis was carried out for the given values of the flows of Little Ruaha River and rainfall average of the Myombwe catchment.

Table 3: Karl Pearson's Coefficient of Correlation (r) Calculation

X	Y	X^2	Y^2	XY
27.1	220.5	735.5	48620.3	5979.6
33.3	112	11110.9	12544	3732.7
39.6	404	1568.2	163216	15999.1
38.3	105	1463.1	11025	4015.8
20.1	4	402.4	16	80.3
13.0	-	167.7	-	-
9.6	-	91.2	-	-
7.6	-	57.9	-	-
5.8	-	33.4	-	-
4.4	18	19.3	324	78.99
3.6	41	12.8	1681	146.7
11.8	239.5	139.2	57360.25	2826.8
		15801.6	**294786.5**	**32859.7**

From values given in Table 3 and equation of correlation the following results of correlation is given as.

$$r = \frac{\sum 32859.76}{\sqrt{(15801.56)(294786.5)}}$$

r = 0.5

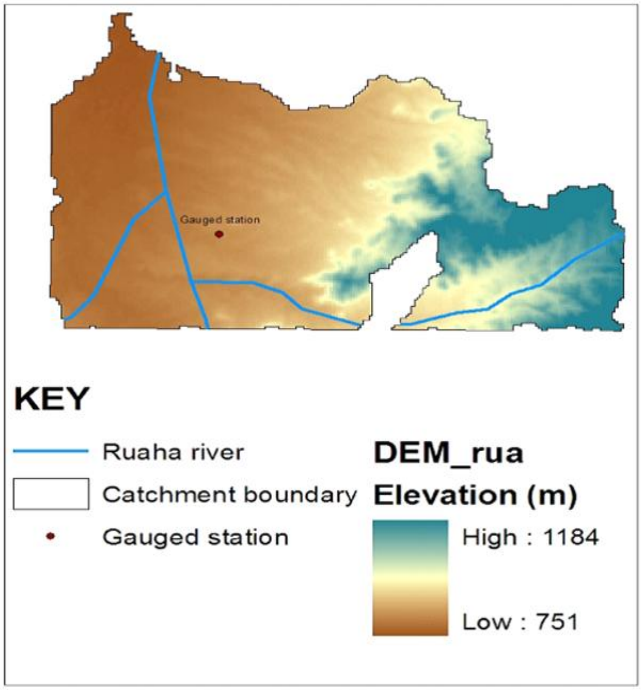

Figure 1(a): Little Ruaha River catchment area delineated using Arc view GIS 9.3.

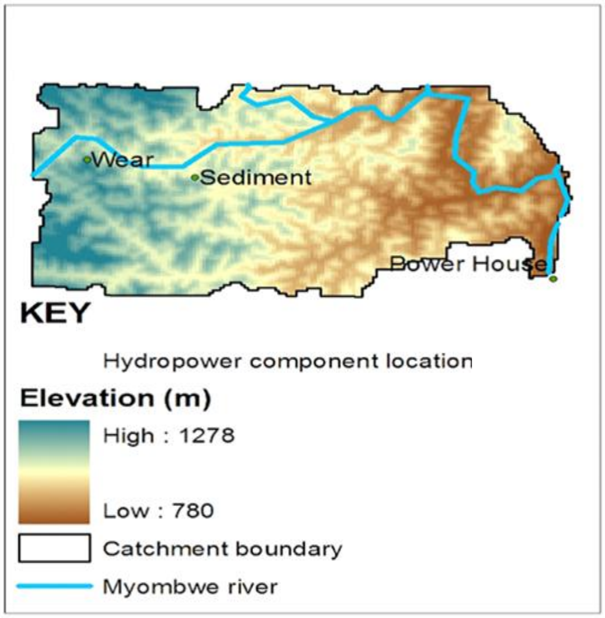

Figure 1(b): Hydropower component location within Myombwe catchment.

The correlation value (r) = 0.5 from Table 3, shows that there is a correlation between two regions. Therefore, the above evidence proves that the regions have similar hydrology. According to the [14] the area ratio method is suitable "when the drainage area at the un-gauged site is within 50% to 150% of the drainage area of the gauged site". The catchment areas of un-gauged and gauged catchments shown in Fig. 1(b) and Fig. 1(a) have areas of 85.7 m^2 and 154.9 m^2 respectively. Equation 2 was used to calculate and to check the flow data values at un-gauged site.

$$M_{ug} = \frac{85.7 * M_g}{154.9}$$

The cross sectional area of Myombwe River was obtained from the equation (5)

$$s = 20\left(\frac{0.1 + 0.6 + 0.4 + 0.2}{4}\right)$$

s = 6.5 m^2

The cross sectional flow area of the Myombwe stream calculated is 6.5 m^2

Velocities and Flow

Table 4: Velocities in m/s obtained in different seasons

Velocities obtained during dry season			Velocities obtained during rainy season			Velocities obtained immediately after rain		
V_{20}	V_{60}	V_{80}	V_{20}	V_{60}	V_{80}	V_{20}	V_{60}	V_{80}
0.1	0.2	0.4	2.1	3.2	6.3	1	2	3

Velocity obtained during dry season

Vm = 0.25* [1.1+ 1.7 + (2*1.6)] = 0.23 m/s

From Table 4 minimum flow of the river during dry Seasons, September to November was found to be 0.23 m/s

Q = 0.23 m/s*.6.5m^2= 1.5 m^3/s

Velocity obtained during rainy season

Vm = 0.25* (0.1 + 2(0.2) + 0.4) = 3.7 m/s

From table 4 the velocity obtained during rainy season was found to be 3.7 m/s

Q = 3.7 m/s*6.5m^2 = 24.1 m^3/s

Velocity obtained immediately after rain

Vm = 0.25* (2.1 +2 (3.2) + 6.3) = 2 m/s

From table 4 the velocity obtained during rainy season was found to be 2 m/s

Q = 2 m/s*6.5 m2 = 13 m^3/s

Estimation a Flow-Duration Curve for Un-Gauged Catchment

Table 6 was used in plotting the flow duration curve for un-gauged catchment which is shown in Figure 1b. In preparing flow duration curve, the discharge flow data of the river was arranged in a descending order. A range of values as class intervals was established from the available daily flows data, from the year 2001 to 2010.

Table 5: Mean monthly flow of Myombwe River for 10 years.

Year	Nov	Dec	Jan	Feb	Mar	Apr
2001	0.4	5.2	35.5	49.6	57.9	44.3
2002	2.9	9.1	38.5	36.5	26.4	39.6
2003	5.7	8.5	14.3	13.8	40.9	42.0
2004	5.6	12.0	25.6	26.6	31.2	25.8
2005	1.7	1.8	5.5	17.0	20.7	27.9
2006	2.0	38.5	56.0	58.2	54.6	38.8
2007	4.9	15.8	30.7	58.1	56.7	55.0
2008	3.8	15.2	24.9	28.5	44.8	47.2
2009	6.6	8.0	30.3	30.9	43.4	33.0
2010	2.3	3.8	9.9	14.2	19.4	28.7
Year	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
2001	23.2	13.8	9.2	6.9	5.3	4.3
2002	17.9	11.9	9.1	7.4	5.2	4.9
2003	18.0	10.8	8.6	7.0	6.3	5.4
2004	11.7	8.6	7.2	6.3	5.1	3.6
2005	18.0	12.2	9.2	7.8	6.1	3.7
2006	24.7	16.9	11.7	9.7	7.9	6.3
2007	34.1	20.9	13.7	9.7	5.7	3.7
2008	21.8	12.4	9.3	7.1	5.3	3.8
2009	16.1	11.2	8.9	7.2	5.4	3.3
2010	15.3	10.9	8.6	7.1	5.4	4.8

Since the hydrology for Little Ruaha, which is gauged, was positively correlated to that of Myombwe River it is possible to estimate the mean monthly flow on it for the past 10 years. The results in Table 6 shows that the maximum monthly flow rate was 21.910 m^3/s, which was available in March, and minimum monthly flow rates 1.979 m^3/s which was in November.

Table 6: Monthly flow data and percentage of time for the Flow duration Curve

Collected Data		Analyzed values			
Mo nth	Q (m^3/s)	Month	Q (m^3/s) de-scend-ing	Ran k	Pp (%)
Jan	15.00	Mar	21.91	1	7.6
Feb	18.44	Apr	21.16	2	15.
Mar	21.91	Feb	18.44	3	23.
Apr	21.16	Jan	15.00	4	30.
Ma	11.10	May	11.10	5	38.
Jun	7.16	Jun	7.16	6	46.
Jul	5.28	Dec	6.53	7	53.
Au	4.21	Jul	5.28	8	61.
Sep	3.20	Aug	4.21	9	69.
Oct	2.43	Sep	3.20	10	76.
No	1.98	Oct	2.43	11	84.
Dec	6.53	Nov	1.98	12	92.

The average monthly flow data obtained from the Table 5 was used to draw the flow duration curve shown in Figure 4, which describes the trend of flow duration of Myombwe River. Results show that with increase percentage time the discharge of the river decreases, while with less percentage equalled or exceeded the discharge of the river increases.

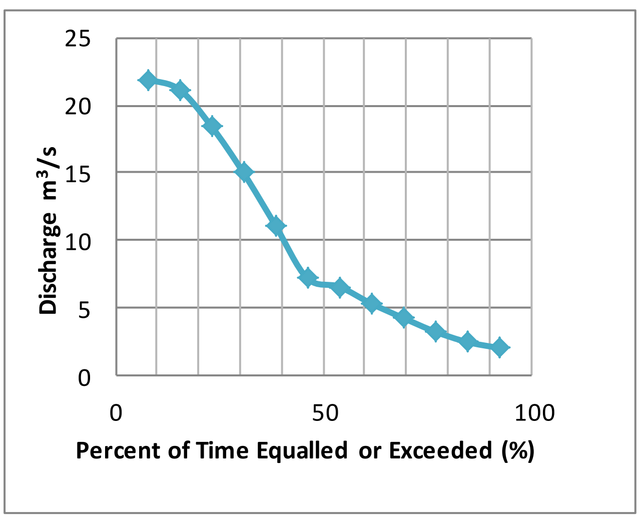

Figure 4: Flow duration curve of Myombwe River.

The Power Potential Available

The data used to estimate available potential power are;
Gross head (H) =636 m
Net head loss should be not more than 5% [15].
The 5% head loss =31.8 m.
Gravitational constant (g) = 9.81 m/s^2
Discharge (Q) = 1.98 m^3/s
The efficiency of turbine (η) = 0.8 as shown in Table 7
Gross head (H) - Head loss (h) = Net head (Hn) = 604.2 m
Density of the water (ρ) =1000 kg/m^3

As stated in the methodology selection of turbine type depends on the site data; mainly the head and flow discharge, which through standard guides gives the head. The flow 1.979 m^3/s was used to determine the hydropower potential because it covers the flows data of ten years which are reliable rather than using 1.5 m^3/s which was obtained in a short period of field measurement. Considering the head of the plant, power generated and discharge rate of the plant with help of Turbine selection chart, the proposed turbine type for Myombwe site is Pelton. Hydraulic efficiency (η) of the turbine was found by using Table 7 to be suitable for the type of the envisaged hydropower plant.

Table 7: Typical Efficiency of Turbines [16]

Turbine	Efficiency Range
Impulse turbine	
Pelton	80-90%
Turgo	80-95%
Cross flow	65-85%
Reaction turbine	
Francis	80-90%
Pump as turbine	60-90%
Propeller	80-90%
Kaplan	80%

Therefore, power potential (P) available at site is given by using equation 8;

$$P = 9.81 * 1000 * 604.2 * 0.8 * 1.98$$
$$P = 9388.68797 \text{ kW}$$

The power potential available = 9388.69 kW

Conclusions and Recommendations

This research has shown that the hydraulic head is 636 m, flow rate 1.979 m^3/s, efficiency is 80% and power potential is 9.39 MW. Therefore there is a high hydrological potential for hydropower production at Magunguli Waterfalls in Myombwe River which is surrounded by 12 villages; Magunguli, Ikiyowela, Isaula, Idete, Nyigo, Ihawaga, Ikimilinzowo, Udumka, Ihomasa, Kilolo, Mtambula, and Ipilimo. The type of turbine which is suitable for installation is Pelton turbine, which is effective to meet the designed head of 636 m and 1.979 m^3/s discharge. Results presented in this paper have clearly elucidated the hydrological potential of Magunguli waterfalls in un-gauged Myombwe River.

Based on these and other technical parameters the hydropower potential of Myombwe River is viable. This paper recommends the following;

i. Proper monitoring and control of the catchment area will be necessary to ensure efficient utilization, maintenance of its hydrological potential and sustainable development of hydropower systems in Magunguli waterfalls.

ii. More investigations, to cover other waterfalls in Tanzania, should be conducted to establish their hydrological potential for hydropower scheme so as to meet the needs of the rural societies.

iii. The Government, private organizations and development partners of Tanzania should provide financial and logistic support to embark on electrification of the needy 12 villages surrounding Magunguli waterfalls.

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