Evaluation of Hydropower Potential of Kapologwe Waterfalls for Rural Electrification in Rungwe District, Mbeya Region Tanzania

[1]Charles J. Mgina* and [2]Zacharia Katambara

[1]Department of Mechanical and Industrial Engineering, Mbeya University of Science and Technology, P.O Box 131 Mbeya, Tanzania

[2]Department of Civil Engineering, Mbeya University of Science and Technology, P. O Box 131 Mbeya, Tanzania

DOI: https://doi.org/10.62277/mjrd2024v5i40064

ARTICLE INFORMATION

Article History

Received: 27th August 2024
Revised: 30th October 2024
Accepted: 02nd November 2024
Published: 05th December 2024

Keywords

Hydropower potential
Kapologwe Waterfalls
Small-scale hydroelectricity
Rural electrification
Pelton turbine efficiency

ABSTRACT

Hydropower remains one of the most significant renewable energy sources, accounting for a substantial proportion of global electricity production. In Tanzania, where electricity access is limited, particularly in rural areas, untapped hydropower resources could play a critical role in meeting local energy needs. This study investigates the hydropower potential of the Kapologwe Waterfalls on the Kala River, located in Rungwe District, Mbeya Region. Key factors influencing hydropower generation, including hydraulic head, flow rate, and turbine efficiency, were analysed using land survey techniques and hydrological modeling. The hydraulic head was measured at 605.15 meters, and flow rates were calculated based on field data, with a design flow of 1.542 m^3/s. A Pelton turbine, known for its high efficiency under high-head, low-flow conditions, was selected for the site. The estimated power potential is 7.238 MW, suggesting that the Kapologwe Waterfalls could significantly contribute to localised electrification and reduce reliance on Tanzania's national grid. This research highlights the feasibility of small-scale hydropower projects in rural Tanzania and their potential to alleviate energy poverty.

* Corresponding author's e-mail address: charlesmgina@yahoo.com (Mgina, C.J.)

1.0 Introduction

Hydropower remains a dominant renewable energy source, providing significant electricity production globally (Santl & Steinman, 2015). Despite being used for over a century, hydropower continues to be the most prevalent source of renewable electricity (Booker et al., 2014). In 2018, it generated 4325 TWh of electricity, representing 68.7% of renewable energy production and 17.3% of the global total (International Energy Agency [IEA], 2019). The International Hydropower Association (2015) reported that hydropower accounts for 16% of the world's electricity, with potential for growth, particularly in regions with untapped resources. Small hydropower systems, those up to 10 MW, had an installed capacity of 75 GW in 2011/2012, with the majority (65%) located in Asia, followed by Europe (16%), the Americas (13%), Africa (5%), and Oceania (1%) (Liu et al., 2013). However, there remains considerable potential, especially on the African and American continents.

In Tanzania, less than 15% of the population has access to electricity, making it one of the least electrified countries in sub-Saharan Africa (Kiwia, 2013). The IEA (2021) identified Tanzania as having the fifth-largest population globally without electricity access, with around 36 million people affected. In rural areas, only about a quarter of the population has access to electricity (Mini-Grids Partnership, 2020). Despite these challenges, Tanzania possesses sufficient hydropower resources to meet local energy needs, particularly in off-grid areas (Mtalo, 2005). Tanzania's current energy demand stands at 1031 MW, nearly equal to its installed capacity of 1082 MW, highlighting the urgency of exploring renewable sources like hydropower (Mtokambali & Jun, 2014).

The country's growing energy demand, driven by an average GDP growth of 7% per year since 2000 (Bank of Tanzania [BOT], 2012), has outpaced electrification efforts, particularly in rural areas (Mdee et al., 2018). These areas often suffer from unreliable electricity supply and frequent power outages. Developing decentralised power schemes, such as mini-grids, can provide a solution to the energy shortage in rural regions and reduce the burden on the national grid. However, challenges such as high investment costs, a preference for centralised power, and limited research on hydropower potential continue to hinder progress (Bishoge *et al.,* 2018).

To address these issues, Tanzania has made national commitments, including the development of large-scale hydropower projects like the 2115 MW Julius Nyerere hydropower plant and dam in the southern zone. Yet, smaller hydropower projects in regions with high renewable potential, like Kapologwe Waterfalls, remain underexplored. Such projects could provide localised energy solutions, reducing energy poverty and contributing to the nation's socio-economic development. The Kapologwe Waterfalls, specifically, have yet to be fully evaluated for their hydropower potential in the Rungwe District. This study aims to fill this gap by assessing the waterfalls' capacity to meet local energy demands, thereby contributing to both community welfare and national energy strategies.

2.0 Materials and Methods

2.1 Study Area

The research was conducted in the middle reaches of the Kiwira River, specifically at Kapologwe Waterfalls, located in Rungwe District in Tanzania's Mbeya Region. The Kiwira River originates from the Poroto Mountains and flows into Lake Nyasa at Itungi in Kyela District. One of its major tributaries is the Kala River, which rises from the volcanic Rungwe Highlands at an altitude of 1500–2500 meters above mean sea level (m.a.s.l.). The Kapologwe Waterfalls, a growing tourist attraction due to their scenic basalt gorge, lie at an elevation of 960 m.a.s.l., approximately 25 kilometres from Tukuyu Township in Kisondela Ward. Kisondela Ward comprises seven villages: Kisondela, Bugoda, Lutete, Kibatata, Ndubi, Mpuga, and Isuba (Mtokambali & Jun, 2014). The study focused on evaluating the hydropower potential of this area.

2.2 Hydropower Potential

The hydropower potential of the Kala River depends on several factors, including the effective hydraulic head, flow rate, and the efficiency of the turbine used. The power potential P was calculated using Equation (1):

$$P = \rho * Q * g * H * \eta \quad (1)$$

where:

P is the power potential (in Watts),

ρ is the density of water (approximately 1000 kg/m^3), Q is the flow rate (in m^3/s),

g is the gravitational acceleration (9.81 m/s^2),

H is the hydraulic head (in meters), and

η is the efficiency of the turbine (Santl & Steinman, 2015).

2.3 Head Measurement

The head, which is the vertical distance between the water intake and the powerhouse, was measured using land survey techniques. A tape measure and an automatic level were used to measure distances and elevations, while GPS equipment provided precise coordinates for the powerhouse and sediment tank locations. The hydraulic head was calculated as the difference in elevation between the potential powerhouse site (PHC) and the sediment tank site (STC) (IEA, 2019).

2.4 Stream Flow Discharge

Stream flow discharge was determined using field measurements during the dry season, when a current meter was employed to record flow velocity and cross-sectional area. For the rainy season, the height of leaves and debris caught on riverbank vegetation, as well as sediment deposits, were used to estimate maximum water levels. The stream discharge Q was calculated using the continuity equation (Equation 2):

$$Q = VA \quad (2)$$

where:

Q is the discharge (in m^3/s),

V is the mean velocity of the water (in m/s), and

A is the cross-sectional area of the stream (in m^2) (Booker et al., 2014).

2.5 Correlation Analysis

Since the Kala River is ungauged, correlation analysis was necessary to compare it with the gauged Kiwira River, located nearby. Karl Pearson's coefficient of correlation was used to evaluate the relationship between rainfall data from the Kala River and the average flow rates of the Kiwira River. The correlation coefficient r was calculated using Equation (3):

$$r = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{(\sum(x-\bar{x})^2)(\sum(x-\bar{x})^2)}} \quad (3)$$

where:

x represents the monthly average flow rates of the Kiwira River,

y represents the monthly rainfall data for the Kala River,

$\bar{x}$ and $\bar{y}$ are the mean values of x and y respectively. The correlation coefficient r ranges from -1 (perfect negative correlation) to +1 (perfect positive correlation) (Mtokambali & Jun, 2014).

2.6 Estimating a Flow-Duration Curve for an Ungauged Catchment

To estimate the flow-duration curve (FDC) for the ungauged Kala River, a ratio of the catchment areas of the Kala and Kiwira rivers was used. The FDC was derived from gauged data for the Kiwira River, multiplied by the catchment area ratio. The flow-duration curve plots discharge rates against the percentage of time that specific flows are equaled or exceeded, as shown in Equation (4):

$$PP = m/(N+1)*100\% \quad (4)$$

where:

PP is the probability (%) that a given flow

Q was equaled or exceeded,

m is the ranked position of the flow rate in descending order,

N is the total number of recorded events (Adejumobi & Shobayo, 2015).

2.7 Selection of Turbine Type and Turbine Efficiency

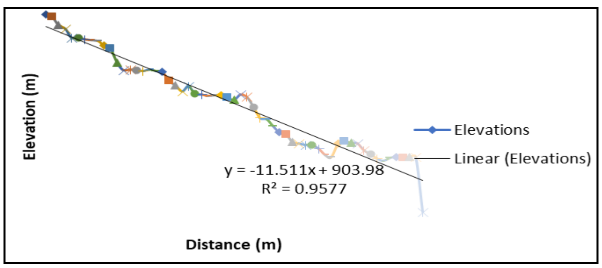
The turbine type was selected based on the head and flow conditions using standard turbine selection guides (Danish Hydraulic Institute, 2017). A Pelton turbine was chosen due to its high efficiency for high-head, low-flow conditions typical of the Kala River. The efficiency (η) of the selected turbine was based on standard tables, with typical ranges of 80–90% for Pelton, Francis, and propeller turbines, 80–95% for Turgo turbines, and 65–85% for cross-flow turbines (Adejumobi & Shobayo, 2015).

3.0 Results and Discussion

3.1 Hydrological Analysis

The hydrological analysis employed land surveying techniques, specifically the rise and fall method, to determine the longitudinal profile of the Kala River. This approach enabled the calculation of key river parameters, including the cross-sectional area and flow characteristics. The longitudinal profile of the river segments, as shown in Figure 1, provided essential data for identifying the elevations of critical components, such as the weir and powerhouse. These elevations are crucial for estimating the hydraulic head, a key factor in determining the hydropower potential. Tables 1 and 2 also show the calculated flow rates, which were based on measurements taken in the field and are used to figure out the river's discharge capacity and the viability of hydropower (Adejumobi & Shobayo, 2015; Santl & Steinman, 2015).

Figure 1
Longitudinal Profile



3.2 Hydraulic Head of Kala River

Figure 1 illustrates the relative positions of land features, both on the Earth's surface and beneath the water surface. The graphical presentation, which includes the rise and fall of elevations, shows a clear profile of the terrain. From a vantage point 2300 meters above the Kapologwe waterfalls, the elevation data reveal a significant drop toward the waterfall's shoulder. The highest elevation recorded is 988.85 meters, while the lowest, at the waterfall's shoulder, is 309.27 meters. This indicates a hydraulic head of 629.58 meters, which is sufficient to generate energy for an installed turbine. The substantial hydraulic head demonstrates how the water flow is driven by differences in gravitational potential energy due to elevation changes. As water descends over a vertical distance of 629.58 meters, it moves from a state of high potential energy to one of low potential energy, thus providing the necessary flow energy for hydropower generation (Berrada, 2019; Pandey et al., 2015; ESHA, 2004).

This method aligns with studies conducted by Berrada (2019), ESHA (2004), and Pandey et al. (2015), who also utilised land survey techniques to analyse site characteristics and calculate the ideal net mechanical power and net head for hydropower plants. These findings were essential in designing the plant's conduit, turbine, and generator, considering pressure losses and market options for optimal energy generation.

3.3 Hydraulic Head of Kala River

The discharge, or flow rate, was calculated using Equation 3 as referenced earlier. The mean measurements for the dry season (October and November) are presented in Table 1. Given the relatively small cross-sectional flow area, velocity measurements were taken at 60% of the subsection depth across the three segments of the river, noted as 0.6D1 to 0.6D3, as shown in Table 1.

Table 1 reveals an average velocity of 0.45 m/s, an average depth of 0.88 m, and an average width of 5.14 m. Using these values, the cross-sectional area of the flow was calculated as 4.53 m^2, and the corresponding flow rate was determined to be 2.02 m^3/s.

Furthermore, Manning's equation was employed to estimate the mean flow velocity and roughness in the waterfalls, based on the river's characteristics. For this analysis, a roughness coefficient (n) of 0.15 was chosen, reflecting conditions of "medium to dense shrubs and trees" along the riverbank. The lowest and highest cross-sectional areas were found to be 8.23 m^2 and 10.35 m^2, respectively, while the minimum and maximum flow velocities were 2.70 m/s and 3.27 m/s, as detailed in Table 2. The mean discharge during the dry and wet seasons was calculated as 15.24 m^3/s, again using Equation 3. These results suggest that wet season flows can be reasonably estimated by observing the river's physical features. Additionally, the wet season discharge was found to be approximately 13 times greater than that of the dry season, with a flow range of 26.43 m^3/s.

Table 1
Dry Season Flow Velocity, Wetted Cross Sectional Area and Discharge

SECTION	Flow Velocity (m/s) 0.6D1	0.6D2	$0.6D_3$	Average	Depth (m)	Width (m)	Area (m^2)	Flow (m^3/s
1	0.24	0.55	0.25	0.35	0.92	5.56	5.12	1.77
2	0.25	0.55	0.25	0.35	0.92	5.85	5.38	1.88
3	0.40	0.48	0.45	0.44	0.80	5.56	4.45	1.97
4	0.40	0.50	0.45	0.45	0.83	4.85	4.04	1.82
5	0.50	0.65	0.55	0.57	1.08	4.52	4.90	2.77
6	0.60	0.65	0.42	0.56	1.08	4.62	5.01	2.79
7	0.50	0.45	0.55	0.50	0.75	4.55	3.41	1.71
8	0.40	0.45	0.42	0.42	0.75	5.54	4.16	1.76
9	0.20	0.50	0.52	0.41	0.83	5.52	4.60	1.87
10	0.20	0.52	0.62	0.45	0.87	4.85	4.20	1.88
$Mean_{dry}$				**0.45**	**0.88**	**5.14**	**4.53**	**2.02**

3.4 Hydraulic Head of Kala River

Since the Kala River is ungauged, it was necessary to determine whether its hydrology correlates with a gauged river in a similar environment. The Kiwira River, which is gauged and located within the same habitat, was selected for comparison. Table 3 presents the average monthly flow data for the Kiwira River over a ten-year period, providing insights into the river's flow behaviour.

Table 2 illustrates the wet season velocity, cross-sectional area, and discharge for various sections of the river. The results indicate that the average velocity is 3.06 m/s, and the mean cross-sectional area is 9.29 m². The mean discharge for the wet season, calculated using Manning's equation, is 28.45 m³/s.

Table 2
Wet Season Velocity, Cross Sectional Area and Discharge

SECTION	Mean Depth(m)	Mean Width(m)	Area (m^2)	P	R=A/P	$R^{2/3}$	$S^{1/2}$	n	V (m/s)	Flow (m^3/s)
1	0.89	9.25	8.23	11.03	0.75	0.9	0.5	0.15	3.00	24.7
2	0.85	9.7	8.25	11.4	0.72	0.81	0.5	0.15	2.70	22.3
3	1.02	9.6	9.79	11.64	0.84	0.89	0.5	0.15	2.97	29.0
4	0.95	9.45	8.98	11.35	0.79	0.86	0.5	0.15	2.87	25.7
5	0.98	9.95	9.75	11.91	0.82	0.98	0.5	0.15	3.27	31.9
6	0.99	8.9	8.81	10.88	0.81	0.98	0.5	0.15	3.27	28.8
7	1.05	9.15	9.61	11.25	0.85	0.95	0.5	0.15	3.17	30.4
8	0.89	9.95	8.86	11.73	0.75	0.93	0.5	0.15	3.10	27.5
9	1.04	9.85	10.24	11.93	0.86	0.91	0.5	0.15	3.03	31.1
10	1.04	9.95	10.35	12.03	0.86	0.96	0.5	0.15	3.20	33.1
$Mean_{Wet}$	**0.97**	**9.89**	**9.29**	**11.51**	**0.81**	**0.92**	**0.5**	**16.95**	**3.06**	**28.45**

Table 3 shows that the peak flow occurs in April, with an average flow of 39.60 m³/s, while the lowest flow is observed in November, with an average of 3.58 m³/s. To determine whether the hydrology of the ungauged Kala River correlates with the gauged Kiwira River, Karl Pearson's coefficient of correlation (r) was calculated using the average monthly flows of the Kiwira River and the rainfall data for the Kala catchment, as shown in Table 4.

Table 3

Kiwira River Average Monthly Flows over a Ten-Year Period

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
2012	0.40	5.17	35.48	49.57	57.92	44.33	23.16	13.80	9.20	6.87	5.28
2013	2.94	9.15	38.49	36.46	26.42	39.62	17.85	11.86	9.05	7.45	5.21
2014	5.66	8.49	14.30	13.79	40.93	42.02	18.01	10.78	8.58	7.03	6.32
2015	5.60	12.00	25.59	26.57	31.17	25.79	11.67	8.56	7.20	6.26	5.05
2016	1.70	1.82	5.50	16.99	20.69	27.91	17.99	12.17	9.21	7.77	6.14
2017	1.97	38.52	55.98	58.22	54.58	38.85	24.67	16.87	11.72	9.69	7.92
2018	4.86	15.80	30.68	58.07	56.74	54.97	34.05	20.91	13.68	9.73	5.73
2019	3.82	15.24	24.92	28.48	44.79	47.21	21.81	12.44	9.31	7.06	5.30
2020	6.56	8.00	30.34	30.92	43.41	33.01	16.08	11.19	8.92	7.21	5.39
2021	2.25	3.83	9.91	14.21	19.38	28.75	15.33	10.92	8.60	7.08	5.43
Mean	**3.58**	**11.80**	**27.12**	**33.33**	**39.60**	**38.25**	**20.06**	**12.95**	**9.55**	**7.61**	**5.78**

Source: REN21, (2014)

The results show that the peak monthly flows of 39.6 mm is experienced in the month of April, and the lowest mean flows of 3.58mm is observed in November. The correlation analysis was done for average monthly flows of Kiwira River and rainfall (mm) for Kala catchment as shown in Table 3 and Table 4.

Table 4

Average Flows and Rainfall Data (Decade)

Month	Mean Monthly Flows (m^3/s)	Rainfall Mean (mm)
January	27.1182	132.3
February	33.3273	120
March	39.6018	206
April	38.2452	130
May	20.0638	19.4
June	12.9493	0.8
July	9.5467	0.8
August	7.6142	0.3
September	5.7773	0
October	4.3882	1.3
November	3.577	39.4
December	11.8028	149

The correlation analysis yielded a coefficient (r) of 0.78, indicating a strong positive correlation between the flow rates of the Kiwira River and the rainfall in the Kala catchment. This suggests that the hydrological behaviour of the two rivers is similar, which can be attributed to their proximity and similar environmental conditions.

The correlation was further validated using data from other studies, including Gang et al. (2015), Archfield and Vogel (2010), and Kentel and Ergen (2015), who also demonstrated that rivers in similar localities tend to exhibit comparable hydrological patterns. Consequently, the findings support the hypothesis that the Kiwira and Kala Rivers share similar hydrological characteristics, making it feasible to use data from the Kiwira River to model the hydrology of the ungauged Kala River.

3.5 Flow Duration

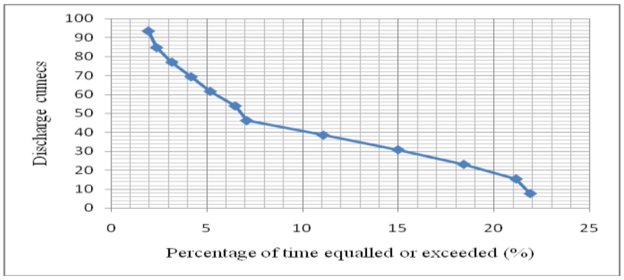
The flow duration for the ungauged Kala River is presented in Table 5. The discharge flow statistics were organised in descending order to create the flow duration curve. Given the positive correlation between the hydrology of the gauged Kiwira River and the Kala River, the flow duration curve was developed using ten years of monthly flow data. Class intervals were established based on the daily flow data available. Table 6 shows that the maximum monthly flow rate is 21.91 m^3/s, observed in March, while the minimum monthly flow rate is 1.542 m^3/s, recorded in November.

Table 5
Flow Duration of Kala River

Collected Data		Analyzed values			
Month	Q (m^3/s)	Month	Q (m^3/s) descending	Rank	Pp (%)
January	15.1	March	21.91	1	7.69
February	18.44	April	21.16	2	15.39
March	21.91	February	18.44	3	23.08
April	21.16	January	15.1	4	30.77
May	11.1	May	11.1	5	38.46
June	7.16	June	7.16	6	46.15
July	5.28	December	6.53	7	53.85
August	4.21	July	5.28	8	61.54
September	3.21	August	4.21	9	69.23
October	2.43	September	3.21	10	76.92
November	1.542	October	2.43	11	84.62
December	6.53	November	1.542	12	92.31

Figure 2 shows the flow duration curve, illustrating the trend of Kala River's flow duration. The curve plots daily stream flow against the percentage of time the stream flow value is exceeded (Katambara, 2021). The results indicate that as the percentage of time increases, the flow rate decreases, signifying that there is a high likelihood of the stream flowing but at a decreasing rate over time. This suggests that the availability of flow for hydropower production may decline, and thus, a design flow lower than 100% of the time should be considered if the system is to remain independent. Otherwise, supplemental energy sources might be required.

Figure 2
Flow Duration Curve



3.6 Turbine Selection

The potential weir, sediment tank, and powerhouse locations, along with their elevations, are shown in Table 7. The gross head for the Kala River hydropower site is calculated to be 637 meters, derived from the elevation difference between the diversion site (946.27 m) and the powerhouse (309.27 m). Accounting for a 5% head loss as suggested by Pandey (2015), the net head is 605.15 meters.

Using the net head (H = 605.15 m), gravitational constant (g = 9.81 m/s^2), discharge (Q = 1.542 m^3/s), turbine efficiency (η = 0.8), and water density (ρ = 1000 kg/m^3), the hydropower potential P was calculated as follows:

PP=ρ×g×H×η×Q=1000×9.81×605.15×0.8×1.542= 7.238MW

This confirms a potential power output of 7.238 MW, making the Kala River a viable site for small-scale hydropower generation.

Table 7
Latitude, Longitude and Elevation for Location of Hydropower System

Location	Latitude South	Longitude East	Elevation (m)
Potential Weir	93 885 94	33 610 010	946.27
Sediment Tank	93 864 77	336 09 860	935.42
Potential Power house	93 919 55	336 128 16	309.27
Foot of Dam	93 932 52	336 13 207	87.59
Dam Shoulder	93 930 98	336 13 250	327.59

4.0 Conclusion

This study demonstrates that the Kapologwe Waterfalls on the Kala River possess significant potential for hydropower generation. The hydrological analysis indicated a hydraulic head of 605.15 meters with an average flow rate of 1.542 m^3/s, making the site well-suited for a Pelton turbine system. The power potential of 7.238 MW confirms that this site is viable for small-scale hydropower development. Moreover, the strong correlation between the Kala and Kiwira Rivers supports the use of flow data from the Kiwira to model the ungauged Kala River. The findings suggest that hydropower from the Kapologwe Waterfalls could meet local energy needs, promoting socio-economic development in surrounding rural areas and easing the demand on Tanzania's national grid. However, further environmental and socio-economic impact assessments are recommended before the project is implemented.

5.0 Recommendations

The study's findings recommend the implementation of Small-Scale Hydropower at the Kapologwe waterfalls to improve local electrification rates, contribute to the socio-economic development of the region, and expand the study to other untapped sites.

6.0 Funding Statement

No grants from funding organisations in the public, private, or non-profit sectors were given to this research.

7.0 Acknowledgement

The author would like to thank everyone who gave technical support throughout the duration of the research.

8.0 Conflict of Interest

The authors declare that they have no associations with or participation in any group or organisation that might have a vested financial or non-financial interest in the topics or resources covered in this paper.

9.0 References

Abe, N., & Hong, H. (2012). Millennium development goals and energy access: Strategies for success. *Energy Policy, 45,* 285–292.

Adejumobi, I. A., & Shobayo, E. E. (2015). Hydropower energy resources in Nigeria: An assessment. *Renewable Energy and Sustainable Development, 1* (2), 34–45.

Archfield, S. A., & Vogel, R. M. (2010). Map correlation method: Selection of a reference streamgage to estimate daily streamflow at ungaged catchments. *Water Resources Research, 46* (10). https://doi.org/10.1029/2009WR008481

Bank of Tanzania (BOT). (2012). *Economic growth report.*

Berrada, A. (2019). Hydropower generation: Design considerations for turbines and power plants. *Renewable Energy Engineering Journal, 45* (3), 85–97.

Bishoge, O., Zhang, L., & Mushi, W. G. (2018). The potential renewable energy for sustainable development in Tanzania: A review. *Clean Technologies, 2* (2), 115-129. https://doi.org/10.3390/cleantechnol2020010.

Booker, A., Hansen, B., & Freeman, D. (2014). The role of hydropower in global electricity generation. *Renewable Energy Journal, 68,* 123–131.

Danish Hydraulic Institute (DHP). (2017). *Hydraulic turbines: Selection guide.*

European Small Hydropower Association (ESHA). (2004). *Guide on how to develop a small hydropower plant.* ESHA Publications.

Gang, L., Fu, L., Zhan, W., & Song, W. (2015). Hydrological modeling and flow correlation analysis for ungauged rivers in northern China. *Journal of Hydrology, 520,* 16–29.

Hydropower Research and Engineering Technology (HRET). (2017). *Turbine selection and design.*

International Energy Agency (IEA). (2019). *World energy outlook.* https://www.iea.org/reports/world-energy-outlook-2019.

International Energy Agency (IEA), International Renewable Energy Agency, United Nations Statistics Division, World Bank, & World Health Organization. (2021). *Tracking SDG 7: The energy progress report.*

International Hydropower Association (IHA). (2015). *Hydropower status report.* https://www.hydropower.org/publications/2015-hydropower-status-report.

Katambara, Z. (2021). Application of conceptual model in developing the Jangwani mini-hydropower plant in Ruvuma Region, Tanzania. *MUST Journal of Research and Development, 1*(5), 290–297.

Kentel, E., & Ergen, K. (2015). Estimating streamflow in ungauged basins using watershed similarity: A case study in the Eastern Black Sea Region, Turkey. *Water Resources Management, 29* (12), 4413–4428.

Kiwia, H. R. (2013). Electrification in Tanzania: A critical review. *Energy Policy Review Journal, 35* (3), 215–223.

Liu, H., Masera, D., & Esser, L. (2013). *World small hydropower development report.* United Nations Industrial Development Organization.

Mdee, A., Thorley, L., & Watson, E. (2018). The electrification of rural Tanzania. *Energy Research & Social Science, 39,* 154–164.

Mini-Grids Partnership. (2020). *Rural electrification in Tanzania: A case study. Mini-Grids Progress Report.*

Mtalo, E. (2005). Hydropower resources of Tanzania: Opportunities and challenges. *Energy Policy, 34* (1), 1–7.

Mtokambali, R., & Jun, L. (2014). Tanzania's energy load demand: Future prospects and sustainability. *Energy Sustainability Journal, 29* (3), 123–130.

Narula, K., Reddy, B. S., & Pachauri, S. (2012). Electricity for all: Enabling social and economic development through access to clean energy. *Energy for Sustainable Development, 16* (1), 85–92.

Pandey, A. (2015). Estimation of hydropower potential in ungauged rivers: Case studies from South Asia. *Renewable Energy Journal, 50,* 299–315.

Pandey, A., Rajvanshi, D., & Kothari, D. P. (2015). A comprehensive overview of hydropower development in India: Opportunities, challenges, and benefits. *Renewable and Sustainable Energy Reviews, 50,* 299–315.

REN21. (2014). *Renewables 2014 global status report.* Paris: REN21 Secretariat.

Sangal, S., Garg, M. K., & Kumar, M. (2013). Selection of hydro turbine for hydroelectric power plant. *Energy Reports, 2* (1), 23–28.

Santl, F., & Steinman, S. (2015). Hydropower: A renewable energy source. *Energy Systems Review Journal, 37* (5), 245–252.