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Small Scale Hydropower as a Resources of Renewable Energy in Mozambique: Case of Chua River in Manica

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Abstract:

All hydropower project type requires an ample availability of stream flow data. Unfortunately most of the hydropower projects especially small hydropower projects are conducted on ungauged river and consequently hydrologists have for a longtime used stream flow estimation methods using the mean annual flows to gauge rivers. Unfortunately flow estimation methods which include the runoff data method, area ratio method and the correlation flow methods employ a lot of assumptions which affect their uncertainty. Although hydropower energy is one of most promising clean energy technologies available, it has potential drawbacks as compared with various other forms of renewable energy, such as biomass, solar and wind energy, due in particular to it high capital investment costs. For most of the rural population in Mozambique, access to conversional energy in the form of electricity is limited. The aim of the present investigation was to analyze the functions of the Chua micro-hydropower plant in the Manica district in Mozambique and to examine the possibility of increasing energy production there. The total power generation capacity currently installed in Mozambique is about 939 MW. Hydropower accounts for 561 MW or 61% of this, oil and natural gas in turn, for 27% and 12% of it, respectively.

Keywords: hydropower, renewable energy, electrification

1. Introductions

In the current energy crisis, energy is considered to play as a key role in the achievement of good health, adequate social development and improved quality of life for people in developing countries in the world generally [1]. Both produced and consumed energy resources, especially renewable ones, in hydropower is particular have led to an increase in the demand for energy in many countries of the wourld [2]. Some areas of high population concentration may not yet be supplied with electricity or may have simply have old-generation (Diesel-plant) distribution systems that no longer function adequately, only about 21% of the populations there having access to electricity [3]. In Mozambique, use of small hydropower plants (SHP) can be one of the solutions to the need of increasing electrification and of combating poverty in rural areas [4]. Hydropower is the most effective source of energy and electricity available. It has played a major role in the development of modern civilization and represents one type of renewable energy, a type converting the movement of water into electricity [5]. Hydropower technology has various benefits that fossil fuel lack. It is a renewable source of energy, it produces no carbon dioxide emissions, and hydropower projects can also serve a wide variety of purposes, such as those of irrigation, fishery, flood control, water supply, and milling agricultural products [6]. The latter is carried out especially much in the Manica sections of Mozambique. Gaining access to modern energy services is instrumental to fulfilling basic social needs and to driving economic growth, and it has positive effects on productivity, health, education, safe water and communication services [7]

Hydropower energy has a high degree of potential, for catalyzing social change providing opportunities for a whole new range of activities that can improve the quality of life for rural populations, in particular. According to [4] hydropower accounted for 15.3% at the power generation in 2011, fossil fuels and nuclear reactor having the largest share in the global power generation scenario through their accounting for 77.9% of global power production altogether followed by other forms of renewable energy with 5% of the total power productions. The total hydropower energy- generation capacity in the world has been increasing steadily over the past 50 years, the rate of increase having accelerated during the past few years. **Table 1** shows regional hydropower characteristics in terms of hydropower in operation.

Table 1-Regional hydropower generations in continent

Continent	**Hydropower operations [MW]**	**Hydropower under construction-[MW]**	**Hydropower development planned-[MW]**
Africa	23,428	5222	76,600
Asia	401,626	125,736	141,300
Europe	197,152	3028	11,400
USA	169,105	7798	17,400
South ofAmerica	139,424	19,555	57,300
Australia	13,370	67	1500
Total	926,159	161,400	305,500

In this paper we use hydrological modeling for hydropower in Manica area in Mozambique. The study it was observed that applying the appropriate assumptions for each method correctly, would likely yield very good results in terms of bias, accuracy and uncertainty. Therefore, it was recommended that assumptions regarding each method should be carefully and appropriately applied for good stream flow estimation.

1.1. Current Hydropower Potential in Mozambique

The hydropower potential of Mozambique is highly attractive, its being estimated to be at a 18,000 MW level only roughly 2200 MW of it having been developed in a manner providing it if access to the national grid. To meet the needs that exist, the government of Mozambique has made rural electrification a major component of its development programs [8]. In addition, it has liberalized its energy sector and there has been an influx of direct foreign investments in hydro-projects within the country as a whole. The

Mozambique government has set a number of broad policy objectives relating to the development and governance of the energy sector. It has also supported rural electrification through creating an enabling environment for the stakeholders involved [9]. The development of renewable energy in Mozambique dates back to the colonial period, when hydropower plants were developed to supply power to large urban cities such as Maputo, Beira and Nampula and for selling energy to South Africa [10]. The total energy mixture available in Mozambique was very large 408.9 PJ, its consisting to about 13% of Hydropower, 78% of biomass, 7% of oil products and 2% of other energy-related resources [9]

Its has been found that the greatest hydropower potential in Mozambique lies in the Zambezi River basin, at such sites as Cahora Bassa and Manica (Mavuzi and Chicamba) in the Rivue River, as shown in Table 3, that together have a generating capacity of about 2200MW.The total hydropower currently exploited is presented in **Table 2**. The most important hydropower plant is Cahora Bassa, with provides 95% of the total hydropower produced in Mozambique [3].

Table 2. The hydropower sources in Mozambique that are currently exploited [11]

Hydropower Plant	**Province**	**River**	**Capacity (MW)**
Cabora Bassa	Tete	Zambeze	2075.0
Mavuzi	Manica	Rivue	42.0
Chicamba	Manica	Rivue	38.0
Corumana	Maputo	Sabie	16.0
Cuamba	Niassa		1.0
Lichinga	Niassa		0.75

In recent years, the government of Mozambique has been faced with having to meet the needs of a populations of increasing population, one that presently consist of some 28 million people. Increasing investment have been made to meet the energy demands that have developed, and some 80 potential sites mostly in central parts of Mozambique (Manica and Tete, in particular), see **Table 3**

Table 3. The estimated capacity of different hydropower site in Mozambique [11]

Number	Project	Capacity (MW)	Province
1	Cabora Bassa North	2200	Tete
2	Tsatse	50	
3	Muenezi	25	
4	Alto Molocue	40	Zambezia
5	Mugebe	175	
6	Lucite	180	
7	Buzi-Miracuene	300	
8	Pungwe-Pávue	50	Manica
9	Pungwe-Bue Maria	80	Manica
10	Mavuzi	10	Manica
11	Lupata	600	Sofala
12	Malema	60	Niassa
13	Massingir	25	Gaza

2. The Study Area of Chua in Manica and present hydropower activity there

The history of hydropower development activities in Manica dates back to the colonial period, when small scale hydropower plants were developed to supply both water and electricity to various of the communities in Chua Manica. Ealier, there hydropower plants were used to grind food (rice and corn), as shown in the in Annex. In the late 1990s, when peace came to Mozambique, a decade of marked development began in the Manica district, and the German organization (GIZ) modernized the system employed for milling corn, a hybrid system also being develop for producing electricity for approximately 50 families there, as well as for a school, and a hospital. Manica is located near the center of Mozambique **Figure 1**. It covers approximately 7500 km^2 and had a population in 2017 of about 2,4 million persons [12]. The climate a seasonal wet-dry one with about 1090 mm rain per year.

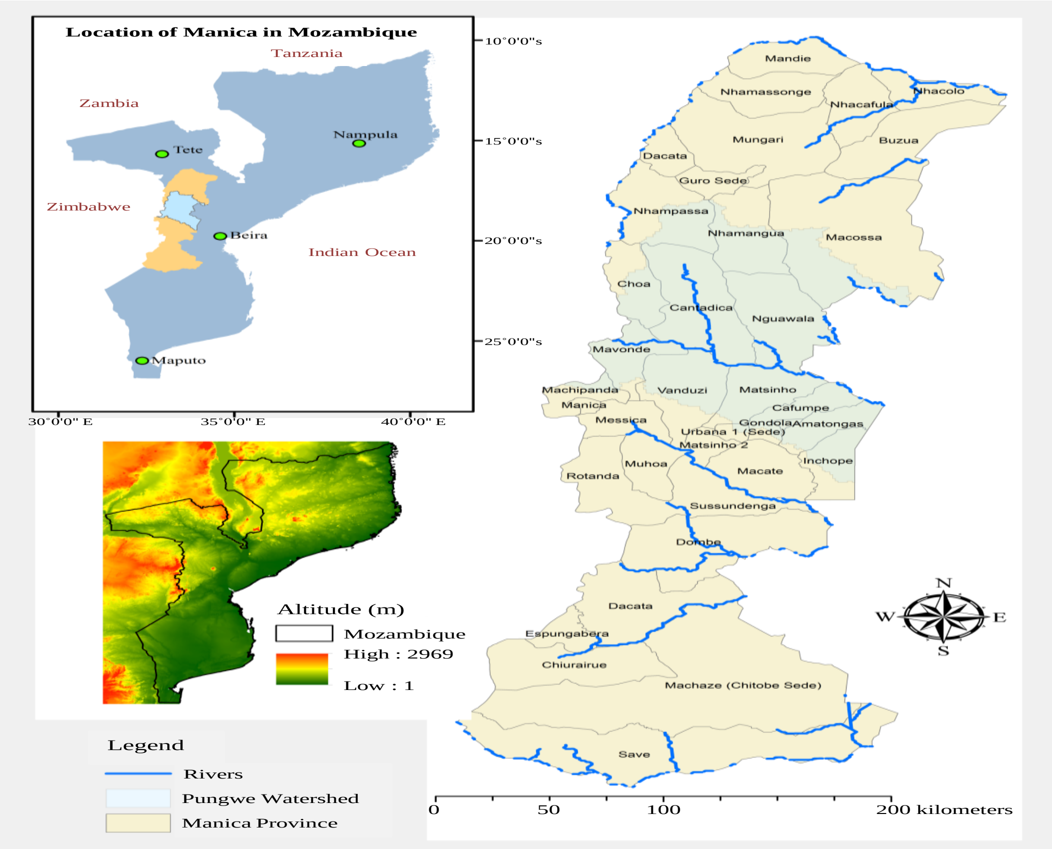

Figure 1. Manica study area in Central of Mozambique

3. Methodology

The present work began with a survey of the hydropower plants in the Manica district, the objective being to redesign and optimizing the new hydropower system there with two aim in mind: To continue grinding agricultural products (corn and rice) and producing electricity for supplying one a hospital, a primary school and 50 houses in the vicinity of the Chua hydropower plant. After conducting a flow study to estimate the flow rate, a study was carried out for selecting suitable turbine based on knowledge of flow and head.

3.1.FLOW ESTIMATION METHODS

Generally there are three main flow estimation methods used in small hydropower which basically use mean annual flows to estimate flow. These three flow estimation used in small hydropower include the runoff data method, the area ratio method and the correlation flow method [13]. Unlike the flow correlation method, when using the runoff data method and the area ratio method the first thing is to compute the Mean Annual flow (MAF) of the ungauged river. The MAF is computed using equation [14]:

$$MAF_{Ungauged} = Mean\ Annual\ Runoff \times Area_{Ungauged} \qquad (1)$$

The method does not require a gauged site to be located near an ungauged site proposed for the hydropower plant . However, basically the method uses the runoff data which is usually available on runoff maps. Runoff maps can be downloaded online. The mean annual flow of the ungauged catchment was calculated from the Equation 5 below [15]:

$$MAF_{ungauged} = mean\,annual\ flow \times \left[\underbrace{\frac{\left(rain\,over\,each\,m^{2}/s\right)}{\left(mean\,annual\,rain,mm/yr\right)}}_{conversion\ factor} \right] \times drainage\,area \qquad (2)$$

Then in order to estimate the flow of the ungauged river, the vertical ordinates (x_n) representing the flow duration curve of the gauged stream are multiplied by the ratio of the MAF of the ungauged site/stream to that of the gauged stream/site.

$$Q_{ungauged} = x_n \times \frac{MAF_{ungauged}}{MAF_{gauged}} \qquad (3)$$

[16] explains that where the runoff map for the proposed site is not available, the area method becomes useful however, he further advices that a gauged site should exist in the vicinity. On the other hand, he says this method is used upon the assumption that both the ungauged site and the gauged site in the vicinity have similar hydrological characteristics which include: topography, land use, lithography and geomorphology as well as similar precipitation. Having those similar hydrological characteristics it therefore means that both the gauged and ungauged site have the same runoff values since they have similar parameters that generate the runoff values for rivers and catchments [16]. Subsequently, the mean annual flow will be approximately proportional to the drainage area [13] The mean annual flow for the ungauged site was estimated using Equation 7 below:

$$MAF_{Ungauged} = MAF_{Gauged} \times \frac{(Drainage\ Area)_{Ungauged}}{(Drainage\ Area)_{Gauged}} \qquad (4)$$

Again the flow of the ungauged site was estimated using Equation 6 above.

There exist circumstances when the area of the ungauged site is unknown. [16]explains that in this case the correlation flow method is best handy. He says this method strictly requires that the gauged site must not be located too far from the ungauged site. Besides, this method demands constant site visits to make occasional stream flow measurement. The method requires and assumes that both the gauged and the ungauged sites display similar precipitation patterns and that their areas, vegetation cover, and geomorphology do not significantly different [16].

3.2. UNCERTAINTY ANALYSIS

The study was done on a well gauged catchment for the analysis of flow estimation methods. An overall of three sites/gauging stations qualified for uncertainty analysis and bias, accuracy and uncertainty measures for each flow estimation method was computed for all the respective sites/gauging stations and the means for bias, accuracy and uncertainty for the candidate stations were considered as final measures of uncertainty analysis for each respective estimation method. The study was done on a well gauged river in order to validate the uncertainty results by comparing the estimated flows with the original stream flows which have been termed as “true stream flows” in this study. Therefore, the variation pattern between the original flows (true flows) and the estimated flows will be revealed for further inferences and decision making for practitioners’ use. Due to the assumptions for each flow estimation method explained earlier, it is unlikely that all the three gauging stations/sites can qualify for the uncertainty analysis for each and every method apart from the fact that they fall under a homogeneous region. Consequently not all stations qualified among these three stations.

The true stream flows were the true values in the uncertainty analysis of the flow estimations.

Bias (Mean Error), accuracy (RMSE) and standard error (uncertainty) were computed accordingly for each the flow estimation method. The bias was computed from the formula below:

$$Mean\,Error(ME) = \frac{1}{n}\sum_{i=1}^{n}\left(Q_{e_i} - Q_{t_i}\right) \qquad (5)$$

Where Q_{e_i} and Q_{t_i} are the estimated stream flow and true stream flow respectively.

As one of the important elements in measurement process, just like the bias, accuracy was computed using the formula below:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(Q_{t_i} - Q_{e_i}\right)^2}{n}} \qquad (6)$$

And finally the uncertainty also called the impression expressed as the standard error (S_e) which is simply an expectation of the spread of errors was computed using equation as follows (Atkinson and Foody, 2008):

$$S_e = \sqrt{\frac{\sum_{i=1}^{n}\left(ME - Q_{e_i}\right)^2}{n-1}} \qquad (7)$$

3.3. Turbine Dimension

The choice of what type of water turbine is most appropriate depends upon the conditions at the site in questions, the water head level and the water flow rate being indispensable parameters. Charts have been developed for selection of a turbine as a starting point to determining what turbine may be most appropriate for particular locations [6]. The specific speed is a dimensionless parameter that characterizes the hydraulic properties of a turbine in terms of the diameter the speed (Nr) runner, the jet velocit, the width of the jet, the radius of the blade and the specific speed (Ns), as expressed as below the **Table 4**:

This turbine chart depends upon the size of power plant, pico, small, medium or large which is combined with other parameters such as head and water flow rate as presented in the **Figure 2**.

Table 4 the mathematic calculations of turbine dimentions

	Parameter	Formula	Equations number
I	Diameter of the turbine runner	$D_{runner} = \frac{40\sqrt{H}}{N}$	8
II	Specific speed	$N = \frac{N_s \times H^{0.75}}{\sqrt{Q}}$	9
III	Velocity of the Jet	$V = Cd\sqrt{2gH}$	10
IV	Number of blades	$n = \frac{\pi D}{t + t_{jet}}$	11

where D is the diameter of the runner, H is the net head, N is the speed of the runner in revolution per minutes, N_s is the specific speed, Q is the volume flow rate (m^3/s), C_d is the coefficient of discharge and V is the velocity in m/s. For this design, N_s = 30 was selected.

Hydropower schemes use the kinetic energy of moving water to produce electricity. The amount of electricity produced by a turbine is determined by rate of flow of the water and the vertical fall of the water from the upstream to the downstream level, termed the Head see equations [17]. The turbine, both the old one and projected one are shown in **Figure 2**,

$$P = \rho g H Q \eta \tag{8}$$

where P is the mechanical power produced by the turbine shaft; ρ is the density of water (kg/m^3); Q, is the rate of flow through the turbine (m^3/s); η, is the hydraulic efficiency of the turbine; and H, is the effective pressure head of water across the turbine (m).

4. Results and Discussion

According to the uncertainty analysis results of this study the, area method for gauging and estimating the stream flows of an ungauged catchment presented the least measures/values of bias accuracy and uncertainty followed by the correlation flows method and the runoff data method presented the largest values of bias accuracy and uncertainty.

Therefore, the results of this study were confidently accepted as the area method being more accurate, precise and having least values of over/under estimations reflected by the value of bias. The correlation flow method was the second from the area method followed by the runoff data method in terms of bias, accuracy and uncertainty/precision.

Also, in this section, the methodology employed is described and the results and findings of the study are presented and interpreted. All of the calculations were made based on the formula that were presented and discussed in the proceedings reference being made to the appropriate formula in connections with the results that are reported. Some of the data collected are referred to directly in this article, such as η = 80%, Q = 0.15 m^3/s, H = 48 m, and the assumed N_s = 25 rpm. The dimensions of the turbine, as based on this, are shown in **Table 5**. Since the plant has, a capacity of has no more than 34.220 kW, power can be supplied, in addition to the Chua village hospital and the primary school, to no more than a rather small number houses.

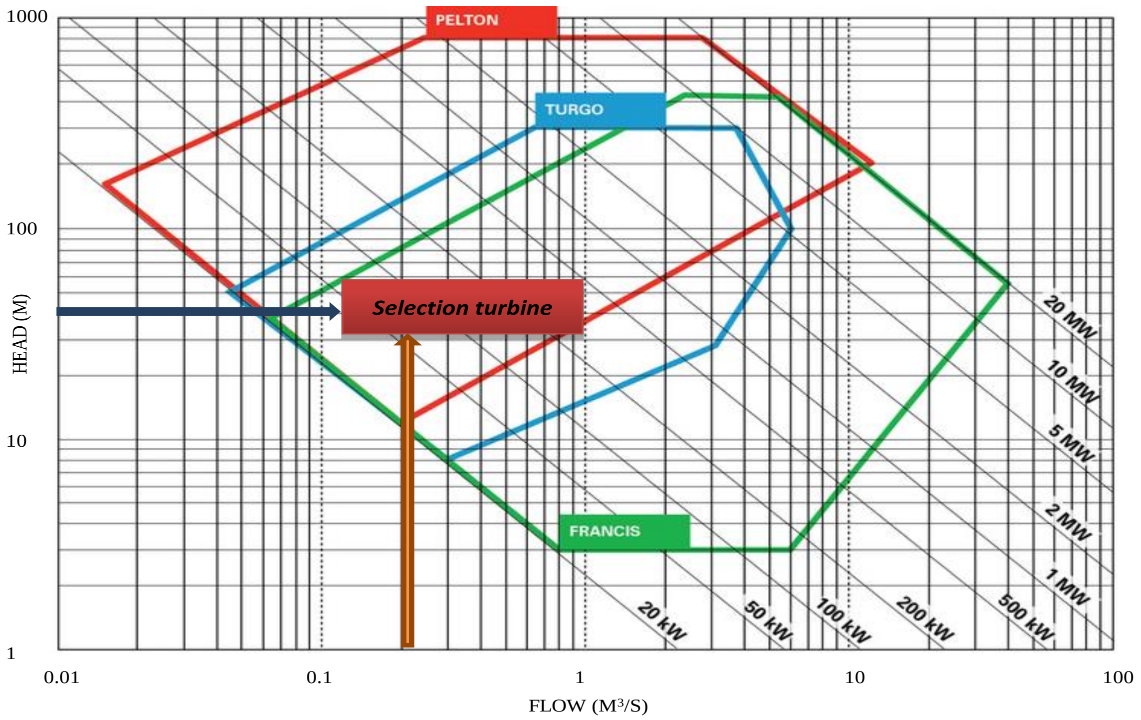

Figure 2 The chart of result of turbine selections adapted from [16]

Since the net head of the mini hydropower system at Chua is 48 m in length and the as discharge designed is 0.15 m^3/s, the appropriate turbine for this scheme, as can be seen from the turbine chart in **Figure 2**, is Pelton, with has an efficiency of 80-90% and a rated power capacity of 34.220kW. N=1649.5rpm,n=15blades, Ns=30;Aj=0,0049m2,V=30m/s

The analysis carried out for estimating the flow rate of made use of historical flow data records from a nearby gauging station on the Chua River. A set of historical flow data recorded over a period 39 years from 1956 to 2004, were used in conjunction with a Wavelet neural network model. In addition, in assessing, the performance of model we found the training and the validation. The correlations Coefficients is (R^2) to be 0.9031 and 0.89, respectively, the root mean square error (RMSE) to be 258 and 176.4 and NSE is 0.771 and 0.72 respectively. Establishing the optimal flow in line with both model WNN and ARIMA values and the flow durations curve in the model showed that the flow rate of to be 0.15m^3/s

5. Conclusions

The present study was carried out with the aim of being able to optimize operations in the Chua mini-hydropower plant on the Chua River in Manica in Mozambique, where a hydropower plant was built for the milling of corn and other cereals. The results obtained in the study show it to be possible to increase the power achieved in the Chua hydropower plant to approximately 34.0 kW as the power needed in the village increases. Success in refurbishing or upgrading the small-scale hydropower setups there would create job opportunities during successful operation of the system, as well as providing energy for households and promoting various economic activities such as trade and irrigation.

Analysis of the present flow in the Chua River showed that the flow rate for producing energy would presumably be sufficient for a long period of time, since the stream flow stems from a waterfall in the mountainous terrain there. The measured flow rate was $0.15 m^3/s$ and associated as it is with the high head there, one of nearly 50 meters, it enable the Pelton turbine that is shown in figure 3 to be used.

Two of the advantages that the energy thus provided would bring to the village of Chua will be to increase development of the village and to eliminate poverty for the local populations there. With the electricity that is made available, life expectancy there should increase since the local hospital already benefits from this energy and will continues doing son, such as though being able to sterilize various hospital supplies and materials. The educational system there will also benefits through students being able to readily do homework in the evening when it is dark, for example.

Beginning of the study it was hypothetically thought that the runoff data method would present the best/least measures of bias, accuracy and uncertainty since the methods directly uses the mean annual runoff or runoff coefficient data to estimate the mean annual flow of an ungauged river. The mean annual runoff and runoff coefficient are one of the powerful and most-used parameter used to estimate both surface and underground water dynamics and/or flows since they reflect the behavior of a catchment after integrating the most important properties of a catchment that are related to topography and surface cover.

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