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IMPACT OF HYDROLOGY AND FINANCIAL COST ANALYSIS ON THE PRODUCTION OF MINI HYDROPOWER: THE CASE OF DJENDJENNI, MALI

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Declaration

I, Mohamed Lamine Bachir, hereby affirm that the master thesis at hand is my own written work and that I have used no other source and aids others than that indicated. Only the cited sources have been used; direct quoting and paraphrase quoting have been identified as such.

	31/08/2017
Signature	Date

“Dedicated to my beloved mother, brothers, sisters and to the memory of my father”

Acknowledgment

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Abstract

Energy is a central factor that affects society's living standard and improves people well-being and welfare. It is a pillar of economic development. In order to have sustainable future, the energy production pattern has to be moved towards renewable and sustainable energy. This thesis investigated the pre-feasibility of a potential mini hydropower site, which is located in Djendjenni, Mali. Area rainfall method using rainfall and mean temperature data for the catchment area was used to estimate the discharge. The outcomes of the work reported here indicate that the proposed site has a designed flow of 0.79 m^3/s *which is available 90 % through the year and gross head of 20 m. A Kaplan turbine was selected based on the design discharge and the net head. A calculation was made to design the parameters of the turbine for a specific speed of 165 rpm, runner diameter of 0.29 m and runner length of 0.72 m. A 10 pole induction motor was selected as the generator for an estimated size of 156.84 KVA and a rotational speed of 612 rpm. The estimated power produced was 113 kW. The RETScreen model was used to analyze the financial viability of the project. Annual energy production estimated from the model was 837 MWh and the anticipated revenue to be generated is USD 382 187* with the specific costs per installed kW 4206 USD. *The initial cost of the project estimated by RETScreen was USD 437,356. From the running RETscreen, the simple payback of the project was 7.4 years and a benefit-cost ratio B-C of 3.68 which make the potential site feasible. The results of this study will serve as a potential feasibility to harness this site and serve as a proposed financing of mini hydropower scheme for rural electrification.*

Keywords: *small hydropower, pre-feasibility, hydrology, RETScreen, rural electrification, Mali*

Résumé

L'énergie est un facteur central qui affecte le niveau de vie de la société et améliore le bien-être de la population. C'est un pilier pour le développement économique. Pour avoir un avenir durable, le modèle de production d'énergie doit être orienté vers les énergies renouvelables. Ce mémoire porte sur l'étude de préfaisabilité d'un potentiel site de microcentrale hydroélectrique, situé à Djendjenni, au Mali. Deux modèles hydrologiques ont été utilisés pour estimer le débit en ayant comme données la précipitation et température moyenne pour le bassin versant. Les résultats rapportés ici indiquent que le site proposé à un débit de conception de 0,79 m^3 / s qui est disponible à 90% au cours de l'année et une chute d'eau de 20 m. La turbine Kaplan a été sélectionné en fonction du débit de conception et de la hauteur de la chute. Un dimensionnement a été effectué pour concevoir les paramètres de la turbine pour une vitesse spécifique de 165 tr / min, un diamètre de 0,29 m et une longueur de 0,72 m. Un moteur à induction de 10 pôles a été sélectionné comme générateur pour une puissance estimée de 156,84 KVA et une vitesse de rotation de 612 tours par minute. La puissance estimée produite est de 113 kW. Le logiciel RETScreen a été utilisé pour analyser la viabilité financière du projet. La production annuelle d'énergie estimée à partir du modèle serait de 837 MWh et pour un revenu de USD 382 187 avec un coût d'installions par kW de 4206 USD. Le coût initial du projet en se référant sur des études antérieures a été introduit comme donné sur RETScreen pour un montant 437 356 USD. À partir de l'exécution sur RETScreen, le retour sur investissement du projet est de 7,4 ans et un bénéfice-cout B-C de 3.68 qui indique que ce projet est viable. Les résultats de cette étude serviront de référence pour une future étude de faisabilité détaillée pour exploiter ce site et trouver un potentiel financement pour cette microcentrale hydroélectrique et explorer d'autres sources d'énergie pour l'accès à l'électrification rurale.

Mots clés : *Microcentrale hydroélectricité, préfaisabilité, hydrologie, RETScreen, électrification rurale, Mali*

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Nomenclature

α	Albedo value
δ	Solar declination angle
ω	Sunset hour angle
Φ	Latitude
ρ	Water density
DNE	National Directorate of Energy
D_{runner}	Turbine runner diameter
ET	Evapotranspiration
g	Gravitational acceleration
H	Head level
H_t	Soil Moisture
I	Yearly thermal index
i	Monthly thermal index
kW	Kilowatt
kWh	Kilowatt –hour
L	Penstock length
LCOE	Leveled Cost of Energy
MWh	Megawatt-hour
N	Rotational speed
N_S	Specific speed
P	Power
P_t	Precipitation
PET	Potential Evapotranspiration.
Q	Water discharge.
R	Return of the project
r	Discount rate
rpm	Revolution per minute
S_n	Amount of solar radiation
S_o	Amount of solar extraterrestrial radiation
T	Temperature
USD	American dollar

Chapter 1

Introduction

1 Introduction

Mali located in the heart of West Africa between the 10th and 17th degrees north latitude is a landlocked country with a population of 17 million for an annual growth of 3.6% (World Bank Data, 2017). It covers an area of 1,241,248 km^2 with a highly variable climate, characterized by a long dry season and a rainy season averaging one month in the north and up to five months in the south. With four climatic zones in the country, the rainfall is highly variable along the north to the south. The Sahara climate in the north occupies 2/3 of the territory, rainfall ranging from 50 to 250 mm per year. The Sahelian climate in the center has an average annual rainfall ranging from 400-600 mm. The Sudanian climate in the south has an average annual rainfall ranging from 700-900 mm. And lastly, the Sudano-Guinean climate, of which the rainfall ranges from 1000 to -1200 mm. This climatic reparation formed a diversified agricultural potential which is the first income for more 80% of the population (African Development Bank , 2015). The country is crossed by the two large rivers of West Africa, namely the Niger and the Senegal. They formed some immense watersheds 300,000 km^2 for the Niger, and 155,000 for the Senegal. The total flow potential of these two river systems is evaluated at 56,000,000,000 m^3 per year and the country's theoretical hydropower potential is estimated to 2.17 GW (ECREEE , 2017).

As a developing country, the economy of Mali is growing at high speed. The gross domestic product (GDP) grows at a rate of above 5% per year for the last decade. In 2015, the GDP reached 12.75 billion US dollars (USD), with a per capita GDP of 720 USD (World Bank Data, 2017). Access to energy directly contributes to economic growth and development. (Ahlborga & Sjöstedt, 2015) has been shown that there is a strong correlation between energy consumption and economic activities, poverty reduction through the creation of income-generating activities. While paying attention to sustainable development goal, reduction of poverty may come from freeing up time for other productive activities.

Mali has made progress regards to electricity access in this last decade, recording 51% of urban electricity access and 12% for rural electrification as of 2014 (IBRD/WB and IEA, 2017). In addition, the national electrification program has a target of increasing rural electrification. The government make a short scheme target to diversify the energy production and plans to produce 15% of its total energy in the form of renewable by 2020 (IRENA, 2015). Regardless the progress of Malian's electricity access and high aspirations, there are significant challenges that inhibit energy development with constant energy shortage and insufficient energy production.

By 2014, the total installed capacity of electric power of Mali amounted to 1591 GWh with an electricity generation from hydropower of 997.1 GWh (ECREEE , 2017). Hydropower has been harnessed to meet a substantial proportion of the present demand for electricity. In line with that, a considerable expansion is foreseen in some localities of the country although financial and environmental constraints may retard investment.

Therefore, this study will focus on the hydrology of the waterfall, the technical power plant design and the economic viability of the mini hydropower for this potential site. Various factors will be investigated including the design discharge, the net present value, and the benefit-cost ratio on the project to show if the project is feasible and financially attractive for a potential investor. In the following subsections, background, research questions, hypothesis are described to announce the key point of this thesis project. The output of this thesis is to be a recommendation that the site has a potential for further developments.

1.1 Background

Appropriate and affordable energy supply is key for socio-economic development and transition to modern industrial and service-oriented societies. Energy is a central factor which affects society's living standard and improves people well-being and welfare. It is a pillar for of economic development. Nowadays, its importance is becoming more and more important, especially in regard to the sustainable development of communities including social and economic aspect. Aiming at tackling this chronic lack of access to electricity, Africa in his new conductive environment for advancing socio-economic development and integration defined in the Agenda 2063, through long-term planning, set a target of ensuring access to modern, efficient, reliable, cost-effective, renewable and environmentally friendly to all while harnessing all its energy resources.

Africa is the second largest continent following Asia in terms of land area, containing roughly 20% of world total land area with 54 countries. In 2013 more than 1.5 billion people in the world are without access to electricity and the estimation for Africa is less than 20% of the population. In some countries, the direct access to electricity is as little as 5% (Adejumobi et al., 2013). The figure significant decrease to 2% in rural areas (Adejumobi et al., 2013).

Energy is generally a key precondition to sustainable development and also a fundamental human right hence, a critical concern. Africa as a continent is endowed with huge energy resources both conventional and renewables. However, the access level is chronically poor. It is quite unfortunate that more than half of the population do not have access to modern energy service (Thornley et al., 2015). Despite the high demand and a huge resource endowment, Africa's share of the global energy consumption is only 3.5% (Ejigu, 2012) which is mostly traditional biomass, hence, very low. In addition, end-use energy efficiency is also considered a challenge from technical perspective due to low technical know-how as virtually 10-40% of Africa's total primary energy input is lost on transformations (Ejigu, 2012).

In this perspective, mini hydropower has emerged as an alternative source of energy that can be implemented easily with low environmental impact. These features have increased small hydropower development and getting the attention in both developed and emerging economy countries. North America and Europe have already exploited most of their hydropower potential. On the other hand, Africa, Asia, and South America have still substantial unexploited potentials of hydropower (Lejeune, 2012). Mini hydropower can be a resort for the insufficient energy production in developing countries, as China did with 43,000 small schemes and 265 GW of total installed capacity (Hailun & Zheng, 2009). As well, Mali should follow these success stories to harness the small hydropower potential and therefore scale up the renewable energy resources. By this decentralized energy, the country can reach the objective of the sustainable development goals and contribute to the social and economic development for the reduction of the poverty.

1.2 Study Area

The Djendjenni waterfall site is located in the south-western region of Mali at 24 km from the chief town of Siby in the administrative district of Koulikoro. This study area has a single raining period in summer only beginning mostly from mid of May till the end of September, where the intensity of precipitation is higher in July and August. With a perennial watercourse throughout the year and their proximity to electrify many rural villages, a mini hydropower plant can be a good opportunity for the development of this remote area.

Table 1-1 Coordinate of the site

Site	Longitude	Latitude	Attitude
Djendjenni	08° 22' 160''W	12° 28' 268''N	497 m

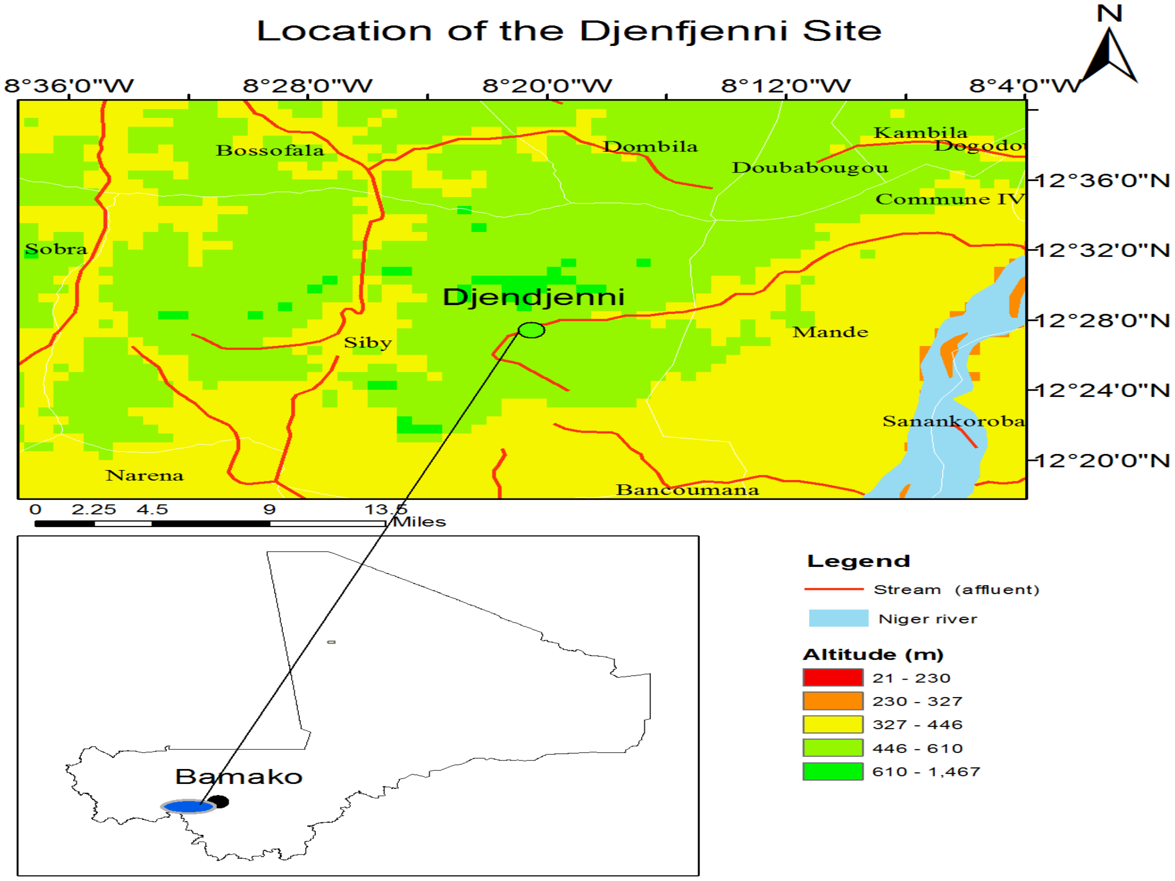

Figure 1.1 Location of the site

1.3 Research question

How does the availability of the reliable discharge, precipitation, evapotranspiration, availability of financial sources of an investment can impact the production of mini hydropower in a remote area of Mali?

1.4 Hypotheses

It is technical, economically, environmentally feasible to install a mini hydropower plant in the rural area of Mali. To address our research question, the following hypotheses will be tested in this study.

- H1: The availability of discharge, precipitation will positively impact the production of mini hydropower
- H2: The project is attractive financially for a return of an investment
- H3: A production of the energy which will meet the load charge of the village

1.5 Objective

The general objective of this project is to analyze the technical and financial viability of mini hydropower scheme in this remote areas.

The specific objectives are to:

1. Assessment of the stream flow rate, head available and other preliminary data for mini hydropower generation.
2. Evaluate the energy output of a mini hydropower scheme at the site.
3. Carry out a preliminary design of the mini-hydro plant.
4. Carry out a financial analysis of the hydropower scheme using RETScreen software.

1.6 Methodology

To address the research question, analytical approach will be adopted. For instance, to estimate the flow-rate of the river, some analytical techniques such as the area-rainfall method will be used. In either case, a hydrology study should be based on many years of daily records. With the limitation of time, the area-rainfall method is preferable since a historic precipitation data can be obtained.
In this study, the flow duration curve will be estimated as follows:

- 20 years of daily rainfall data for the catchment area would be obtained from different satellite observation source (rainfall, Tmax, Tmin, and sunshine)
- A Catchment area map would be estimated for the drainage basin with the software ArcGIS.
- The two hydrological Thornmaithe and Blaney Cridle model will be used to estimate the evapotranspiration with an input value rainfall, mean temperature, and sunshine at the watershed.
- Evapotranspiration of the site and runoff quantities would be calculated and then to simulate the discharge and confirm the appropriateness of the estimated flow duration.
- The specific flow-duration curves would be constructed to calculate the power potential of the site.

Based on the flow rate and available head of the site, the technical evaluation will consist of sizing the components of the project. In addition, a financial sensitivity analysis of the site would be run with RETSceen software to determine the project financial viability.

1.7 Thesis chapter outline

This thesis is organized into five chapters. The first one, introduction to give the background, the relevance of this study, the subject and major focus of the study. In the second one, a relevant literature review related to the topic within hydropower will be presented (the hydrology study, hydropower technologies, and financial aspect of hydropower plant development).
In chapter three discusses the mythology applied. It consists of the survey of the site, hydrology data processing and the sizing of the main hydropower components. Furthermore, energy production value from flow curve will be estimated. In the chapter, four will delay with the finding and also the financial viability of the mini hydropower plant. At the end, the last chapter will be the conclusion and recommendation for further development of the site.

Chapter 2

Literature Review

2 Literature Review

In this chapter, three main literature blocks will be reviewed, which are hydropower, hydrology, and economic and financial aspect. The relevant literature review related to the hydropower success stories in the world are presented and the main components for small hydropower plant will be described. Furthermore, a different hydrological model is presented for water balance in the watershed. In the last subsection economic parameters for a hydropower are explored.

2.1 Hydropower

Renewable energy systems are widely explored because of major interest on sustainable development goals. These energy systems are based on the exploitation of natural energy flows such as solar radiation, the cycle of water, wind, earth heat flux, lunar and solar attraction effect on the oceans. In contrast to fossil and mining energies resources (coal, oil, natural gas, uranium), renewable energy regenerates faster than it is exploited (Sarah et al., 2017). The challenge of renewable energy is more or less intermittent but do not pose major problems in terms of control.

Water constantly moves through a vast global cycle, in which it evaporates (due to the activity of the sun) from the oceans, seas then precipitates as rain. The hydrological cycle is a never ending system. By definition, hydropower is considered as a renewable energy source where the electricity comes from the energy of water moving from higher to lower elevation (Cleveland & Morris, 2015). It's the flux of energy that uses almost exclusively the terrestrial part of the water cycle. The primary hydraulic energy is in mechanical form and is easily converted into electrical energy which constitutes the most flexible form of energy use. As a result, in the pool of potential electricity resources, hydroelectricity ranks first among renewable resources.

Hydroelectricity is the oldest form of renewable energy, existed since the beginning of the twentieth century. It accounts for more than 94% of the world electricity production based on renewable energies and represents 16% of electricity produced throughout the world (Brown et al., 2011).

There are 3 main types of hydropower plant design

Run-of-river power plants: These plants are those which utilize the stream flow as it comes normally with no appreciable poundage on its upstream side. It's the simplest hydropower plant design. Sometimes a weir or barrage is built across a river simply to raise and maintain the water level at a pre-determined level within narrow limits of fluctuation, either solely for the power plant (Breeze, 2005).

Storage power plants: A storage plant is essentially having an upstream storage reservoir of sufficient size so as to permit sufficient carry-over storage from the rainy season to the dry summer season; and thus to develop a firm flow substantially more than the minimum natural flow (Breeze, 2005).

Pumped storage plants: A pumped storage plant generates power during peak hours, but during the off-peak hours, water is pumped back from the tailwater pool to the head water pool for future use. The pumps are run by some secondary power from some other plant in the system. During peak hours, the water flows from the reservoir to the turbine and electricity is generated. During off-peak hours, excess power is available from some other plant and is utilized for pumping water from the tailrace to the head race (Breeze, 2005).

Hydropower stations are distinguished by their powers in two main categories: the large hydropower plant and small scale hydropower production. The former refers to a capacity for the large dam power plants with a capacity generally greater than 10 MW, and the second small hydroelectric which subdivided into subcategories with power below 10 MW (REN21, 2011). Although various categorizations and definition exist based on different region, locality across the world. This second category of development is itself generally subdivided into small, mini and micro hydropowers (Nasir, 2014). It can be considered from (Belhadji, 2013) that in France any hydraulic power plant with a power of less than 5 MW can be called a micro-power plant, and between 5 and 10 MW, a small power plant. This last name is used in particular in the United States for powers between 100 kW and 1 MW. The term pico hydropower is also mentioned for powers below 100 kW but it is a priori used less commonly (Nasir, 2014). Consequently, there is no real consensus on the terms and the boundaries between the different ranges of small hydroelectricity are blurred. The common classification accepted of hydropower plants based on the ability to generate power is provided in Table 2-1

Table 2-1 Classification of hydropower plant

Power Generation Capacity (Watts)	Type of Hydro Power Plant
<10 kW	micro
100-1000 kW	Mini
1 MW- 10 MW	Small
10 MW-300 MW	Medium
>300 MW	Large

By 2010, at least 90% of the electricity generated in 25 countries came from hydropower. Seven of them (Albania, DR of Congo, Mozambique, Nepal, Paraguay, Tajikistan, and Zambia) depend totally on the production of hydroelectric with almost 100% (Ardizzon et al., 2014). Hydroelectricity continues to dominate and plays a key role in the generation of electricity in 65 countries and present in 150 countries in the world. Canada, China, and the United States are the countries with the largest hydroelectric power (IHA, 2011).

The development of large hydropower is on the decline due to the exploitation of almost all the sites around the world and also in strong opposition of the environmentalist which block the inherent development. As a consequence on the environment, the integrity of the landscape and the degradation of the quality of underwater fauna (IHA, 2011). On the other hand, a high potential is available for small hydro, which gives it an important place in the future energy mix based on renewable energy with a low impact on the environment (Lejeune, 2012). The application and target are to supply in power isolated site or support interconnected network.

2.1.1 Mini hydropower in the world

Hydropower, large and small is by far the most important source of renewable energy generation. It's undoubtedly one of the most mature energy technologies with an installed capacity of about 3500 TWh in 2010 (Ardizzon et al., 2014). On the International Energy Agency (IEA) roadmap for hydropower (IEA, 2012), states that the remaining technical potential hydroelectric is estimated at 14 576 TWh /year which represents the equivalent of 100% of current world electricity demand. The economically feasible proportion of this potential is currently considered equivalent to 8080 TWh / year.

Between the period 2001 to 2010, there were 135 GW adding installed hydroelectricity capacity in the world (Belhadji, 2013). All other combined renewable energies provide less than 2% of global consumption. As illustrated in Figure 2.1, North America and Europe have developed most of their economic hydro potential, but the enormous potential remains in Asia, Africa, and South America. Small hydropower plants (<10 MW) currently contribute more than 40 GW of global generating capacity (IHA, 2011). The world potential of small hydropower is estimated at over 100 GW (IEA, 2012). In China, a power equivalent to more than 15 GW is in service and a power of 10 GW is in development for the next decade (Hailun & Zheng, 2009). Therefore, this energy contributes to the independence energetic which is an important aspiration of most states. It also represents decentralized energy solution, with a production mainly located in mountainous areas as well as in rural areas.

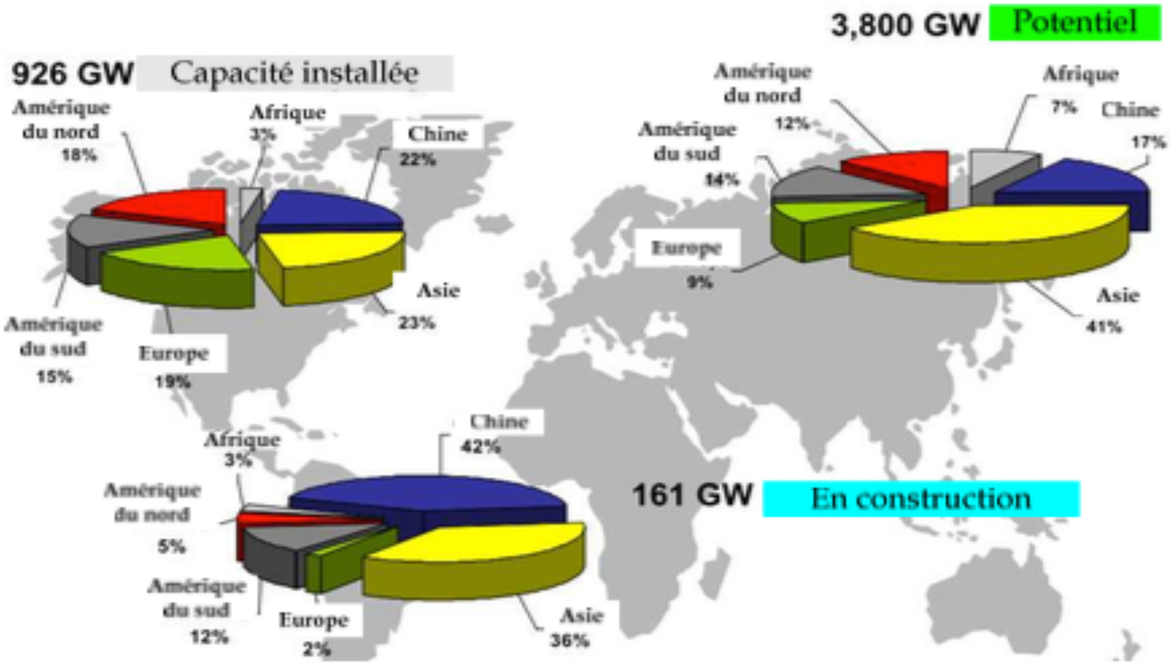

Figure 2.1 World hydropower capacity and technical potential Source: IHA

2.1.2 Turbine

The heart of any mini hydro project is the turbine that is capable for the production of electricity through the rotation of the shaft. Hence much attention had to be taken in genuine choice and performance of such turbine as the clue rest in the coherence transfiguration of the energy in the water to useful electrical energy. According to the available head, turbines are classified as (Jawahar & Michael, 2017)

- Low Head (up to 40 m) – Propeller and Kaplan Turbine.
- Medium Head (40–100 m) – Francis, Pump as Turbine, Cross Flow, and Pelton Wheel.
- High Head (> 100 m) – Turgo and Pelton Wheel.

In hydroelectric systems, the turbine used have runners of different shapes and size (Okot, 2013). In general, the choice of the type of turbine depends mainly on the flow rate, the height of fall and the speed of rotation of the shaft. In addition, for a system where the flow rate is sufficiently constant throughout the year, it is also possible to use turbo pump units, this system making it possible to store a large amount of potential energy upstream of the installation during the low demand and returning it at peak consumption times.

There are two main categories of hydro turbines in use: action or impulse turbine (Pelton, Crossflow) and reaction turbine.

2.1.2.1 Impulse Turbine: Pelton and Crossflow

The principle of operation:
A jet of water acts on buckets shaped like a double spoon placed on the periphery of the wheel. This jet exerts a hydraulic force on the bucket in the rotation, which force is converted into torque on the turbine shaft (Paish, 2002). The operating turbine is characterized by the fact that the energy available to the blading takes place at constant pressure, generally at the atmospheric pressure. The turbine wheel is pitted and rotates in the air.

Pelton Turbine:
The Pelton turbine is constituted by a bucket wheel which is set in motion by a jet of water coming from an injector. The buckets (vanes) are profiled for maximum performance while allowing water to escape to the sides of the wheel. The nominal speed of the turbine varies from 500 rpm to 1500 rpm (Okot, 2013), which allows direct coupling without multiplier to the electric generator.

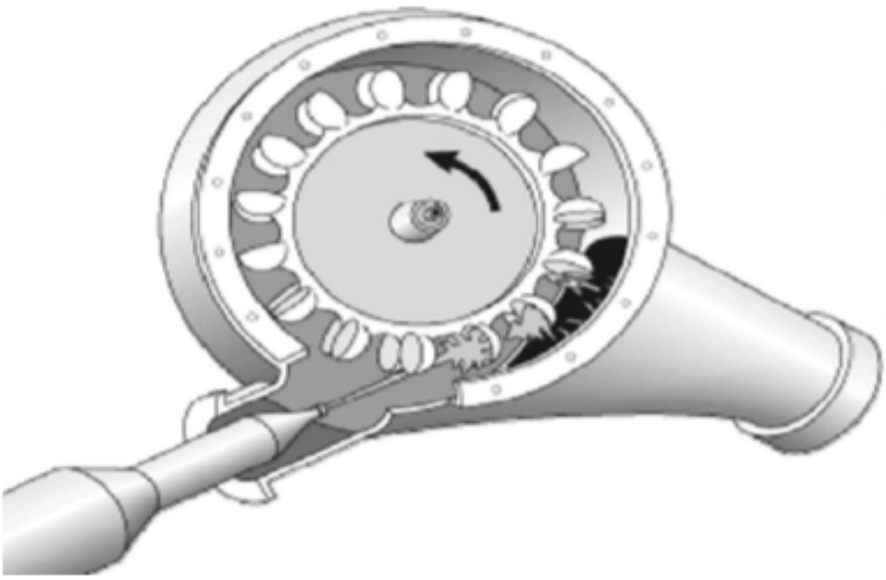

Figure 2.2 Typical Pelton Turbine (HK RE NET, 2017)

Crossflow Turbine (or Banki Mitchell):
The Crossflow turbine, also known as a through-flow turbine, is an action machine which has the particularity that the water crosses the wheel twice. Simple construction, it consists of three main parts:

- An injector of rectangular cross-section, the flow rate of which is adjusted by means of a rotating profiled blade, similar to a butterfly valve.

- A drum-shaped wheel with cylindrical profiled blades.
- A frame enclosing the wheel and on which the bearings of the turbine are fixed.

In general, its speed is low which justifies the use of a multiplier to couple it with a generator (Ozdemir & Orhan, 2012).

2.1.2.2 Reaction turbine: Francis and Kaplan

The principle of operation:
A reaction turbine is a machine completely immersed in water and rotated by a vortex effect by means of a spiral tarpaulin and fixed or movable guide vanes. The vanes of the turbine are shaped so as to give the water streams a direction parallel to the axis of rotation at the outlet of the turbine. It is both the kinetic energy of the water and the difference in pressure between the intrados and the extrados of the blading that generates the torque, in contrast to the turbines with action for which only the kinetic energy of the water is involved (Ozdemir & Orhan, 2012).

Turbine Francis:
The Francis turbine is used for small variations in flow rate (average flow rates between 100 l/s and 6000 l/s) (Nasser, 2011). It adapts well to the average falls of 10 m to 100 m. It has good efficiency and high speed (1000 rpm). Water is going to the runner from all sides by the vanes causing it to spin. Its radial flow reaction turbines, with fixed runner blades and adjustable guide vanes, used for medium water falls.

Turbine Kaplan:
Kaplan turbines are the turbines best suited for low drops (about 2 m) and high flows of the order of 300 l/s to 15000 l/s. They are suitable for variable flow rates and their efficiency is good (84-90% maximum) in spite of a low speed of rotation (Nasser, 2011). The Kaplan turbine wheel is similar to a boat propeller and the blades are steerable to optimize the efficiency coefficient of the turbine. It offers an interesting analogy with wind turbines on the aspect of setting the orientation of the blades (Müller et al., 2002).

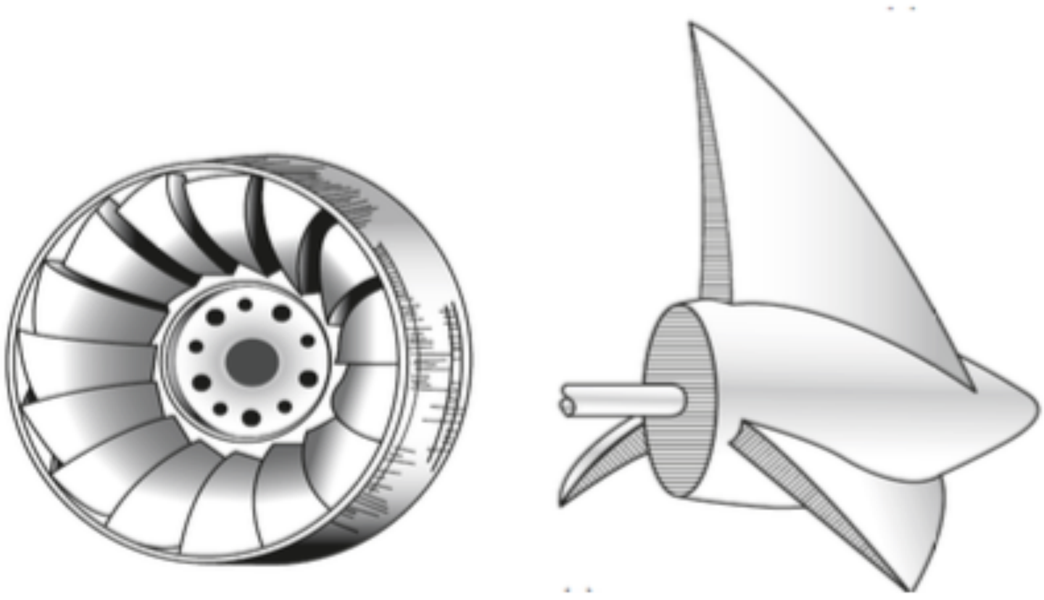

Figure 2.3 Reaction Turbine: Francis and Propeller

There are few equations to calculate the turbine dimensions. For the Francis turbine, the runner diameter is:

$$D = 84.5(0.31 + 2.5 * 10^{-3} N_s)\frac{\sqrt{H_0}}{60N} \quad \text{Equation 2.1}$$

For the Propeller or axial turbine, the runner diameter is estimated as (Helena, 2013):

$$D = 84.5(0.79 + 1.602 * 10^{-3} N_s)\frac{\sqrt{H_0}}{60N} \quad \text{Equation 2.2}$$

2.1.2.3 Summary

Most of the time the selection criteria of the turbine are based on the type, geometry and dimensions of the turbine will be fundamentally conditioned by the following criteria:

- Net head
- The range of discharges through the turbine.
- Rotational speed
- Cavitation problems
- Cost

The preliminary design and choice of a turbine are both iterative processed. Figure 2.4 gives a chart that links the turbine models with head, flow and producible power (Barelli et al., 2013).

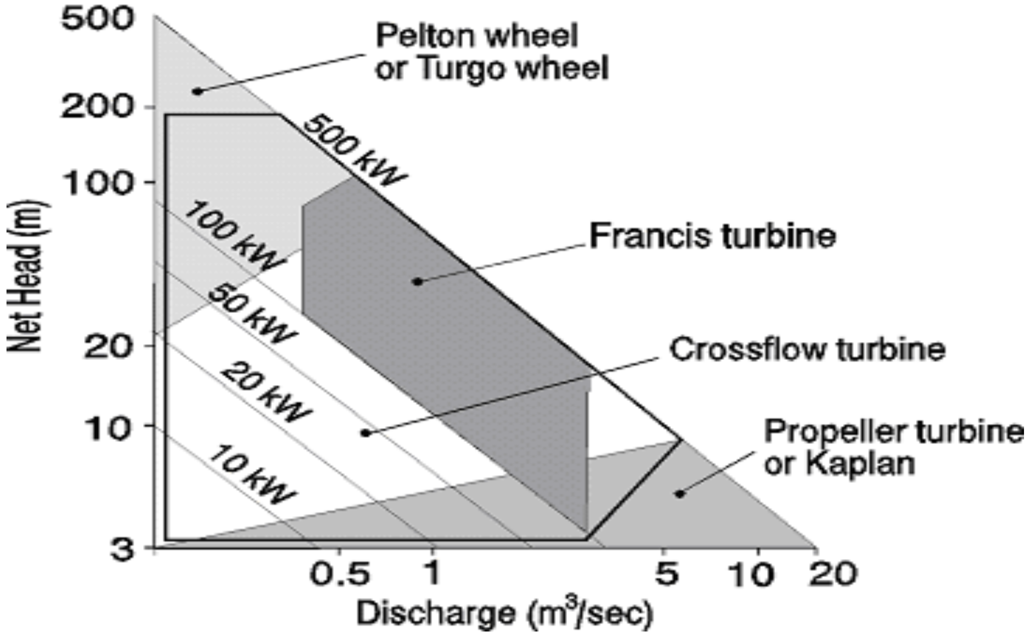

Figure 2.4 Different turbine Application based on head and flow

Once the characteristic the power, specific speed and net head are known, we can proceed to the turbine selection for the reliable design need. Table 2-2 represents a consolidated picture of the review on turbines in the published literature (Jawahar & Michael, 2017).

Table 2-2 Summary of Turbine published in the review (Jawahar & Michael, 2017)

Turbine	Net head (m)	Discharge (l/s)	Output (kW)	Efficiency (%)
Axial Pump as Turbine	4	6	6	61
Reaction Turbine	1.45	0.28	0.28	65-70
Single stage Centrifugal Pump	15	3	3	60
Propeller Turbine	4-9	20	20	68
Pump as Turbine	25	30	30	
Cross Flow Turbine	-	-	-	89
Nano Hydraulic Turbine	1.2	0.1-0.2	0.1-0.2	20
Axial (Kaplan) Turbine	24	-	-	85
Cross Flow Turbine	8.5-10	-	-	55
Cross Flow Turbine	35	-	-	70
Cross Flow Turbine	5.5	3.5	3.5	85
Cross Flow Turbine	6	6.2	6.2	60
Cross Flow Turbine	3	2.5	2.5	83
Cross Flow Turbine	10	7.3	7.3	77
Pelton and Turgo Turbine	13-28	<5	<5	80
Simple Reaction Turbine	1-4	0.150	0.150	50
Turgo Turbine	1-3.5	0.250	0.250	87-91
Pump as Turbine	5.98	6.2	6.2	79

2.1.2.4 Turbine efficiency

Figure 2.5 shows the evolution of the efficiency relative to the maximum efficiency of the turbine as a function of the maximum flow rate (Cobb & Sharp, 2013). It can be seen that the yield is highly variable with the flow rate. The Pelton and Kaplan turbines have very high efficiencies when running below design flow. For the Francis turbine, it's in contrast with the two cited the efficiency falls. The mechanical power P_{mec} is calculated from the measurement of the torque C_{mec} on the shaft of the turbine and the measurement of the speed of rotation Ω of the model.

$$P_{mec} = C_{mec} * \Omega \qquad \textit{Equation 2.3}$$

Then the hydropower efficiency is calculated by:

$$\eta_{hyd} = \frac{P_{mec}}{P_{hyd}} \qquad \textit{Equation 2.4}$$

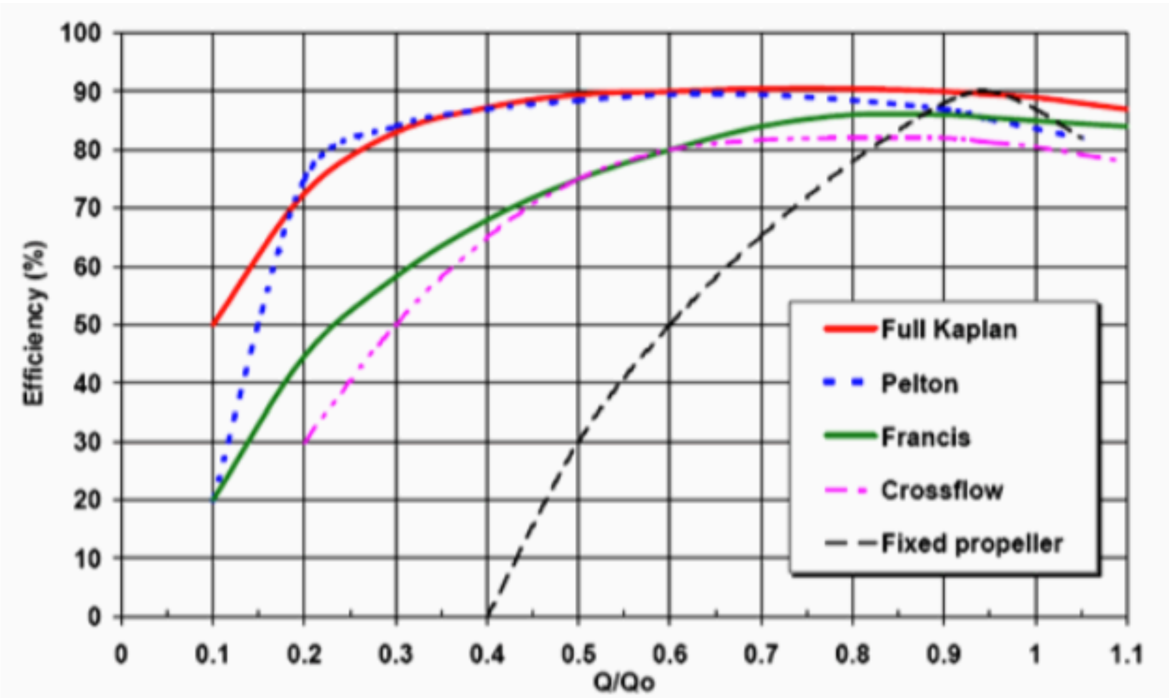

Figure 2.5 Curve of turbine efficiency for a variable flow rate

2.1.3 Generator

The generator in the hydropower plant has the role to convert the mechanical energy from the turbine to electrical energy. It can be either of a synchronous or asynchronous machine.

In the mini hydropower, we mainly encounter synchronous machines with permanent magnets or wound rotor (Nasser, 2011). They remain the most generators used to produce a sinusoidal alternative current voltage. To provide a constant frequency, a mechanical water flow control system is required to maintain a constant speed of the turbine. The overall hydraulic efficiency is reduced due to the introduced pressure drops by the control valve (Cobb & Sharp, 2013).

Asynchronous cage machines can run on a network or on an isolated load. His usage is still limited but should rapidly evolve because of the relatively low cost of the asynchronous machine compared to the synchronous machine. In autonomous operation, the asynchronous generator raises important problems of stability in voltage and frequency. Self-excitation capabilities are required to magnetize the machine, and operation can only be done with a restricted speed range. The loads used must therefore not be demanding in terms of voltage and frequency.

Dual power asynchronous machines

At present, there is very little use of the double-feed asynchronous machine in the micro hydropower plant. However, examples of interesting applications exist in wind systems (Müller et al., 2002) and its use is envisaged in aeronautics. It makes it possible to overcome the previous stability problems of the asynchronous cage machine and actually allows variable speed operation. An auxiliary excitation supplied to the rotor windings allows the voltage and the frequency to be controlled at the stator.

Capacity Factor

The extent of use of the generating plant is measured by the capacity factor, frequently also termed plant factor or use factor. If during a given period a plant is kept fully loaded, it is evident that it is used to the maximum extent, or operated at 100% capacity factor (Cobb & Sharp, 2013). The capacity factor of a power plant is the ratio of generated energy output over a period of time, compared to the maximum potential energy output when the generator is operating at its rated capacity continuously. The formula for capacity factor is as follows:

$$Capacity\ factor\ (\%) = \frac{Energy\ generated\ per\ year\ (kWh)}{Installed\ capacity\ (kW) * 8760\ (hr/year)}$$ *Equation 2.5*

Capacity factor vary from with design flow as shown in table 2-3

Table 2-3 Design flow in relation to capacity factor

Design flow Q_0	Capacity factor
Q_{mean}	40 %
0.75 Q_{mean}	50%
0.5 Q_{mean}	60%
0.33 Q_{mean}	70%

2.1.4 Intake and Weir

The main civil engineering work of a small hydroelectric power station is to build a weir, intake, penstock and the conveyance system as shown in the small scale hydropower components Figure 2.6. The principal feature of a weir is to regulate the water discharge through the intake. It's the primary means of conveyance of water from the source of water in required quantity towards the waterways of hydropower project (European Small Hydropower Association, 2004). The shape and dimensions of this structure are to adapt with the nature of the site. It is constructed of rip-raps, gabions in earth, masonry or concrete. It can sometimes take advantage of natural faces and does not require any development. The water intake can also be installed on an irrigation canal. The position and location of an intake in a hydropower project would generally depend upon the type of hydropower development, whether the project is of run-of-river type or storage type. In case of low discharge rivers (less than 4 m^3/s), it may be possible to build a Weir (Helena, 2013). It is designed such that the following points comply, as far as possible:

- There should be a minimum head loss as water enters from the reservoir behind a dam or the pool behind a barrage into the water conducting system.
- There should not be any formation of vortices that could draw air into the water conducting system.
- There should be the minimum entry of sediment into the water conducting system.
- Floating material should not enter the water conducting system.

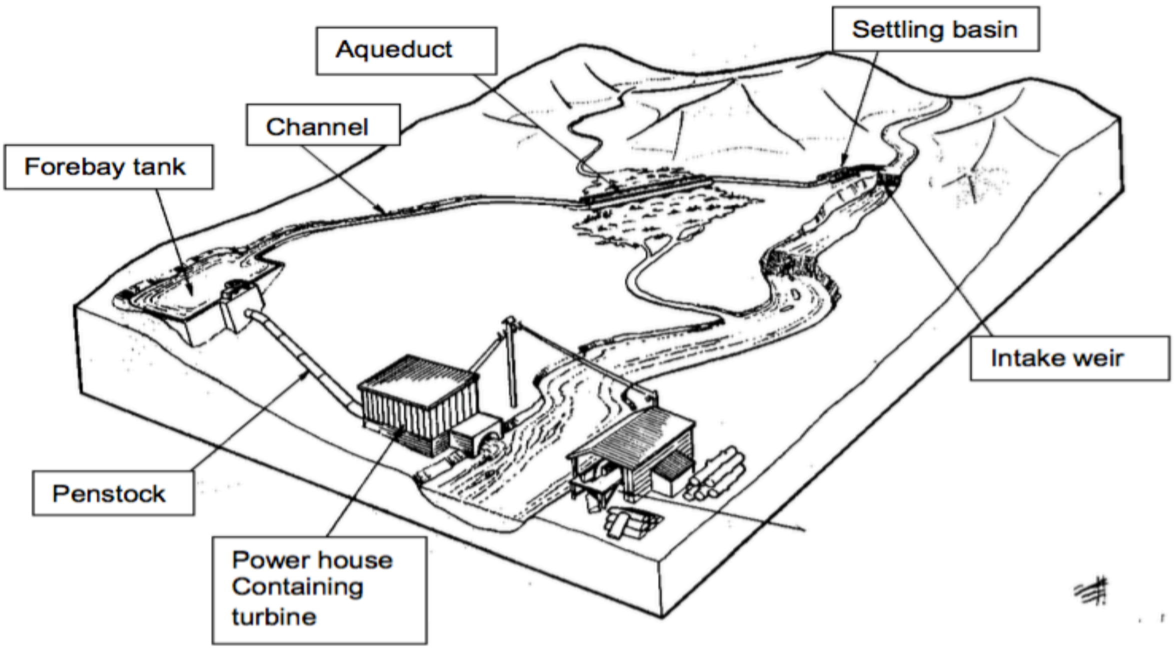

Figure 2.6 Small scale hydropower components

2.1.5 Penstock

A penstock is a conduit that is used to carry water from the supply sources to the turbine. This conveyance is usually from a canal (forebay) or reservoir. Penstocks are classified based on the construction type (Ahlborga & Sjöstedt, 2015). The first type pressure penstock requires that the water discharging to the turbine always be under a positive pressure (greater than atmospheric pressure). The siphon penstock is constructed in such a way that at points in the penstock the pressure may be less than atmospheric pressure and sections of the conduit act as a siphon. This requires that a vacuum pump or some other means for initiating the siphon action must be used to fill the conduit with water and to evacuate the air in the conduit. Another type which is reinforced concrete penstock adapted for low head and low discharge capacity, the water quality shall be good for the concrete. In addition, the steel penstocks have become the most common type of installation in hydropower developments due to simplicity in fabrication, strength, and assurance that they will perform in a wide variety of circumstances (Helena, 2000). Normal practice is to use welded steel pipe sections. Through forebay, the water carried by a power canal is distributed among penstocks that lead to turbines. Water is temporarily stored in a Forebay in the event of rejection of load by the turbine and is withdrawn from it when there is demand (European Small Hydropower Association, 2004). Thus it is a sort of regulating reservoir. It is located at the end of the canal. The forebay is used mainly:

- To decrease the distance to the power house so as to get the turbine on and off within a shorter period.
- To decrease the length of the penstock.
- To halt the propagation of pressure waves to the power canal.

The net head for the calculation is given by the gross head and the losses due to the friction (ΔH_{ab})

$$H = H_g - \Delta H_{ab} \qquad \textit{Equation 2.6}$$

The friction losses which occur in the penstock is given by the product L length of the penstock and the hydraulic gradient J

$$\Delta H_f = JL \qquad \textit{Equation 2.7}$$

With the hydraulic gradient defined by

$$J = f\frac{V^2}{2gD} \qquad \textit{Equation 2.8}$$

Where V is the velocity in m/s, D diameter of the penstock and f the friction factor that is defined by

$$f = \frac{1}{\left(-2\,log\left(\frac{k}{3.7D} - \frac{5.16}{Re}\,log\left(\frac{k}{3.7D} + \frac{5.09}{Re^{0.87}}\right)\right)\right)^2} \qquad \textit{Equation 2.9}$$

Where the Reynold number Re is defined by the equation below.

$$Re = \frac{D\upsilon\rho}{\mu} \qquad \textit{Equation 2.10}$$

k is the absolute roughness value of the pipe

Table 2-4 Absolute roughness K for different materials (Helena, 2000)

Material	k (mm)
New Cast Iron	0.25
Strongly Rusty Cast Iron	1.50
New Steel	0.10
Rusty Steel	0.40
Rough Concrete	0.6
Smooth Concrete	0.18

2.2 Hydrology

One of the fundamental issue in determining hydropower plant potential is the water flow that runs on the site river. Hydrology is the study of the occurrence, movement, and distribution of water on, above, and within the earth's surface. Parameters necessary in making hydropower studies are water discharge (Q) and hydraulic head (H). The measurement and analysis of these parameters are primarily hydrologic problems (Ostojic et al., 2013). River flow is determined by the hydrology of the catchment area, the consequent runoff, and the groundwater condition. The catchment is the fact of capturing or collecting water or the reservoir that does this area (Cleveland & Morris, 2015). The river flow of a catchment is dependent upon many factors such location area, rainfall, climate, topography, and geology. Although even if a site has a very promising topographic condition, at the end of the day the energy that is harnessed from a river is dependent on the discharge. To utilize the maximum available energy, it is important to know or estimate the water discharge data through the year. With a hydrology study, some data characterization is expected.

- The design discharge of plant sizing is based on the runoff data at the river. This data will also include the water intake sizing, and diversion circuit sizing.
- The peak flow design is based on the flood/peak flows. This data will determine the size of dam/weir, and the diversion channel on the plant.

The water discharge is a much more difficult problem to cope with because the flow in streams is normally changing throughout the length of the stream as tributary

streams increase the flow and some diversional water uses to decrease the flow (Ostojic et al., 2013). Similarly, the flow changes from one time to another due to hydrologic variation caused by the variation in precipitation, evaporation, snowmelt rate, and groundwater recharge that affects the magnitude of stream flow.
For the difficulties to estimates the flow, if there are a gauging station data available for the river (which is most of the time, not the case), then this data can be used. But, this data should be gauged regularly and expected for a long period or even for a decade. In the case, there is no recorded data or not enough data is available, the study of rainfall and streamflow based on catchment area, evapotranspiration, and geology are executed (European Small Hydropower Association, 2004).
The option where there is some hydrological station near the proposed site, the mean rainfall and runoff can be presented to deduct the discharge. Also, additional data such as climate and geological could be presented through this path.

2.2.1 Rainfall

Precipitation is water released from the atmosphere in the form of rain, snow, sleet or hail. While it's raining, some of the moisture is evaporated back into the atmosphere before even to reach the ground. Plants intercept the rainfall, a portion infiltrates the ground, and the remainder flows off the land into rivers, lakes or oceans (Poter & Colman, 2003). To measure the amount of rainfall ideally, a number of rain gauges are deployed within the catchment area to measure the adequate quantity of data. However, since very often in the case of hydropower development the rain gauge is not placed at the catchment area, it is sometimes necessary to sample few station that is located near to the proposed site.

Table 2-5 Errors occurs within gauging station (Rusin, 1970)

	Area per gauge (km^2)					
	10	50	100	500	1000	5000
Number of gauges	Error: percent of mean (%)					
1	26	28	34	38	47	54
2	18	20	23	27	35	38
5	11	12	15	17	22	24
10	8	8	10	14	16	17
20	6	6	8	8	10	12
50	4	4	4	6	7	8
100	2	2	3	4	5	6

To reduce the rain gauge error for the sample station, we can refer to the table 2-5. It's necessary to have a more hydrological station in the area for the accuracy in the data. On the other hand, in Mali very often the rainfall data provided is very limited. So providing data from these station is unusable.

2.2.2 Evapotranspiration

Evapotranspiration is defined as the total loss of water from a particular area, equal to the sum of the amount of water lost by evaporation from the soil and other surfaces and the amount lost by transpiration from plants (Cleveland & Morris, 2015).
Evapotranspiration is the representation of total evaporation and transpiration that comes from the land to atmosphere. and transpiration is the rate of water added to the atmosphere as it moves from the soil through the stomata of vegetation (Poter & Colman, 2003). Evapotranspiration (ET) is thus a compound term that describes the collective effect of evaporation of water and transpiration of plants. The factor that affects evapotranspiration is the air temperature, relative humidity, wind speed, and radiation of the sun during the day.
If it exists an amount of water resource, this amount of evapotranspiration that occurs is called as potential evapotranspiration (PET). Depending on the available data, there are some methods that can be used to estimate evapotranspiration (Perrin et al., 2003).
For the application of watershed that is large, the model of Blaney Cridle calculation with monthly time step could be adequate. The formula is given by the equation 2.11.

$$PET = K * P \frac{(45.7 * T + 813)}{100} \quad \text{Equation 2.11}$$

PET is the potential evapotranspiration in (mm), P is the monthly rate of annual sunshine in (%), and K is the monthly coefficient of vegetation. The value of K varies from the vegetation region and climatic zone (FAO, 2017). When the measurement of daily radiation data, daily temperature data, and wind speed data is available, Penman-Monteith approach is recommended to calculate the evapotranspiration value. This approach uses more data, needs more detailed time step, and also need accurate data (FAO, 2017).
For a location, where the data is not available or it is not estimated with accuracy, some empirical methods could be applied. The first method is by using temperature based evapotranspiration models, which are developed to estimate the evapotranspiration using data with low time resolution (for example, monthly temperature data). One of the most used models is the Thornwaithe-Mather evapotranspiration model (Perrin et al., 2003), which is described in the following equations 2.12 to 2.14.

$$PET = f16\left(10\frac{T}{I}\right)^{\alpha} \quad \text{Equation 2.12}$$

$$I = \sum_{1}^{12} i \quad \text{Equation 2.13}$$

$$i = \left(\frac{T}{5}\right)^{1.514} \quad \text{Equation 2.14}$$

With PET (mm) monthly potential evapotranspiration, T is the mean monthly temperature (°C), I is the yearly thermal index, i is the monthly thermal index, α is the empirical factor ($\alpha = 675x10^{-9} I^3 - 77.1x10^{-6} I^2 + 17.92x10^{-3} I + 492.39x10^{-3}$), and f is the correction factor which is described as:

$$f = \frac{D_m N_m}{360} \qquad \text{Equation 2.15}$$

where D_m is the number of days in the month, and N_m is the mean daily sunshine duration (hours).
The second method is based on radiation models. For tropical countries, Turc method has been known to perform well (Bradbury, 2000). The required data for this method is the average daily temperature, daily relative humidity data, and solar radiation measurement. For the climate with relative humidity more than 50%, the potential evapotranspiration can be calculated by the equation 2.16 (FAO, 2017):

$$PET = 0{,}313 \frac{T}{T+15} (S_n + 2.1) \qquad \text{Equation 2.16}$$

$$S_n = S_0 (1 - \alpha) \left(\alpha_s + b_s \frac{n}{N} \right) \qquad \text{Equation 2.17}$$

S_n is the amount of solar radiation (mm/day), S_0 is the extraterrestrial radiation (mm/day), α= 0.23 is the albedo value that is recommended in the absence of knowledge of land cover (Bradbury, 2000), a_s = 0.25 and b_s = 0.5 is the Angstrom coefficient (FAO, 2017), the value n over N is the percentage of bright sunshine hours compared to the total day length. Extraterrestrial radiation S_0 is calculated as follows:

$$S_0 = 15.392 d_T (\omega_s \sin(\phi) \sin(\delta) + \cos(\phi) \cos(\delta) \sin(\omega_s)) \qquad \text{Equation 2.18}$$

Where d_r is the relative distance of sun-earth, ω_s is the sunset hour angle (rad), ϕ is the latitude (rad), δ and is the solar declination angle (rad) .

2.2.3 Water balance

Approximately a quarter of the energy from the sun that reaches the globe surface is due to water from the ocean, lakes to evaporate. Figure 2.7 represents a conceptual model of the hydrologic cycle and shows Earth's water movement between the ocean, land, and atmosphere. As with all cycles, it is ongoing and continuous, and there is no specific start or end point (Poter & Colman, 2003).

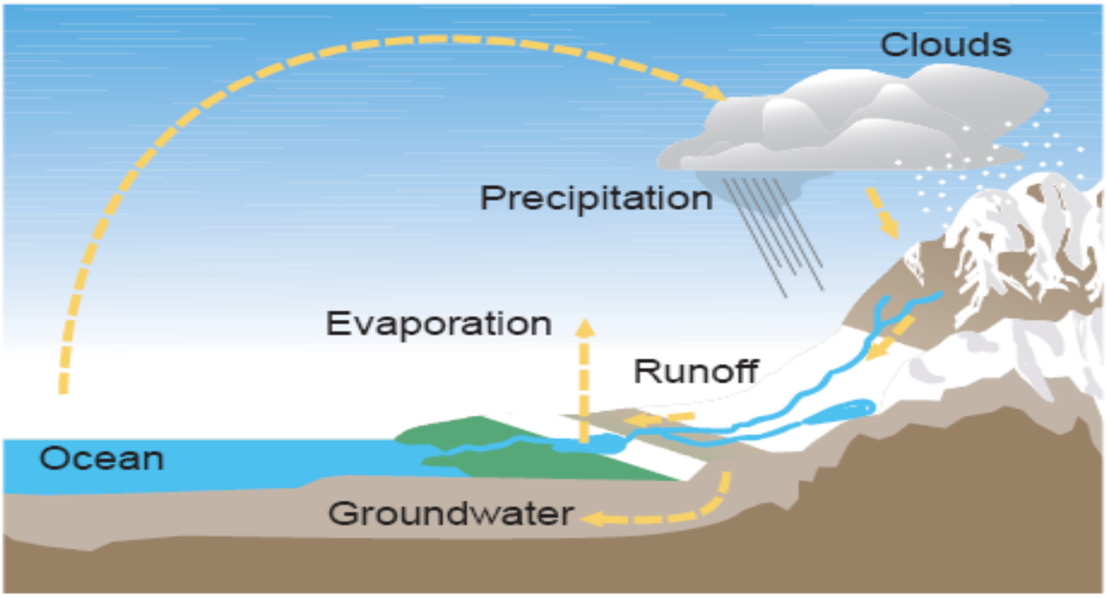

Figure 2.7 Hydrologic cycle of water

The water balance simply refers to the volume of water that flows through various components of the hydrologic cycle. More specifically, it is another useful conceptual model in which the components of the hydrologic cycle are evaluated as storage units that are affected by various inputs and outputs. For hydropower development, the water balance methods serve as a way to calculate the water discharge in the site (Perrin et al., 2003). The Thornwaithe-Mather method provides a model to know the monthly water quantity in a year, including the monthly runoff. This method needs the air temperature data, water holding capacity data from the soil, and also the correction factor based on site's latitude. Those data will produce the number of water used by plants for evapotranspiration, and knowledge about surplus or deficit of water in soil (FAO, 2017). To estimate monthly actual evapotranspiration, this method uses a bookkeeping model with monthly precipitation values and potential evapotranspiration values.

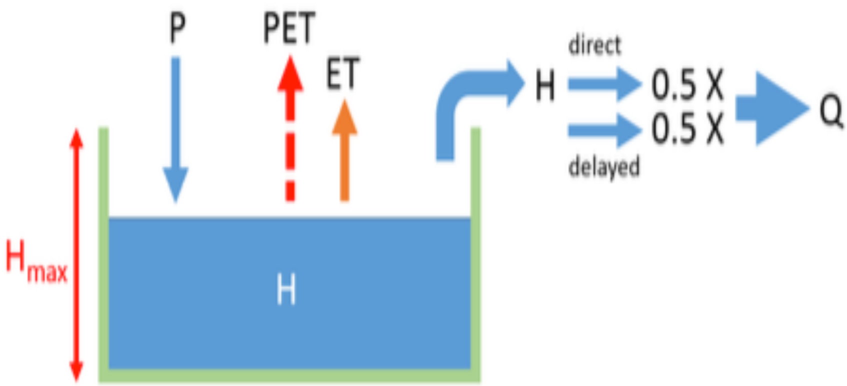

Figure 2.8 Thornwaithe-Mather Model

Steps to calculate the water discharge using the Thornwaithe-Mather method is as follows:

- Determine the precipitation data and temperature data on the same time series and time step.
- Calculate the potential evapotranspiration based on the same time series.
- Calculate the amount of water available in the soil at each time step. At the time t, amount of water available in soil is:

$$H = \begin{cases} H^{max} & if\ P_t - ET_t \geq H^{max} - H_{t-1} \\ H_{t-1} + P_t - ET_t & if\ P_t - ET_t \leq H^{max} - H_{t-1} \end{cases} \quad \text{Equation 2.19}$$

The value of H_{max}, water holding capacity, is determined by the product of soil depth and soil porosity.

• Calculate the water available in soil for evapotranspiration

$$H_t^{disp} = \begin{cases} min\left((PET_t - P_t)\frac{H_{t-1}}{H^{max}}; min\,(H_{t-1}, H_{max})\right) & if\ P_t \leq PET_t \\ No\ need\ of\ calaculation & if\ P_t \geq PET_t \end{cases} \quad \text{Equation 2.20}$$

Calculate the real evapotranspiration during time step t,

$$ET_t = \begin{cases} PET_t & if\ PET_t \leq P_t + H_t^{disp} \\ P_t + H_t^{disp} & if\ PET_t \geq P_t + H_t^{disp} \end{cases} \quad \text{Equation 2.21}$$

calculate the water discharge Qt

$$Q_t = \alpha S_t + (1 - \alpha)S_{t-1} \quad with\ S_t = P_t - ET_t - (H_t - H_{t-1}) \quad \text{Equation 2.22}$$

Where α is the reservoir coefficient and $\alpha < 1$ (general case $\alpha \approx 0.5$). If stream flow data are available, α can be empirically determined from hydrograph recession analyses.

2.3 Economic and Financial aspect

Economics looks to analyze and develop tools for individuals, organizations, and governments to make rational decisions about their allocation of scarce resources (Twidell & Weir, 2015). For hydropower it consists to analyze the projects concerns, measuring the benefits from the development and the costs expended. In the context of hydropower planning, benefits are the goods and services produced by the development. The costs are the goods and services used in constructing and maintaining the development. An economic analysis is necessary to determine whether the project is worth building and to determine the most economical size of the development or components of the development. Because both benefits and costs come about at different times, it is necessary to evaluate the benefits and costs in equivalent monetary terms, considering the time value of the expenditures and revenues involved. This is primarily an engineering economics problem.

The total cost of mini hydropower plant consists of four main parts: civil engineering, controls equipment, turbine generator, and management. The construction part which takes the most expensive part of the project investment 40% followed by the electric and mechanical equipment cost 30%. The cost of the control equipment and management consists of the project respectively 22% and 8% (Ogayar & Vidal, 2009). The economic cost of hydropower project includes all the aspect varies and can be different from location to another. It can be shown in Figure 2.9 that micro hydropower plant has the lowest minimum pay-back period than the other renewable energies resources (Laghari et al., 2013).

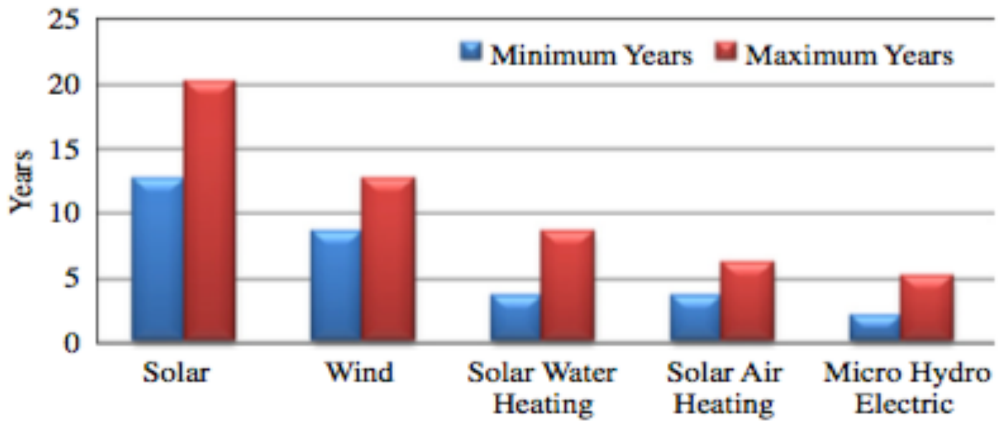

Figure 2.9 Payback period of renewable energies (Laghari et al., 2013)

Compared to the other renewable energies, hydropower provides a clean, cheap and reliable energy. The average Levelised Cost of Energy (LCOE) for hydropower plant project is around USD 0,05/kWh, while on some specific site the LCOE could be as low as USD 0,02/kWh (IRENA, 2015). One of the ways to compare the cost of electricity is by comparing the LCOE, which is measured by the amount of cost of the project per amount of energy.

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad \text{Equation 2.23}$$

where:
LCOE = The average lifetime levelised cost of electricity generation;
I_t = The investment expenditure in the year t;
M_t = Operation and maintenance cost in the year t;

F_t = fuel expenditures in the year t;
E_t = electricity generation in the year t;
r = discount rate;
and n = economic life of the system.

The operation and maintenance cost (O&M) for Hydropower plant is very low and has a long life cycle. This is one of the advantages of hydropower in term of the investment. The O&M costs are usually calculated as the percentage of yearly investment costs, with value averaged for about 2,5% (IEA, 2012).
In Mali, Independent companies are able to generate electricity through Power Purchase Agreement. In this scheme, the national utility "energie du Mali" (EDM) guaranteed the rights to generate electricity and manage it. The electricity produced can then be bought and distributed in the grid by EDM.

In order to determine whether a project is feasible and profitable to be launched, the standard investment decision metric for a renewable energy project is done. Generally, the study is based on components that are taken from cost structure of hydropower project, while also considering the potential revenue and the contingency cost from the project.

2.3.1 Net Present Value (NPV)

The Net Present Value shows the sum of the present value of future return at a corresponding discount rate that is reduced by the present value of investment costs. His approach also referred to as discounted cash flow (DCF) approach, used the time value of money to convert a stream of annual cash flow generated by a project to a single value at a chosen discount rate. This future return required (%) is typically expressed as a discount rate (Twidell & Weir, 2015). NPVs are commonly calculated for a project as a whole. This means the period cash flows of the initial investment and the subsequent cash flow available for finance (revenues, less operating costs, and taxation) are discounted by a single discount rate. NPV concerns the present value of future transactions. It is a powerful accountancy tool for project analysis. If different transactions at different times can be brought to their present monetary values, these can be added as one sum for the 'present value of the project'.

$$NPV = \sum_{i=1}^{i=n} \frac{R_i - (I_i + O_i + M_i)}{(1+r)^i} \qquad \text{Equation 2.24}$$

R is the return of the project, while I is the investment, M and O are the maintenance and operations costs.

2.3.2 Internal Rate of Return (IRR)

The internal rate of return (IRR) is the discount rate that makes the NPV of all cash flows from a particular project equal to zero. This is another measure of project desirability as, generally speaking, the higher a project's IRR, the more profitable it will be. Project IRR is simply the discount rate that makes the NPV of the period on period cash flows of the initial investment and then the subsequent cash flow available for finance (revenues, less operating costs, and taxation) equal to zero. So if a project's IRR is calculated at 12%, but the weighted average cost of finance (the blended return required by debt and equity providers) is 8% the project can be viewed as profitable (Twidell & Weir, 2015).

2.3.3 Payback Period

The calculation of simple payback time, in contrast to discounted payback time, does not account for the change of the value of money with time. As the name implies, this simply compares the total cost of project development with the income after all operating costs, to calculate the point at which the income pays back the development cost. A payback can be calculated for all finance provided or a payback just on the equity invested. While this gives a good 'rule of thumb' as to viability, it is almost never used by finance providers. On the other hand, community business or community groups that are self-financing a project can use this approach as one of a number of metrics to decide if they want to invest their own money into a project. For the small hydro project, the payback ratio should not exceed 7 years to be considered profitable (European Small Hydropower Association, 2004). Payback time is defined as the amount of time required to recover the cost of an investment. It can be calculated with the following formula.

$$Payback\ Time = \frac{Investement\ Cost}{Net\ Annual\ Revenue} \qquad \text{Equation 2.25}$$

2.3.4 Benefit to Cost Ratio (BCR)

In benefit cost ratio BCR, the benefit that is adjusted to present value is compared to the capital investment. In order to be considered as a feasible project, the value of BCR usually have to be more than 1to consider a project attractive. Following is the calculation of BCR.

$$BCR = \frac{\sum_0^n \frac{R_n}{(1+r)^n}}{\sum_0^n \frac{I_n+O_n+M_n}{(1+r)^n}} \qquad \text{Equation 2.26}$$

2.3.5 Sensitivity Analysis

Sensitivity analysis maps the risks that are associated with a hydropower project, and also shows risks that could potentially impact the project (IRENA, 2016). Since there are many assumptions made in a project, it is important to understand which assumptions that could most potentially change the project outcomes. The sensitivity analysis is made by changing some of the assumptions in the project while keeping other assumptions at their base (original) values. Therefore, the new project outcomes can be compared to the base outcomes, and then the impact of some particular assumptions can be assessed.

In the hydropower development, the assumption of standard investment finance metric is important for the project preliminary study. Based on the common practices, few parameters options that usually varied in the feasibility study is the total installed costs and interest rate.

Chapter 3

Methodology and Preliminary Design of the Power Plant

3 Methodology and Preliminary Design of the Power Plant

In this chapter, the hydropower potential site watershed will be presented. Furthermore, the two hydrological model was applied for the evapotranspiration calculations. The hydrology data processing and prefeasibility lay out consideration are described. These procedures delivered the monthly available discharge on the site that serves as the basis for the power plant design and annual energy generation. The most optimum designs are selected by taking into account the mechanical and electrical characteristics of the site.

3.1 Reconnaissance Survey

From a team of the Malian directorate of energy (DNE) and the national department of hydraulic (DNH), a reconnaissance of the small scale hydropower site was conduct across the country. The purpose of this brief investigation is to evaluate and estimate the potential of small scale hydropower. During these visits which consist to gain an understanding of each site characteristics such as the flow regimes, gross head, topography, the geology of the area, the itineraries road to access the place. Based on this brief reconnaissance, the site of Djendjenni was selected to conduct a further investigation in this study. This approach also provided an overall idea of the topography of the study area.

3.2 Catchment area

Watershed are characterized by their own climatic zone based on the vegetation, soil characteristics and the mean annual or seasonal precipitation. Knowing the geographical position of the site, it was possible to estimate the watershed concerned using a digital elevation model (DEM). Therefore the delimitation of the study area was defined using the file obtained from the earth resources observation and science (USGS, 2012) and ECREEE hydrology studies (Povry, 2017) proceed with the software ArcGIS. The resolution of the image is numerical 1-second arc height (30 m). The DEM data allowed to know the topography and the landscape of the watershed as input data for the hydrological analysis. This analysis was treated to get the discharge values and to assess other relevant characteristics of this basin. The watershed area of the site is traced as shown in figure 3.1.

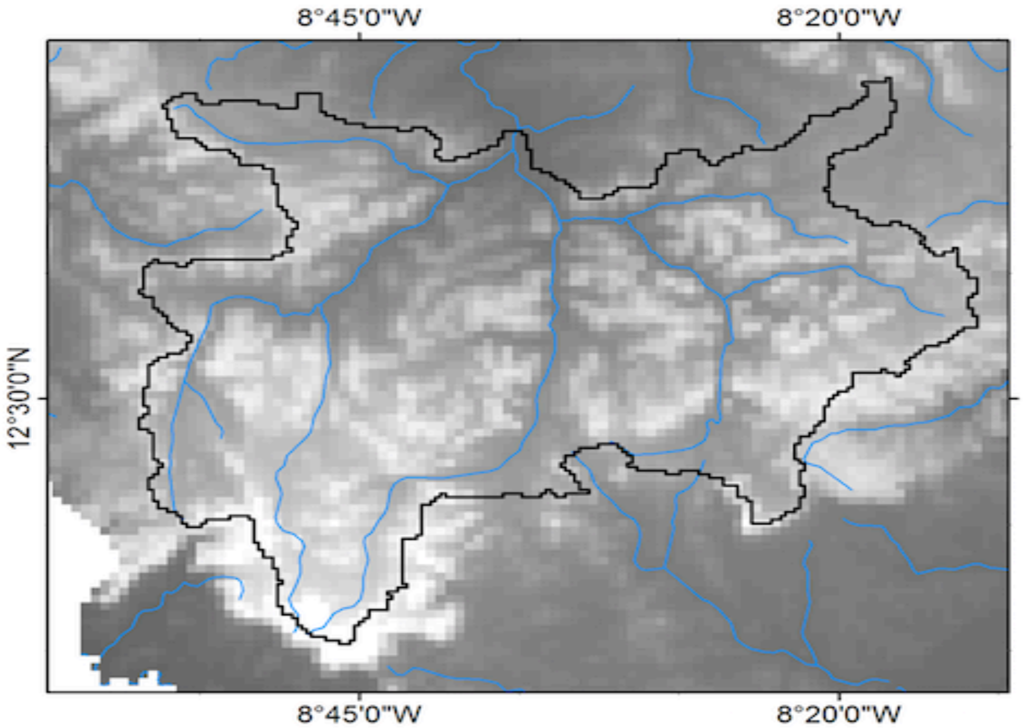

Figure 3.1 Watershed in Djendjenni site

3.3 Weather data input and sources

The Blaney Cridle and the Thornthwaithe Mather model were used to calculate the evapotranspiration and so as to get the discharge Q. As a climatic input data, the two methods were conducted with just mean temperature, precipitation, and rate of annual sunshine. Daily data sets interpolated to a 0.5° grid obtained from the Global Climatic Data and Climatic Forecast System Reanalysis (CFSR) at 38 km resolution were used (WorldClim, 2016; Global Weather Data for SWAT, 2017). The CFSR weather data was proven to be a valuable option for hydrological prediction in data scarce regions such as this case where conventional gauges are not in the area (Dile, 2014). The rainfall and other estimates parameters were previously corrected for gage bias. Data from a large number of terrestrial stations and oceanic grid points were used to estimate the rainfall (Fuka et al., 2013). The climatology data are available globally for each hour since 1979 which gave a recent rich data. Thus the weather parameters estimated in the area are summarized in Table 3-1.

Table 3-1 Weather Parameters and Units used in determination of evapotranspiration

Weather parameters	Units
Rainfall	mm
Minimum and Maximum Temperature	°C
Sunshine	MJ/m^2
Humidity	In percent %

3.4 Precipitation

Monthly rainfall data were calculated from the daily rainfall data for the catchment using the data source cited previously. Weather data at four different point were considered in the catchment area and used for subsequent calculations due to the distribution and variation of the precipitation. The arithmetic average of these points with different elevation is calculated to determine the estimate precipitation value. The precipitation estimates for the watersheds are presented in the table below.

Table 3-2 Monthly rainfall (mm) in the watershed from 1994 to 2014

Month /Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994	0.00	0.00	0.71	2.25	5.75	29.26	57.16	410.65	245.96	150.65	1.13	0.00
1995	0.00	0.23	2.83	3.86	12.05	18.19	158.78	128.82	86.72	8.69	0.00	0.01
1996	0.00	1.58	0.05	2.66	20.43	16.62	134.83	146.59	18.95	11.07	0.00	0.00
1997	0.00	0.00	0.00	6.44	33.92	80.66	114.43	409.96	67.16	45.86	0.00	0.00
1998	0.00	0.00	0.00	0.54	10.02	10.28	24.64	159.32	132.90	4.66	0.00	0.00
1999	0.00	0.00	0.02	6.46	0.92	0.53	18.30	181.10	23.18	1.69	0.26	0.00
2000	0.00	0.00	0.41	0.06	2.97	2.51	43.98	35.09	5.71	9.06	0.99	0.00
2001	0.00	0.00	0.00	1.78	2.36	5.80	64.77	197.67	9.42	2.59	0.03	0.00
2002	0.11	0.00	0.33	0.36	17.70	10.70	22.43	17.18	5.96	1.92	0.00	0.34
2003	0.00	0.00	0.00	0.67	1.68	15.83	106.92	23.27	23.34	2.36	0.66	0.00
2004	0.00	0.03	0.00	1.16	0.32	8.47	67.58	106.99	38.93	0.46	4.11	0.00
2005	0.00	2.10	1.14	0.27	0.73	9.55	55.35	33.59	17.96	0.18	0.00	0.00
2006	0.00	0.06	0.00	1.90	5.15	1.81	19.91	34.18	108.93	7.18	0.00	0.00
2007	0.00	0.00	0.00	0.74	8.00	11.04	101.35	222.46	72.90	5.99	0.90	0.00
2008	0.00	0.00	3.47	5.93	10.76	50.47	310.40	381.19	104.87	31.38	0.00	0.49
2009	0.00	3.69	4.13	0.03	7.28	27.21	64.38	342.03	182.89	7.89	53.32	0.00
2010	0.00	0.00	0.00	10.72	82.77	21.72	348.47	398.02	250.39	141.52	5.60	0.00
2011	0.00	0.01	0.01	4.62	31.64	17.46	293.48	310.33	155.59	36.21	0.02	0.00
2012	0.01	0.00	0.06	3.51	8.04	158.3	153.34	392.03	394.70	170.31	1.20	0.01
2013	0.04	0.00	0.01	2.44	14.77	41.49	236.16	229.33	141.29	71.40	0.00	0.02
2014	0.00	0.00	0.03	0.35	40.91	26.38	251.67					

It can be seen that the recorded rainfall series show different hydrological regimes.

One before 1998 with an annual rainfall of 903 mm and the other after 1998 where the annual rainfall is reduced by more than half. Just then after 2006, the rainfall has found his annual frequency in the catchment. This significant variation between the two periods can be explained by the fact that all West Africa, the frequency of rainfall was reduced in the early 2000s.

The Djendjnni site is located in an area of tropical climate characterized by two seasons: a dry season and a rainy season. With an average annual rainfall of 903 mm /year, this zone is classified as Sudanian agro-ecological climate. The duration of the rainy season and the intensity of the rain shower are at least important as the overall quantity. In addition, interannual variability of rain is very common in the region. In recent decades, the distribution of climatic zones has shifted to the south. That means the country has generally become drier. The highest amounts of rain are recorded during the months of July, August, and September. These large precipitations are manifested by heavy runoff and a strong recharge of the water ground. From November to April, the study area receives just small amounts of rain, in general, it's not raining.

3.5 Evapotranspiration

Since the data accessibility is limited for the evapotranspiration calculation in this area. The Thornwaithe-Mather and Area rainfall methods were used due to the simplest way to provide a quick estimation for water balance in the watershed. For these models, the temperature and the rate of annual sunshine data are needed. For a prefeasibility study purpose, it is supposed that the adjusted mean temperature data from one point in the catchment can represent the temperature data which is presented in figure 3.2.

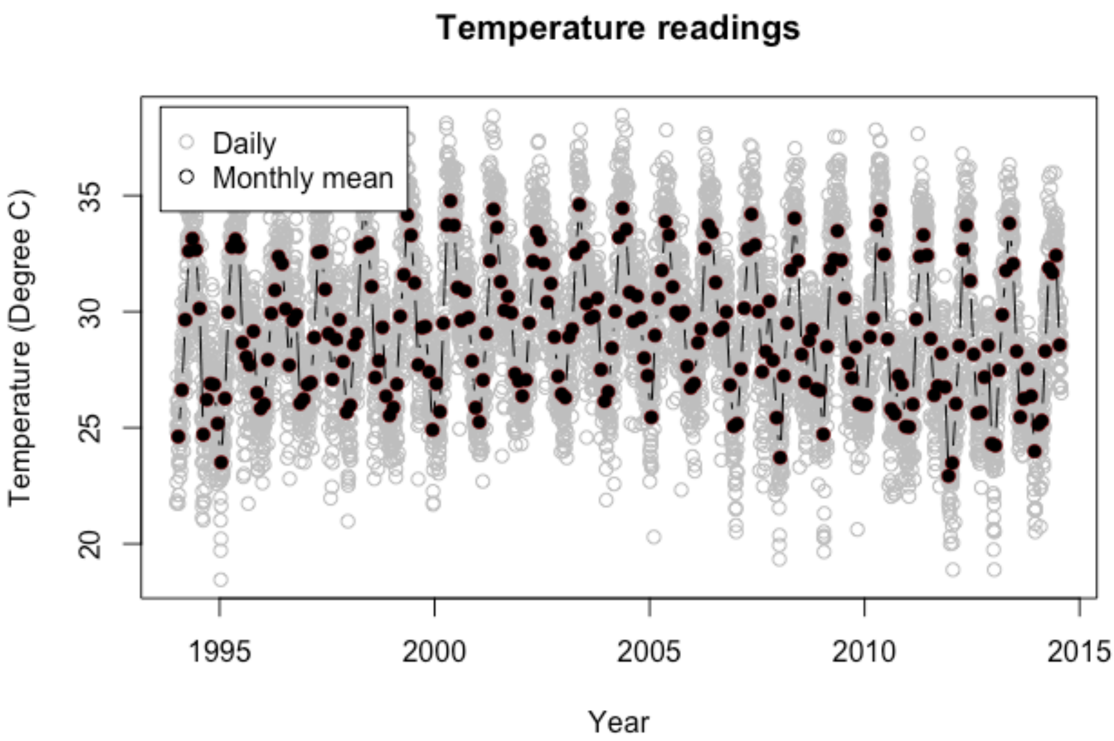

Figure 3.2 Daily and monthly mean temperature in the catchment area

The average extreme temperatures range from 19 °C (minimum) to 36 °C (maximum) with an annual mean temperature 29 °C. The hottest periods are from March to May with peaks in April. The lowest temperatures are obtained from November to February, which corresponds to the cool period. The insolation is the duration of the sunshine. The highest monthly mean values of insolation at Djendjenni are obtained during the months of January, March, and April with more than 260 hours by month. The months of July and August show the lowest values around 200 hours by month.

Based on the monthly mean temperature and the monthly rate of sunshine data, the monthly potential evapotranspiration was calculated using equation 2.11 and equation 2.12 which represents respectively the Blaney-Cridle and Thornwaithe-Mather model. Here it's a tropical climatic zone there is only one wet season which occurs at the end May to October. The iterative calculation starts at the beginning of the wet season for the Thornwaithe Mather model. The result of these calculations is shown in figure 3.3.

In order to compare the data, the global monthly potential evapotranspiration data from the climatic research unit CRU TS3.24, University of East Anglia (UK) was used (CEDA Data server for CRU, 2016). The result of the comparison is that the Blaney-Cridel model performs well in the area of interest by providing calculation results close to the data from CRU, which is an average 92 mm/month. Figure 3.3 shows the monthly data calculation of the two model from the period 1994 to 2013.

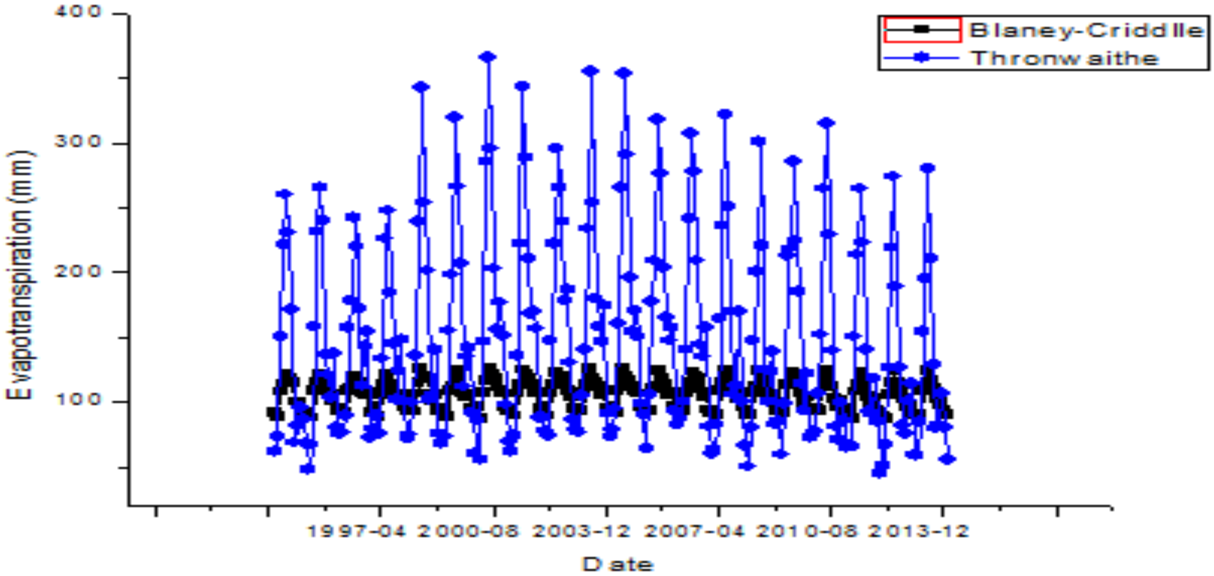

Figure 3.3 Monthly evapotranspiration calculation

3.6 Stream Flow Estimation

From the brief survey at the site, the stream flow was measured using the float method. The measurement was taken at the upstream of the river where the axis of the streambed is straight and has an approximately constant cross sectional area.

The value measured there for the potential are as follows:

- Estimated fall height: H = 20 m
- Cross sectional area: S = 3.33 m^2
- Measured flow: 0.46m /s
- Discharge calculated by Q = Vx S = 1.5m^3 /s

By applying the equation

$$P = g\ x\ Q\ x\ H\ x\ k \qquad \text{Equation 3.1}$$

where k is on the order of 0.6 to 0.7 for small power plants, an approximate power of 180 kW was obtained.

Since the waterfall of Djendjenni is not gauged, there is no discharge data that can be used for planning Mini hydropower project. Since only rainfall data is available, the stream flow was estimated using Area Rainfall method.
The step to calculate the stream flow are:

- Estimation of the base runoff and direct runoff
- Calculation of the potential evapotranspiration
- Calculation of evaporation
- Computation of monthly runoff data

The relation of precipitation, runoff (include direct runoff, base runoff) and evaporation are indicated by the viewpoint of annual water balance shown in the equation 3.2. The total volume of rain passing in the watershed in a month is the sum of the daily recorded.

$$R = P - PET \qquad \textit{Equation 3.2}$$

Where, P: Annual rainfall (mm)
R: Annual runoff (mm)
PET: Evapotranspiration (mm)

The runoff is delivered from subsurface water, the ratio of sub-surface water to annual runoff (R) is shown in Table 3-3. Rb is subsurface water, for the following calculation, Rb / R = 0.35 is constant, and the base runoff is taken as constant.

Table 3-3 World water balance model, Source: (Lvovich & Stoklisky, 1973)

Area	Asia	Africa	North America	South America	Europe
Rainfall (P)	726	686	670	1648	734
Runoff	293	139	287	583	319
Direct Runoff	217	91	203	373	210
Subsoil Water	76	48	84	210	109
Evaporation	433	547	383	1065	415
R_b/R (%)	26	35	32	36	34

The monthly discharge data were calculated with the derivation of the monthly runoff at the site using the equation 3.3

$$Q(i) = \frac{Monthly\ runoff\ R\ (mm)}{1000} * A * 10^6 * \frac{1}{86400 * n} \qquad \textit{Equation 3.3}$$

Q(i) : Monthly mean discharge (m^3/s)
$A_{catchment}$: Catchment Area (Km^2)
n: Number of days in the month

The Tables 3-4 and 3-5 represent the estimation of the monthly stream flow of the Djendjenni watershed from the monthly mean temperature, rainfall and rate of annual sunshine data for the year 1994.

Table 3-4 Calculation of real evaporation year 1994

Month	(1) Temperature (°C)	(2) Rate Of Annual Sunshine (%)	(3) PET equation 2.11 (Blaney- Criddle) (mm)	(4) Rainfall (mm)	(5) Real Evaporation(mm) (small value of (3) and (4))
Jan	24.62	8.06	93.73	0	0
Feb	26.63	7.43	90.50	0	0
Mar	29.65	8.44	109.79	0.70	0.70
Apr	32.61	8.4	116.09	2.25	2.25
May	33.14	8.87	123.87	5.74	5.74
Jun	32.66	8.69	120.21	29.25	29.25
Jul	30.14	8.92	117.23	57.15	57.15
Aug	24.71	8.76	102.08	410.64	102.08
Sep	26.21	8.26	99.66	245.95	99.65
Oct	26.9	8.31	101.83	150.64	101.83
Nov	26.86	7.85	96.11	1.12	1.128
Dec	25.18	8.01	94.38	0	0

Table 3-5 Calculation of the monthly stream discharge 1994

Month	(6) Runoff (mm) (4)-(5)	(7) Direct runoff (6)*0.65	(8) Base runoff (mm)	(9) Monthly runoff (mm) (7)+(8)	(10) Mean discharge Q (m^3/s)
Jan	0	0	17.7	17.70	0.79
Feb	0	0	16.65	16.65	0.83
Mar	0	0	17.7	17.70	0.79
Apr	0	0	17.47	17.47	0.81
May	0	0	17.7	17.70	0.79
Jun	0	0	17.47	17.47	0.81
Jul	0	0	17.7	17.70	0.79
Aug	308.56	200.57	17.7	218.27	9.78
Sep	146.30	95.10	17.47	112.57	5.21
Oct	48.81	31.73	17.7	49.43	2.21
Nov	0	0	17.47	17.47	0.81
Dec	0	0	17.7	17.70	0.79

After taking into account some of the key characteristics like the evapotranspiration, the vegetation crop coefficient in the watershed. The estimated flow available at the project site for energy production is presented in the figure below.

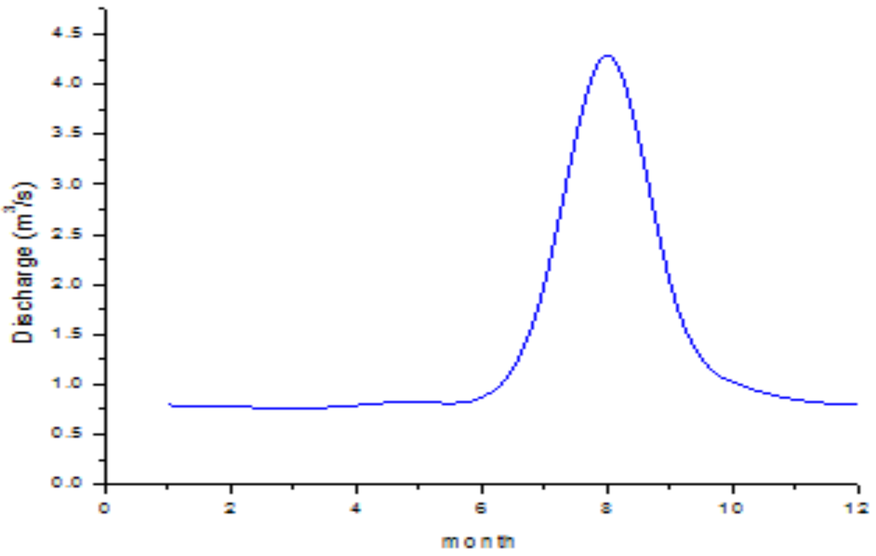

Figure 3.4 The mean discharge calculated for the period 1994 to 2013

During the period considered (1994-2013), daily flow rate range from 0.0 m^3/s to a value of 9.77 m^3/s with an overall average of 1.32 m^3/s. Whereas the average annual maximum flow rate is almost 4.36 m^3/s. The peak of the discharge occurs in the wet season with a heavy precipitation from June to October. On the other hand, there is a low flow rate at the drier period from December to June with a minimum in March.

3.7 Sizing of the equipment

3.7.1 Design discharge

The flow available for generating electricity at the site of a hydroelectric generating station is generally expressed using the Flow Duration Curve (FDC) which indicates the percentage of time during which the flow is likely to equal or exceed a given specific value. This curve provides the flow rate that is reached or exceeded at the site for a certain percentage of the time. The flow rate curve is calculated using the estimated daily intake flows on the site for years which the discharge is calculated.

The first stage to make the flow duration curve is to determine the data time step. Generally, the daily time step is used when the data is available, that will give a step curve. Thus, the monthly discharge data calculated in the previous section from years 1994-2013 are used, with total 247th time step. By increasing the time step, the resulting curve is expected to be flatter, since the extreme low or high value are averaged out in these time periods.

Next, these data ordered from the highest to the lowest value, from the 1st value to the 247th value, with the 1st value is the highest discharge. For each discharge value, the exceedance probability (P) is then calculated by the equation 3.4. The curve obtained is shown in the figure below.

$$P = \frac{M}{n+1} * 100\% \qquad \textit{Equation 3.4}$$

where P is the probability that given flow will be exceeded or equaled (% of the time), M the order number of discharge (or data rank) and N are the numbers of data points in the list.

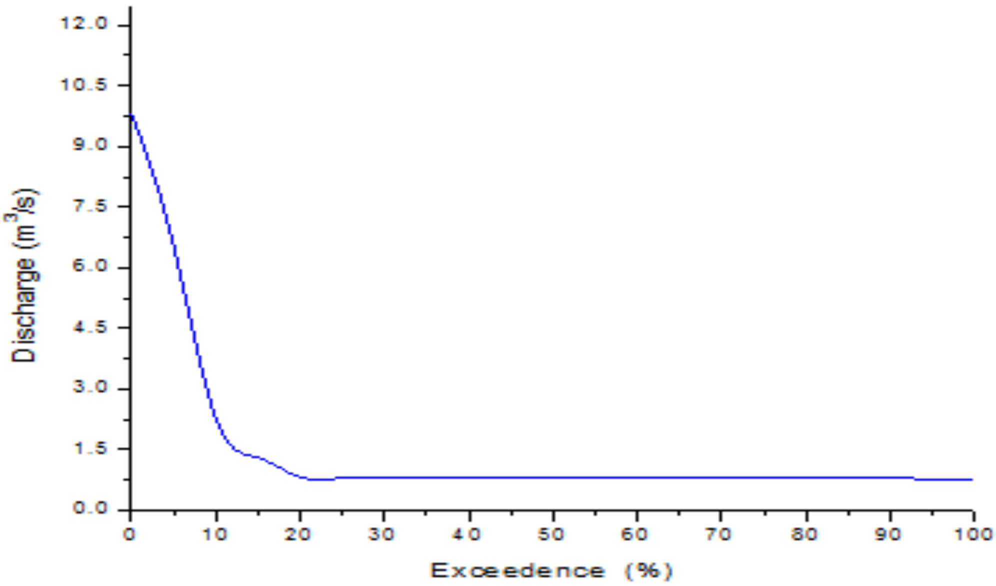

Figure 3.5 Flow duration Curve in the potential site

Form the graph, the design discharge can be determined for an optimum operation and an efficient use of the turbine. An optimization process is carried out generally by comparing the economic parameters of few discharge values based on assumptions. The optimization process was done by taking into account the flow duration curve and the minimum technical turbine flow. A design discharge of Q=0.79 m^3/s which occurs 5% of the time will be chosen for an available energy production. Since a volume of water is allowed to flow all the time for the species and a sustained environment purpose, a compensational flow of 0.05 m^3/s should be considered.

3.7.2 Turbine

The Turbine selection is based on the output of the turbine, the design discharge and available head for the site. From the figure 2.4 in the chapter literature review, the suitable turbine for this small power plant is the Kaplan. After selecting the turbine type, there are various parameters that need to be designed in order to ensure that turbine would work efficiently. Those parameters are rotational speed, specific speed, and range of discharges through the turbine.

The specific speed of the turbine n is determined by the following calculation:

$$N_s = \frac{N\sqrt{P}}{H^{1.25}}$$ *Equation 3.5*

With the rotational speed $N = \frac{2700}{\sqrt{H}} = \frac{2700}{\sqrt{20}} = 603\ rpm$

Net head = Gross head – Head loss Net head

= Gross head – 6% (Gross Head) an assumed 6% of hydraulic losses

H_{net} = 20 m – (0.06x20) = 18.8 m

So the specific speed for the Kaplan turbine will be $N_s = \frac{603*\sqrt{115}}{18.8^{1.25}} = 165$ rpm

This specific speed corresponds well to the range of a Kaplan turbine 40 < Ns < 200.

The runner diameter will be calculated using the formula below

$$D_{runner} = \frac{41 * \sqrt{H_{net}}}{\text{N (the rotational speed)}} = 0.29\ m$$

D= 0.29 m

The turbine runner length L_{runner} is obtained from the orifice discharge equation. The jet thickness is usually between one tenth and one fifth of runner diameter.

$$Q = A_{nozzle} * \sqrt{2gH_{net}}$$ *Equation 3.6*

$$Q = t_{jet} * L_{runner} * \sqrt{2gH_{net}}$$

with $t_{jet} = \frac{1}{5} * D$ = 0.2*0.29=0.058 m

$$L_{runner} = \frac{0.23*Q}{t_{jet}*\sqrt{H_{net}}} = 0.722 \text{ m}$$

the runner length L= 0.72 m

The efficiency curve for the turbine is shown in figure 3.6. The turbine parameter was based on the previous mechanical input and the typical parameters from RETscreen simulation for small scale hydropower system.

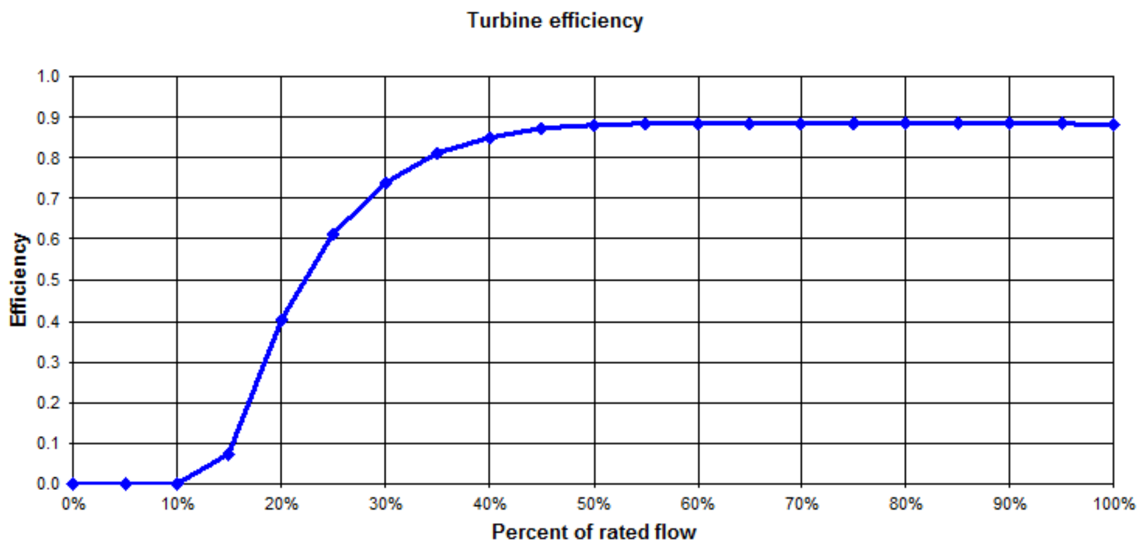

Figure 3.6 Turbine performance for the design discharge of the Djendjenni site

3.7.3 Generator

The generator output in KVA is calculated from the following equation

$$P = \frac{g*H*Q*\eta}{pf} \quad in \;\; KVA \qquad \text{Equation 3.7}$$

η is the combined efficiency of the turbine, generator, and transmitter. Taking into account the base load and the turbine, the simulation in the RETscreen gave a value of 84.5 % for the power factor (pf).

$$\eta = \eta_{turbine} * \eta_{generator} * \eta_{transmitter} = 0.88*0.98*0.99 = 0.85$$

$$P = \frac{9.81*20*0.79*0.85}{0.84} = 156.84 \qquad \text{(KVA)}$$

The sizing of the generator is following the calculation the speed and number of poles. The value of the rotational speed is indicated according to the frequency 50 Hz of the power network. Also, the number of poles as shown in the equation below for induction generator selected for this site.

$$N_g = \frac{120 * f}{P} * (1 + s)$$

Where P is the number of poles of generator and F the frequency of the system in Hz. S is the slip of generator. Generally, its given by the manufactured 0.02.

Then from the turbine sizing section, the desired speed of the generator is 603 rpm and the synchronous speed Ns = 165 rpm. Therefore, the number of the pole is calculated herein.

$$Nbre\ of\ poles = \frac{120*f}{N} = 9.95$$

The number of pair poles has to be an integer, so a value of 10 pole generator is taken.
The Rotational speed of induction generator

$$N_g = \frac{120*50}{10} * (1 + 0.02) = 612 \text{ rpm}$$

Knowing the rotational speed of the turbine and for the induction generator, the gearing ratio G is estimated

$$G = \frac{generator\ rpm}{Turbine\ rpm} = \frac{612}{603}$$

Then the ration G=1.014

These dimensions do not include the dimensions of the power house where the turbine and the generator will be installed. The latter is necessary to ensure a proper installation for the electrical equipment such as the substation. For operation in isolated mode, a flywheel is required for the couple turbine/ generator. The dimensioning of the flywheel is a matter for a specialist and is generally carried out by the manufacturer of the speed regulator. During the implementation phase, these dimensions can vary in an order of magnitude approximately ± 10% depending on the manufacturer.

Chapter 4

Economics Analysis and Energy Production

4 Economics Analysis and Energy Production

A preliminary cost estimation was made based on the design discharge and the optimal engineering option as described in the previous chapter. The financial and economic analysis was carried out with RETscreen software to evaluate the viability of the project. This model is based on the estimated feed in tariff of electricity production, the design discharge and the cost estimation of the project components. Furthermore, with these optimum design the annual energy production is calculated in the last section of the chapter.

4.1 Preliminary cost estimation

4.1.1 Cost Estimation using the software RETscreen

The RETscreen small hydro project model is simple but a very useful tool for a preliminary investigation of the financial and technical feasibility of a small hydro project. It can provide a worldwide analysis of energy production, life cycle costs and greenhouse gas emissions reduction.it is written in visual basic code with iterative excel worksheets, provides a means to calculate the available energy at any potential small scale hydro site that could be provided to a central-grid or for an off grid loads, and the financial viability of the project by estimating project costs. The model addresses both run-of-river and reservoir developments and calculates efficiencies of a wide variety of hydropower turbines (RETScreen, 2004).

The small hydro model was used to evaluate the small hydro projects. The direct cost was estimated by multiplying the quantities with a unit rates for the main construction activities for each of the components of the project. The unit rates applied to civil works were estimated based on the feasibility studies carried out for similar projects in the subregion and in the world. The construction and subsequent implementation were given a particular importance to the project cost estimation. The costs of the intake, electromechanical equipment, and other hydraulic constructions were estimated using specific values dependent on the suppliers (Home Power, 2017). In addition to direct estimated project costs, there were indirect costs (unforeseen engineering case, operation, and maintenance) were also estimated and added to the direct cost. The table below summarizes the results obtained with the RETscreen software.

Table 4-1 Estimated project initial cost

Project costs and savings/income summary			
Initial costs			
Feasibility study	3.2%	$	15,000
Development	4.2%	$	20,000
Engineering	25.2%	$	120,000
Power system	40.0%	$	189,910
Balance of system & misc.	27.4%	$	130,426
Total initial costs	**100.0%**	**$**	**475,336**

The result of the preliminary cost estimation is USD 475,336 and the specific costs per installed kW will be 475,336/ 113 = 4206 USD/kW which is in the range of a typical small hydro system cost 1200 to 6000 USD per installed kW.

4.1.2 Economic analysis

Hydroelectric projects require considerable capital and investment over a relatively long period and a full completion and commissioning before a return of investment. The financial analysis is based on the assumptions of the best practice approach in the company and also literature study.

- It is estimated that the power plant will have an installed capacity of 113 kW and basic price to import the electricity USD 0.11 /kWh.
- It is estimated that the development to build the power plant for a period of 15 months.
- The lifetime of the equipment was assumed to operate for a period of 40 years for civil engineering structures and 20 years for electrical components. Electromechanical, hydro mechanical and electrical equipment. After 20 years, a major rehabilitation of the hydraulic circuit, mechanical and electrical equipment should be considered.
- Annual operation and maintenance costs were estimated at 3% of capital costs.
- For this case, a mixed project public private partnership was assumed to be the funding source. So a discount rate of 7% was used.

The main assumptions considered in RETScreen for the project investment costs and financing costs are summarized in the table below:

Table 4-2 Assumed financial parameters for the project funding

Financial parameters		
General		
Fuel cost escalation rate	%	0.0%
Inflation rate	%	2.0%
Discount rate	%	7.0%
Project life	yr	40
Finance		
Incentives and grants	$	
Debt ratio	%	70.0%
Debt	$	332,736
Equity	$	142,601
Debt interest rate	%	3.50%
Debt term	yr	30
Debt payments	$/yr	18,091

The incentives and grants were not taken account in the model due to the supposition that the project will not benefit any contribution or subsidies. Considering a basic tariff for the sale of electricity of USD 0.11 /kWh, the project achieves a positive return on capital within 7.4 years which could possibly attract private investors or convince commercial banks to participate in the financing of the project. A majority share of concessional financing for public investment will lead to an improvement in the internal rate of return (IRR). This effect can even reduce the levelised cost of the electricity.

4.1.3 Financial sensitivity analysis of the project

In the financial analysis, the viability of a project is estimated from the point of view of a potential investor. According to this view, a project is viable if a certain rate of return on the equity is reached. To cover investment and operation costs, discounted unit costs are determined. These costs are defined as the net present value of investment costs, operating costs and maintenance divided by the net present value of total production. In addition, costs and revenues for the project were calculated between the start of construction and the end of project life and also to estimate the internal rate of return, the rate of return on capital and the net present value of the project. Finally, sensitivity analyses were carried out with the cost of the project, the generated electricity, the discount rate, and the tariff of the electricity to determine the feasibility of the project. For this sensitivity study, the following parameters are summarized in the table 4-3

Table 4-3 Financial viability of the project

Financial viability	Financial viability		
	Pre-tax IRR - equity	%	30.9%
	Pre-tax IRR - assets	%	8.0%
	After-tax IRR - equity	%	30.9%
	After-tax IRR - assets	%	8.0%
	Simple payback	yr	7.4
	Equity payback	yr	3.1
	Net Present Value (NPV)	$	382,187
	Annual life cycle savings	$/yr	28,668
	Benefit-Cost (B-C) ratio		3.68
	Debt service coverage		3.54
	Energy production cost	$/MWh	75.75

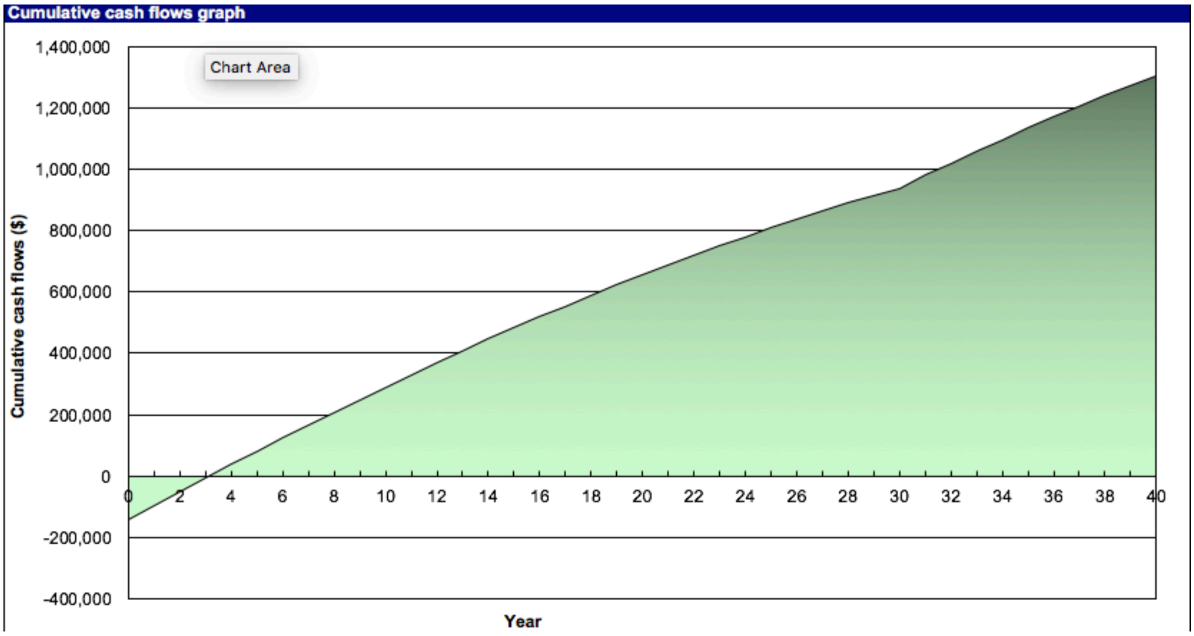

Figure 4.1 Cumulative cash flows graph

With high price assumptions, the project gives a very high return on the investments, with Benefit/ Cost Ratio of 3.68. In this supposition, the payback period is also small below 7.4 years, which is very attractive. Compared to the LCOE data for small hydropower from IRENA (IRENA, 2015), the assumptions made on the projects result in the value of LCOE which is high, over the range value USD 0.02 to 0.05/kWh. But the project is still profitable in financial view and feasible.

4.2 Energy Production

The study of electricity demand in the project area is one of the first step for a pre-feasibility study before to project for the implementation. It consists for a projection of the future energy consumption in the area up to 2040 (a period of 20 years) and deducing the necessary hydroelectric power generation. Forecasting electricity demand is an essential step, as it conditions the operation of the power plant. The energy demand consists of three electricity demand scenarios in order to determine the necessary investment.

- Basic scenario
- Weak scenario
- Strong Scenario

The weak and strong scenarios are derived directly from the basic scenario in adjusting the annual production. The assumptions used are +10% for the strong scenario and -10 % for the low scenario.
Assuming a specific load per subscriber that increases from 400 W per subscriber in 2020 to 550 W per subscriber in 2040 and a simultaneity factor of 0.9 loads for the village have been estimated. Considering 90% of the electricity production will be used for the domestic purpose and the remaining 10% are for the public lighting.
This estimation also considers the demand for the small and medium-sized enterprises which currently cannot grow due to insufficient energy supply. The result shows that the installed capacity should be extended or limit the load charge.

The electricity requirement for public lighting is estimated on the basis of the length of low voltage LV transmission lines 30 lamps per kilometer and a load of
80 W per floor lamp. Taking account for distribution losses of 20%, the total power demand for the three scenarios is shown table 4-4

Table 4-4 Estimated energy production for the 3 scenarios

Loss in the distribution line		20 %
Load factor		0,39
Annual energy (basic scenario)	MWh	837
Annual energy (strong scenario)	MWh	920
Annual energy (weak scenario)	MWh	753.3

The power plant was designed for the net gross head of 20 m, a designed discharge of 0.79 m^3/s and installed capacity of 113 kW. The operation range of the turbine would be 0% to 900% of the flow capacity. Therefore, the annual generated electricity for the site is calculated. During normal operations, the annual electricity production of the site is 837 MWh.

The case where the demand will be low during the day, a charge of the 30% of the 113 kW will be estimated. For this case, two options can be employed to facilitate the operation. As it will be an isolated mini grid, the first option will be to develop an agribusiness industry for irrigation or to plan to extend the transmission line if there is a village around.

Chapter 5

Conclusions and Recommendations

5 Conclusions and Recommendations

5.1 Conclusions

As part of the pre-feasibility study, this thesis has developed a small-scale hydropower plant preliminary study in the waterfall of Djendjenni. This site shows a promising economic result with an acceptable feed in tariff. However, there are still several steps needed in order to ensure that the project is feasible both economically and technically.

A hydrology study was carried out based on the rainfall, mean temperature and sunshine data for the watershed area to estimate the potential evapotranspiration with Thornwaithe-Mather and Blaney Cridle model and then was validated with the CRU evapotranspiration data. Based on the water balance in the watershed the mean discharge value is obtained. The water discharge data arranged to create the flow duration curve, which is used to determine the design discharge. The hydropower plant capacity is based on the design discharge value. To let a portion of the aquatic to continue to flow and for in irrigation purpose, an optimum design discharge value is obtained at 0.79 m^3 /s for the power plant.

From the design discharge and the net head, a selected Kaplan turbine was adopted for the power plant. The period of commissioning and construction of the project will extend over a period of approximately 15 months as supposition in the RETscreen model. The installed capacity is 113 kW for a flow rate of 0.79 m^3 /s. Average annual energy production with a run-of-the-river operation is 837 MWh. The installed capacity is available for about 90% of the year. For the 10% of the year, there is a low flow rate in a dry period or a higher flow that can occur in the heavy raining season where the turbine cannot be exploited. There more or less mini hydro potential which will be lost.

The financial analysis was made in order to determine the economic parameters of the mini hydropower. The capital costs of the Djendjenni site including (civil engineering, operation, power plant designing, feasibility study) were estimated at USD 475,336 dollars with the specific costs per installed kW 4206 USD. For a mixed financing (public / private) and estimated Levelised cost of electricity 0.11 USD / kWh, the project has a benefit cost of ratio B-C ratio of 3.68 greater than 1 which is attractive for a future development of the site. With a discount rate of 7% and debt interest rate of 3.5%, the site has a simple equity payback of 7.4 years that make profits in an economic point of the view for the project. In this analysis, the revenue is heavily dependent on the annual energy generation to make the project viable

5.2 Recommendations

Based on this study, the Djendjenni site is shown to be a promising site that needs to be advanced to a further phase of development. The future study has to include more detail and direct data measurement to the site. These measurements are

- A rain gauge to record daily data discharge at least for a period of 2 years.
- Topography survey to provide a map for the area, which is used to produce x and y-axis map for a detailed civil engineering, powerhouse, and road plans.
- Electro-Mechanical detailed design and analysis
- Detailed hydraulic studies, including the design of dam/weir, hydraulic circuits, and safety components. They also include surge analysis in transient conditions that happen in plant startup/shut- down, valve maneuvers, pressure and discharge variation.
- A detailed cost estimate based on detailed study data.
- Geology and soil study to determine the feasibility of site development in the proposed sites. A laboratory test of rock and soil type at the project site is recommended to get further geotechnical properties of rock and soil in details.

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Appendix A RETscreen small hydro project software formula

VARIABLE	SMALL HYDRO	MINI HYDRO	MICRO HYDRO
Q_d	User-defined value		
n	User-defined value		
Q_u	Q_d / n	Q_d / n	Q_d
d	$0.482(Q_u)^{0.45}$		
H_g	User-defined value		
Mw_u	$8.22Q_uH_g$ / 1000	$7.79Q_uH_g$ / 1000	$7.53Q_uH_g$ / 1000
MW	Mw_u.n		MW_u
E	= 0.67 if existing dam = 1.0 if no dam		
C_g	= 0.75 if MW < 10 = 1.0 if MW 10		
T	= 0.25 if tote road =1.0otherwise		
A	User-defined factor with recommended range of 1 to 6		
I_a	User-defined value		
D	User-defined factor with recommended range of 1 to 2		
I_T	User-defined value		

V	User-defined value
P	= 0.85 if V < 69 = 1.0 if V 69

VARIABLE	SMALL HYDRO	MINI HYDRO	MICRO HYDRO
C	= 0.44 if existing dam= 1.0 if no dam		
R	= 1 if rock at dam site = 1.05 if no rock		N/A
l_b	User-defined value		
l_d	User-defined value		
n_p	User-defined value		
l_p	User-defined value		
d_p	$(Q_d/ n_p)^{0.43} / H_g^{0.14}$		
t_t	$d_p^{1.3}+6$		
t_b	$0.0375\ d_p H_g$		
t_{ave}	$0.5(t_t+t_b)$ if $t_b>t_t$ t_t if $t_b<t_t$		
W	$24.7 d_p l_p t_{ave}$		
S_s	User-defined value		
S_r	User-defined value		
l_{cs}	User-defined value		

I_{cr}	User-defined value

VARIABLE	SMALL	MINI	MICRO
I_t	User-defined value		N/A
k	User-defined value		N/A
R_v	$0.185 * I_t^{1.375} * [Q_d^2 / (k * H_g)]^{0.375}$		N/A
T_c	User-defined value with range of 15%(excellent rock) to 100%(poor rock)		N/A
C_v	$0.306 R_v T_c$		N/A
i	User-defined value		
f	User-defined value		
F	$110/(365-f)^{0.9}$		
E_c	User-defined value		
F_c	User-defined value		
L_c	User-defined value		
B	$(0.3333E_c+0.3333F_c)/(E_c/L_c)^{0.5}+0.3333(E_c/L_c)^{0.5}L_c$		
K	User-defined value		
J_t	=1 if Hg 25 m =1.1 if Hg > 25 m		
K_t	=0.9 if d < 1.8 m =1 if d 1.8 m		

ITEM (NUMBER)	SMALL	MINI	MICRO
Feasibility Study (1)	q t		q t
Development (2)	q t		
Engineering (3)	$0.37n^{0.1}E(MW/ H_g^{0.3})^{0.54}10^6$		$0.04E(MW/ H_g^{0.3})^{0.54}10^6$
Energy Equipment (4)	Generator and Control: $0.82n^{0.96}C_g(MW/ H_g^{0.28})^{0.9}10^6$		
	Kaplan turbine: $0.27n^{0.96}J_tK_td^{1.47}(1.17*H_g^{0.12}+2)10^6$		
	Francis turbine: $0.17n^{0.96}J_tK_td^{1.47}[(13+0.01H_g)^{0.3}+3]10^6$		
	Propeller turbine: $0.125n^{0.96}J_tK_td^{1.47}(1.17H_g^{0.12}+4)10^6$		
	Pelton&Turgo turbine: $3.47n^{0.96}(MW_u/H_g^{0.5})^{0.44}10^6$ if $(MW_u/H_g^{0.5})>0.4$ $5.34n^{0.96}(MW_u/H_g^{0.5})^{0.91}10^6$ if $(MW_u/H_g^{0.5})<0.5$		
	Cross-flow turbine: (Cost of Pelton&Turgo) / 2		
Installation of Energy Equipment (5)	$B[0.15Eq(4)]$		
Access road (6)	$B[0.025TA^2l_a^{0.9}10^6]$		
Transmission line (7)	$B[0.0011 DPI_t^{0.95} V10^6]$		

ITEM (NUMBER)	SMALL	MINI	MICRO

Substation - transformer (8)	$[0.0025n^{0.95}+0.02(n+0.1)](MW/0.95)^{0.9}V^{0.3}10^{6}$	
Substation - transformer installations (9)	B[0.15Eq(8)]	
Civil works (10)	$3.54n^{-0.04}BCR(MW/H_g^{0.3})^{0.82}*(1+0.01l_b)(1+0.005l_d/H_g)10^{6}$	$1.97n^{-0.04}BCR(MW/H_g^{0.3})^{0.82}*(1+0.01l_b)(1+0.005l_d/H_g)10^{6}$
Penstock (11)	$20n_p^{0.95}W^{0.88}$	
Installation of Penstock (12)	$B[5W^{0.88}]$	
Canal (13)	$20B[(1.5+0.01S_s^{1.5})Q_dl_{cs}]^{0.9}+100[(1.5+0.016S_r^{2})Q_dl_{cr}]^{0.9}$	
Tunnel (14)	$B[400R_v^{0.88}+4000C_v^{0.88}]$	N/A
Miscellaneous (15)	$[(0.275iQ_d^{0.35})+0.1]$ Eq(2 to 14)	(0.187i+0.1) Eq(2 to 14)
INITIAL COSTS (FORMULA METHOD)	**1+2+3+4+5+6+7+8+9+10+11+12+13+14+15**	

Appendix B R code for the data processing

```
rm(list =ls ()) # clean the work environment
library(readr)
library(xts)
library(zoo)

#************************* STATION 1 *****************************#
data <- read_delim("weatherdata-123-84.csv",
           ",", escape_double = FALSE, col_types = cols(Date = col_date(format = "%m/
%d/ %Y")),
           trim_ws = TRUE)
data <- data[order(data$Date), ]
rainfall1 <- aggregate(data$Precipitation, list(DATE = format(data$Date, "%Y-%m")),
sum, na.rm = T)
m.meanTemp <- aggregate(data$Mean.T, list(DATE = format(data$Date, "%Y-%m")),
mean, na.rm = T)
m.mean$DATE <- as.Date(paste(m.mean$DATE, "-15", sep = ""))

m.solar <- aggregate(data$Solar, list(DATE = format(data$Date, "%Y-%m")), mean,
na.rm = T)
plot(data$Date, data$Mean.T, main = "Temperature readings",
   ylab = "Temperature (Degree C)", xlab = "Year",
   col = "grey")

plot(rainfall1$DATE, rainfall1$x, main= "Temperature readings",
   ylab = "Temperature (Degree C)", xlab = "Month",
   col = "grey", "l")

points(m.mean$DATE, m.mean$x, col = "brown")
lines(m.mean$DATE, m.mean$x, type = "b", pch = 16)
legend("topleft", c("Daily", "Monthly mean"),
     inset = 0.02, pch = c(1, 1, 16), col = c("grey",
                        "Black"))

#************************* STATION 2 ****************************#
data2 <- read_delim("weatherdata-123-88.csv",
           ",", escape_double = FALSE, col_types = cols(Date = col_date(format = "%d
/%m/ %Y")),
           trim_ws = TRUE)

rainfall2 <- aggregate(data2$Precipitation, list(DATE = format(data$Date, "%Y-%m")),
sum, na.rm = T)

#************************* STATION 3 *****************************#

data3 <- read_delim("weatherdata-126-84.csv",
```

```
               ",", escape_double = FALSE, col_types = cols(Date = col_date(format =
"%m/ %d/ %Y")),
               trim_ws = TRUE)

rainfall3 <- aggregate(data3$Precipitation, list(DATE = format(data$Date,  "%Y-%m")),
sum, na.rm = T)

#************************ STATION 4 ****************************#
data4 <- read_delim("weatherdata-126-81.csv",
               ",", escape_double = FALSE, col_types = cols(Date = col_date(format =
"%m/ %d/ %Y")),
               trim_ws = TRUE)

rainfall4 <- aggregate(data4$Precipitation, list(DATE = format(data$Date,  "%Y-%m")),
sum, na.rm = T)

write.csv(rainfall1,"finalrainfall.csv")
write.csv(rainfall2,"finalrainfall2.csv")
write.csv(rainfall3,"finalrainfall3.csv")
write.csv(rainfall4,"finalrainfall4.csv")

rainfall <- read_delim("rainfall average.csv",
              ",", escape_double = FALSE, col_types = cols(DATE = col_date(format =
"%d/ %Y")),
              trim_ws = TRUE)

lect<- function(file){
  x<- read.csv(file,header = T, sep =",", dec =",",
           na.strings= c("", "NA", "-9999"))
  return(x)
}

rainfall<- lect("rainfall average.csv")
plot(rainfall$DATE, rainfall$Rainfall.aver, main = "Temperature readings",
    ylab = "Precipiation (mm)", xlab = "Month", col = "blue", "l", xlim=c(0, 1), ylim=c(0,
1))
ggdat <- data.frame(first=rainfall$DATE, second=rainfall$Rainfall.aver)
plot(rainfall$DATE, rainfall$Rainfall.aver, ylim=c(0, 500))
points(rainfall$DATE, rainfall$Rainfall.aver, col = "brown")
lines(rainfall$DATE, rainfall$Rainfall.aver, type = "b", pch = 16)
plot(rainfall$rain1)
```

Appendix C Monthly rate of annual sunshine (Northern Hemisphere) (%)

North Latitude	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
65	3.52	5.13	7.96	9.97	12.72	14.15	13.59	11.18	8.55	6.53	4.08	2.62
64	3.81	5.27	8.00	9.92	12.50	13.63	13.26	11.08	8.56	6.63	4.32	3.02
63	4.07	5.39	8.04	9.86	12.29	13.24	12.97	10.97	8.56	6.73	4.52	3.36
62	4.31	5.49	8.07	9.80	12.11	12.92	12.73	10.87	8.55	6.80	4.70	3.65
61	4.51	5.58	8.09	9.74	11.94	12.66	12.51	10.77	8.55	6.88	4.86	3.91
60	4.70	5.67	8.11	9.69	11.78	12.41	12.31	10.68	8.54	6.95	5.02	4.14
59	4.86	5.76	8.13	9.64	11.64	12.19	12.13	10.60	8.53	7.00	5.17	4.35
58	5.02	5.84	8.14	9.59	11.50	12.00	11.96	10.52	8.53	7.06	5.30	4.54
57	5.17	5.91	8.15	9.53	11.38	11.83	11.81	10.44	8.52	7.13	5.42	4.71
56	5.31	5.98	8.17	9.48	11.26	11.68	11.67	10.36	8.52	7.18	5.52	4.87
55	5.44	6.04	8.18	9.44	11.15	11.53	11.54	10.29	8.51	7.23	5.63	5.02
54	5.56	6.10	8.19	9.40	11.04	11.39	11.42	10.22	8.50	7.28	5.74	5.16
53	5.68	6.16	8.20	9.36	10.94	11.26	11.30	10.16	8.49	7.32	5.83	5.30
52	5.79	6.22	8.21	9.32	10.85	11.14	11.19	10.10	8.48	7.36	5.92	5.42
51	5.89	6.27	8.23	9.28	10.76	11.02	11.09	10.05	8.47	7.40	6.00	5.54
50	5.99	6.32	8.24	9.24	10.68	10.92	10.99	9.99	8.46	7.44	6.08	5.65
48	6.17	6.41	8.26	9.17	10.52	10.72	10.81	9.89	8.45	7.51	6.24	5.85
46	6.33	6.50	8.28	9.11	10.38	10.53	10.65	9.79	8.43	7.58	6.37	6.05
44	6.48	6.57	8.29	9.05	10.25	10.39	10.49	9.71	8.41	7.64	6.50	6.22
42	6.61	6.65	8.30	8.99	10.13	10.24	10.35	9.62	8.40	7.70	6.62	6.39
40	6.75	6.72	8.32	8.93	10.01	10.09	10.22	9.55	8.39	7.75	6.73	6.54
38	6.87	6.79	8.33	8.89	9.90	9.96	10.11	9.47	8.37	7.80	6.83	6.68
36	6.98	6.85	8.35	8.85	9.80	9.82	9.99	9.41	8.36	7.85	6.93	6.81
34	7.10	6.91	8.35	8.80	9.71	9.71	9.88	9.34	8.35	7.90	7.02	6.93
32	7.20	6.97	8.36	8.75	9.62	9.60	9.77	9.28	8.34	7.95	7.11	7.05
30	7.31	7.02	8.37	8.71	9.54	9.49	9.67	9.21	8.33	7.99	7.20	7.16
28	7.40	7.07	8.37	8.67	9.46	9.39	9.58	9.17	8.32	8.02	7.28	7.27
26	7.49	7.12	8.38	8.64	9.37	9.29	9.49	9.11	8.32	8.06	7.36	7.37
24	7.58	7.16	8.39	8.60	9.30	9.19	9.40	9.06	8.31	8.10	7.44	7.47
22	7.67	7.21	8.40	8.56	9.22	9.11	9.32	9.01	8.30	8.13	7.51	7.56
20	7.75	7.26	8.41	8.53	9.15	9.02	9.24	8.95	8.29	8.17	7.58	7.65
18	7.83	7.31	8.41	8.50	9.08	8.93	9.16	8.90	8.29	8.20	7.65	7.74
16	7.91	7.35	8.42	8.47	9.01	8.85	9.08	8.85	8.28	8.23	7.72	7.83
14	7.98	7.39	8.43	8.43	8.94	8.77	9.00	8.80	8.27	8.27	7.79	7.93
12	8.06	7.43	8.44	8.40	8.87	8.69	8.92	8.76	8.26	8.31	7.85	8.01
10	8.14	7.47	8.45	8.37	8.81	8.61	8.85	8.71	8.25	8.34	7.91	8.09
8	8.21	7.51	8.45	8.34	8.74	8.53	8.78	8.66	8.25	8.37	7.98	8.18
6	8.28	7.55	8.46	8.31	8.68	8.45	8.71	8.62	8.24	8.40	8.04	8.26
4	8.36	7.59	8.47	8.28	8.62	8.37	8.64	8.58	8.23	8.43	8.10	8.34
2	8.43	7.63	8.49	8.25	8.55	8.29	8.57	8.53	8.22	8.46	8.16	8.42
0	8.50	7.67	8.49	8.22	8.49	8.22	8.50	8.49	8.21	8.49	8.22	8.50

Appendix D Weather data for the watershed

DATE	Mean Temperature °C	Rainfall average (mm)	Sunshine MJ/m^2	PET (mm) Thornmaithe	PET (mm) Blaney Cridle
1994-01	24.62	0.00	20.71	63.65	93.73
1994-02	26.63	0.00	20.60	75.07	90.50
1994-03	29.65	0.71	20.83	152.07	109.79
1994-04	32.61	2.25	20.61	223.40	116.09
1994-05	33.14	5.75	20.68	261.83	123.87
1994-06	32.66	29.26	20.66	232.68	120.21
1994-07	30.14	57.16	20.14	172.84	117.23
1994-08	24.71	410.65	20.71	70.31	102.08
1994-09	26.21	245.96	21.24	83.33	99.66
1994-10	26.90	150.65	21.14	97.22	101.83
1994-11	26.86	1.13	21.16	88.29	96.11
1994-12	25.18	0.00	21.25	69.90	94.38
1995-01	23.51	0.00	21.29	49.96	91.28
1995-02	26.26	0.23	20.33	69.30	89.74
1995-03	29.97	2.83	21.69	160.36	110.53
1995-04	32.78	3.86	21.78	233.56	116.48
1995-05	33.11	12.05	21.64	266.90	123.80
1995-06	32.78	18.19	21.55	241.62	120.50
1995-07	28.67	158.78	21.12	138.12	113.63
1995-08	28.05	128.82	20.28	122.62	110.11
1995-09	27.70	86.72	20.90	105.60	103.03
1995-10	29.15	8.69	20.94	138.92	106.96
1995-11	26.50	0.00	21.19	81.81	95.33
1995-12	25.82	0.01	21.63	76.51	95.78
1996-01	26.02	0.00	21.72	78.30	96.82
1996-02	27.93	1.58	21.62	91.40	93.15
1996-03	29.92	0.05	21.63	159.62	110.41
1996-04	30.92	2.66	21.74	179.84	112.19
1996-05	32.37	20.43	22.09	244.19	122.00
1996-06	32.07	16.62	22.31	221.46	118.81
1996-07	30.11	134.83	22.57	173.87	117.16
1996-08	27.69	146.59	22.68	114.50	109.24
1996-09	29.63	18.95	23.19	144.31	107.40
1996-10	29.87	11.07	23.00	155.91	108.60
1996-11	26.05	0.00	23.29	74.20	94.36
1996-12	26.24	0.00	23.48	81.00	96.70
1997-01	26.85	0.00	23.99	91.57	98.66
1997-02	26.95	0.00	23.64	77.59	91.15

1997-03	28.89	0.00	23.43	135.23	108.03
1997-04	32.55	6.44	23.08	228.03	115.95
1997-05	32.58	33.92	23.18	249.90	122.51
1997-06	30.96	80.66	23.41	186.48	116.16
1997-07	29.05	114.43	23.22	146.68	114.56
1997-08	27.08	409.96	23.25	103.59	107.78
1997-09	28.81	67.16	22.67	126.42	105.54
1997-10	29.65	45.86	21.23	150.41	108.10
1997-11	27.84	0.00	23.04	102.30	98.22
1997-12	25.66	0.00	22.91	73.56	95.43
1998-01	25.97	0.00	23.49	76.46	96.71
1998-02	28.58	0.00	23.73	101.62	94.47
1998-03	29.03	0.00	24.10	137.93	108.35
1998-04	32.80	0.54	24.39	241.15	116.52
1998-05	34.66	10.02	24.57	344.47	127.57
1998-06	32.96	10.28	24.89	255.48	120.93
1998-07	31.08	24.64	24.15	203.42	119.53
1998-08	27.16	159.32	24.48	103.42	107.97
1998-09	27.88	132.90	24.63	107.23	103.44
1998-10	29.32	4.66	24.73	142.56	107.34
1998-11	26.36	0.00	24.42	77.50	95.03
1998-12	25.53	0.00	25.02	69.90	95.15
1999-01	25.87	0.00	24.26	74.98	96.49
1999-02	26.87	0.00	24.57	75.15	90.99
1999-03	29.80	0.02	24.94	156.74	110.13
1999-04	31.58	6.46	24.96	200.47	113.71
1999-05	34.16	0.92	24.94	321.10	126.35
1999-06	33.29	0.53	24.99	268.37	121.71
1999-07	31.24	18.30	24.99	208.63	119.92
1999-08	27.71	181.10	23.96	114.02	109.29
1999-09	29.31	23.18	20.46	136.89	106.68
1999-10	29.36	1.69	24.91	143.50	107.44
1999-11	27.41	0.26	24.70	93.76	97.29
1999-12	24.91	0.00	24.33	61.94	93.78
2000-01	26.90	0.00	25.21	87.65	98.77
2000-02	25.69	0.00	25.27	57.41	88.58
2000-03	29.50	0.41	25.27	148.50	109.44
2000-04	33.73	0.06	25.09	287.67	118.66
2000-05	34.77	2.97	25.48	367.76	127.83
2000-06	33.72	2.51	25.62	297.15	122.74
2000-07	31.04	43.98	25.69	204.64	119.43
2000-08	29.62	35.09	26.01	157.43	113.88
2000-09	30.88	5.71	26.15	178.51	110.23

2000-10	29.75	9.06	25.41	152.79	108.32
2000-11	27.88	0.99	23.76	99.56	98.30
2000-12	25.86	0.00	21.25	70.92	95.87
2001-01	25.25	0.00	25.70	63.77	95.12
2001-02	27.05	0.00	25.62	75.68	91.35
2001-03	29.06	0.00	23.50	137.64	108.42
2001-04	32.19	1.78	24.89	224.44	115.12
2001-05	34.41	2.36	25.79	345.19	126.96
2001-06	33.63	5.80	25.76	290.85	122.52
2001-07	31.29	64.77	25.22	212.83	120.04
2001-08	30.06	197.67	26.35	170.03	114.94
2001-09	30.65	9.42	26.93	171.48	109.71
2001-10	29.95	2.59	27.13	158.28	108.78
2001-11	27.32	0.03	27.23	90.16	97.10
2001-12	27.01	0.00	27.39	89.64	98.40
2002-01	26.37	0.11	27.01	79.77	97.60
2002-02	27.06	0.00	26.83	75.85	91.37
2002-03	29.51	0.33	25.86	148.98	109.46
2002-04	32.18	0.36	6.07	224.02	115.09
2002-05	33.43	17.70	25.63	297.37	124.57
2002-06	33.09	10.70	25.29	267.50	121.24
2002-07	32.06	22.43	24.04	241.14	121.93
2002-08	30.40	17.18	25.34	180.16	115.75
2002-09	31.21	5.96	26.33	188.20	110.98
2002-10	28.91	1.92	26.42	131.98	106.41
2002-11	27.21	0.00	22.42	88.34	96.86
2002-12	26.45	0.34	24.70	80.52	97.17
2003-01	26.30	0.00	15.83	78.45	97.44
2003-02	28.91	0.00	17.97	106.49	95.14
2003-03	29.25	0.00	12.30	142.26	108.86
2003-04	32.49	0.67	17.13	235.74	115.81
2003-05	34.61	1.68	19.73	356.55	127.44
2003-06	32.79	15.83	26.45	255.74	120.52
2003-07	30.34	106.92	26.06	181.63	117.72
2003-08	29.72	23.27	24.87	160.33	114.12
2003-09	29.81	23.34	20.81	148.60	107.81
2003-10	30.57	2.36	24.02	175.94	110.19
2003-11	27.50	0.66	22.31	93.11	97.49
2003-12	26.14	0.00	24.33	75.55	96.49
2004-01	26.55	0.00	26.72	80.65	97.99
2004-02	28.43	0.03	27.45	96.69	94.16
2004-03	30.01	0.00	27.45	162.23	110.62
2004-04	33.20	1.16	27.80	267.67	117.44

2004-05	34.45	0.32	27.48	355.64	127.06
2004-06	33.55	8.47	24.45	292.83	122.33
2004-07	30.83	67.58	14.99	197.94	118.92
2004-08	29.58	106.99	13.20	155.91	113.78
2004-09	30.67	38.93	23.94	172.53	109.76
2004-10	29.74	0.46	15.02	152.22	108.30
2004-11	28.00	4.11	24.47	100.92	98.56
2004-12	27.24	0.00	19.61	91.89	98.90
2005-01	25.45	0.00	22.77	65.85	95.56
2005-02	28.98	2.10	18.88	107.70	95.28
2005-03	30.58	1.14	25.89	179.08	111.94
2005-04	31.78	0.27	20.47	210.68	114.17
2005-05	33.87	0.73	7.60	320.08	125.64
2005-06	33.31	9.55	20.04	278.28	121.76
2005-07	31.07	55.35	24.28	205.57	119.50
2005-08	29.97	33.59	22.06	167.39	114.72
2005-09	29.84	17.96	25.75	149.33	107.88
2005-10	29.99	0.18	17.52	159.34	108.87
2005-11	27.64	0.00	22.47	95.32	97.79
2005-12	26.73	0.00	18.62	84.46	97.78
2006-01	26.91	0.00	25.12	89.14	98.79
2006-02	28.66	0.06	23.84	102.22	94.63
2006-03	29.25	0.00	22.40	142.58	108.86
2006-04	32.73	1.90	23.70	243.11	116.36
2006-05	33.72	5.15	21.45	308.64	125.28
2006-06	33.42	1.81	23.21	279.63	122.02
2006-07	31.26	19.91	23.31	211.22	119.97
2006-08	29.19	34.18	24.97	146.45	112.85
2006-09	29.33	108.93	25.43	136.92	106.72
2006-10	29.98	7.18	24.90	159.11	108.85
2006-11	26.84	0.00	10.04	82.91	96.06
2006-12	25.06	0.00	10.01	61.68	94.11
2007-01	25.18	0.00	23.78	65.44	94.97
2007-02	27.53	0.00	23.61	84.46	92.33
2007-03	30.15	0.00	24.81	166.01	110.94
2007-04	32.69	0.74	24.20	237.90	116.27
2007-05	34.20	8.00	24.02	324.05	126.45
2007-06	32.87	11.04	23.53	252.84	120.71
2007-07	30.01	101.35	23.12	171.49	116.91
2007-08	27.41	222.46	14.02	107.91	108.57
2007-09	28.28	72.90	22.05	114.80	104.34
2007-10	30.45	5.99	25.24	171.60	109.92
2007-11	27.91	0.90	24.53	102.27	98.37

2007-12	25.43	0.00	24.13	68.27	94.93
2008-01	23.71	0.00	24.75	51.78	91.72
2008-02	27.24	0.00	24.03	81.97	91.74
2008-03	29.50	3.47	20.37	149.10	109.44
2008-04	31.78	5.93	18.75	202.70	114.17
2008-05	34.02	10.76	21.40	303.17	126.01
2008-06	32.19	50.47	16.46	222.52	119.09
2008-07	28.16	310.40	19.58	127.07	112.39
2008-08	26.96	381.19	21.17	102.00	107.49
2008-09	28.76	104.87	19.29	125.55	105.43
2008-10	29.23	31.38	19.80	140.69	107.14
2008-11	26.67	0.00	21.20	84.14	95.70
2008-12	26.60	0.49	22.85	87.64	97.50
2009-01	24.72	0.00	24.21	61.09	93.95
2009-02	28.49	3.69	19.70	100.41	94.29
2009-03	31.84	4.13	22.11	215.09	114.86
2009-04	32.25	0.03	17.13	220.26	115.26
2009-05	33.48	7.28	19.90	287.54	124.70
2009-06	32.21	27.21	23.41	226.52	119.14
2009-07	30.58	64.38	19.82	187.34	118.31
2009-08	27.77	342.03	21.23	115.94	109.43
2009-09	27.15	182.89	20.44	94.95	101.78
2009-10	28.48	7.89	17.90	124.12	105.43
2009-11	26.06	53.32	20.45	74.15	94.39
2009-12	25.99	0.00	20.59	77.19	96.16
2010-01	25.98	0.00	22.69	79.10	96.73
2010-02	28.91	0.00	16.83	107.97	95.14
2010-03	29.71	0.00	23.71	154.07	109.93
2010-04	33.72	10.72	21.99	266.57	118.64
2010-05	34.35	82.77	21.57	316.88	126.81
2010-06	32.46	21.72	19.78	231.23	119.74
2010-07	28.82	348.47	23.27	141.46	114.00
2010-08	25.80	398.02	24.20	83.24	104.70
2010-09	25.59	250.39	18.19	73.14	98.25
2010-10	27.23	141.52	13.48	101.35	102.58
2010-11	26.89	5.60	23.59	87.42	96.17
2010-12	25.05	0.00	20.83	66.40	94.09
2011-01	25.03	0.00	22.95	68.69	94.63
2011-02	26.01	0.01	19.16	67.77	89.23
2011-03	29.68	0.01	14.77	152.67	109.86
2011-04	32.38	4.62	19.35	216.00	115.56
2011-05	33.30	31.64	21.78	266.73	124.26
2011-06	32.43	17.46	18.74	224.98	119.66

2011-07	28.84	293.48	23.48	142.13	114.05
2011-08	26.40	310.33	23.04	94.47	106.14
2011-09	26.79	155.59	24.80	91.97	100.97
2011-10	28.20	36.21	18.73	119.92	104.79
2011-11	26.75	0.02	16.41	86.83	95.87
2011-12	22.93	0.00	14.26	46.36	89.43
2012-01	23.48	0.01	8.50	53.09	91.21
2012-02	26.03	0.00	2.27	68.83	89.27
2012-03	28.53	0.06	14.64	128.35	107.20
2012-04	32.67	3.51	4.57	221.24	116.22
2012-05	33.71	8.04	7.79	276.19	125.26
2012-06	31.33	158.30	7.97	191.20	117.04
2012-07	28.16	153.34	21.13	128.26	112.39
2012-08	25.62	392.03	3.42	83.92	104.27
2012-09	25.67	394.70	17.43	77.23	98.43
2012-10	27.18	170.31	2.78	102.62	102.47
2012-11	28.54	1.20	1.66	115.71	99.72
2012-12	24.31	0.01	12.25	61.25	92.47
2013-01	24.23	0.04	22.48	60.13	92.87
2013-02	27.48	0.00	24.78	86.64	92.23
2013-03	29.86	0.01	23.65	156.47	110.27
2013-04	31.76	2.44	24.75	197.18	114.13
2013-05	33.80	14.77	18.55	282.19	125.47
2013-06	32.06	41.49	22.29	212.52	118.78
2013-07	28.29	236.16	22.62	130.70	112.71
2013-08	25.46	229.33	21.86	81.09	103.89
2013-09	26.24	141.29	14.07	84.39	99.72
2013-10	27.54	71.40	12.83	108.31	103.29
2013-11	26.37	0.00	6.06	81.95	95.05
2013-12	23.98	0.02	11.95	57.12	91.74
2014-01	25.14	0.00	21.92		94.88
2014-02	25.30	0.00	19.39		87.79
2014-03	28.30	0.03	15.51		106.66
2014-04	31.89	0.35	17.01		114.43
2014-05	31.67	40.91	23.84		120.29
2014-06	32.42	26.38	21.53		119.64
2014-07	28.57	251.67	23.10		113.39