



UNIVERSITY OF NAIROBI

Department of Mechanical & Manufacturing Engineering

MASTER OF SCIENCE (MSc) IN ENERGY MANAGEMENT

ENERGY STATUS IN SOUTH SUDAN

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A project submitted in partial fulfillment of the degree of Master of Science in

Energy Management of the University of Nairobi.

DECLARATION

This MSc. research project is my original work and has not been presented for a degree award in this or any other university

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DEDICATION

This mighty research work is dedicated to Almighty God and to all my family members, most significantly, to my dear wife, Dr Lilian Mechack who stood and encouraged me during this task. God bless you dearly.

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God bless those who endeavor to achieve the best of their ability. I give great thanks to God for making me go through this tedious exercise in good health. This work would have not been completed was it not because He lives in us.

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ABSTRACT

South Sudan has a problem for lack of equitable and reliable energy source for power supply. The major source of electricity in South Sudan is thermal using diesel-fired generators. 83% of South Sudan is rural and uses, Kerosene, charcoal and fire wood. Another source of energy that is widely use in South Sudan cities are battery and solar arrays units for lighting and entertainment yet the country has enough water resources to generate long term electricity. Utilization of sustainable low-carbon energy scenarios for the new century emphasize the need to tap the yet to be utilized potential of hydro-energy resources in South Sudan. In 2012, the government initiated construction of Fula rapids hydro dam of 42MW in response to energy crisis in the country but the capacity is not enough to match the demand of 44MW in Juba.

The installed capacity in Juba is 17MW among which some of the units currently require major overhaul. In this research project, energy status in South Sudan has been determined to help the government in selecting priorities in development of energy sector as well as a datum for a venture in renewable energy fields. The objective of this study is to determine the energy status of South Sudan, determine potential from hydro, compare hydro power energy with other sources of energy and propose ways forward for the country. South Sudan is an agricultural region with fertile land, plenty of water resources, livestock, forestry resources, and agricultural resources. Application of new and renewable sources of energy available shall be the viable weapon to accelerate exploitation of these resources.

Energy status in South Sudan was determined by quantifying the amount of energy sources that are in use and those to be utilized later in the country. The data of energy mix was obtained through site survey and by dividing Juba city into three sections based on payams. This data covered a period of two weeks from 1st October to 15th October 2013 with sampling time of eight hours a day. The data was transferred manually from hard copies to excel sheet and was plotted on pie charts in terms of percentages as shown on figure 4.1, 4.2, 4.3 and 4.4 respectively. The results showed that thermal energy dominates the consumption in Juba up to 36% of energy sources followed by solar 27% on figure 4.4 while other major sources like hydro, wind, geothermal and nuclear are zero. In addition to energy mix analysis, potential was determined from Hydro and this was done by measuring the river monthly discharge from four hydro potential sites by using current meter. This meter clearly records the velocity of the water and measures the area by using depth and width of a cross-section of a river.

This data was retrieved from meter data storage unit (DSU) to excel software using export wizard where the calculations of discharge were done and the results were tabulated on table 4.10. These results were plotted as rating curves against the water elevation. Elevation above sea level (FSL) data was sourced from Dam Implementing Unit (DIU) of Sudan. This data was measured by using digital elevation model (Topographical mapping) through aerial photography and transferred from ArcGIS map to excel as presented on table 4.11 for calculation of hydro potential in these rivers. The results found showed that, South Sudan has a large hydro potential to be exploited. Lastly, comparison between hydro electric power and other sources of energy was summarized and the ways forwards were suggested.

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LIST OF ABBREVIATIONS

NBA	Nile Basin Areas
RPS	Reliable Power Supply
EDSS	Economic Development of South Sudan
BNP	Buma National Park
TEC	Twic East County
CPA	Comprehensive Peace Agreement
SSEC	South Sudan Electricity Corporation
MED	Ministry of Electricity and Dams
MEDWRI	Ministry of Electricity and Dams, Water Resources and Irrigation
EES	Eastern Equatoria States
FPHCS	Fifth Population and Housing Census of Sudan
SSCSE	South Sudan Centre for Statistic and Evaluation
SSIR	South Sudan Independence Referendum
JEPP	Juba Emergency Power Project
CJPS	Cummins Juba Power Station
WJPS	Watsila Juba Power Station
IDP	Internally Displaced Persons
RR	Returning Refugees
HEP	Hydro Electric Power
DHM	Distributed Hydrological Model
FDC	Flow Duration Curve

GIS	Geographical Information System
RS	Remote Sensing
SHN	Synthetic Hydro Network
GH	Gross Head
NH	Net Head
DEM	Digital Elevation Model
PRPP	Power Resource Power Potential
Δh_i	Representative difference in Head
ADF	Average Daily Flow
RAM	Random Access Memory
NVE	Norwegian Water Resources and Energy Directorate
MWRI	Ministry of Water Resources and Irrigation
DIU	Dam Implementing Unit
DSU	Data Storage Unit

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1 INTRODUCTION

1.1 Background

Economic and social development in South Sudan can only be achieved through reliable energy sources. Currently, the installed capacity in South Sudan is approximately 30MW with 27MW being administered by the government of South Sudan in state capitals with five state capitals having 2MW each except Juba which has 17MW and 3MW from cooperatives. This installed capacity is 100% Thermal and another 40MW of energy is imported from Sudan generated from all other sources of energy of total primary value of 14,675ktoe in Sudan broken down as Biomass, 72.8%, petroleum 26.3% and Hydro 0.8%. The total installed electricity capacity for Sudan is 1,061MW within which 76% was thermal and the rest, [1]. The total available power for South Sudan becomes 70MW against the current total estimated demand of 154MW for the ten (10) states of South Sudan. This gap is too wide to cover and it's a task to the government and development partners to bridge it by injecting more energy sources in the system to at least match the demand. Demand assessment for the entire country is underway and is expected to be away higher than this existing capacity.

South Sudan is an oil producing country, able to export refined as well as crude petroleum products. Total petroleum exports in 2009, prior to independence, were 19,507 ktoe. Petroleum product covers 98% of South Sudan revenue and generates fuel for thermal generation within the oil field around unity state. It is expected that when the production is stabilized, crude oil shall be utilized as a thermal fuel for most of the watsila Generator sets across the country and this will possibly drop the high cost of diesel fuel [2]. Crude is a readily available fuel within the country since the current fuel for the existing generators is imported from neighboring countries, hence more expensive to procure.

1.2 Hydro Electrical Energy in South Sudan

97% of South Sudan water resources are concentrated within the Nile Basin Areas (NBA) with highest renewable supply of fresh water in the region, as shown in figure 1.1. Hydro potentials are great but yet to be exploited. An assessment done before the war in South Sudan was putting the potentials of hydro over 1,500MW. Currently, the government is also trying to establish hydroelectric power stations in areas such as Fula, Laki, Shukoli and Bedden as long term remedy to power shortages in South Sudan, [4].

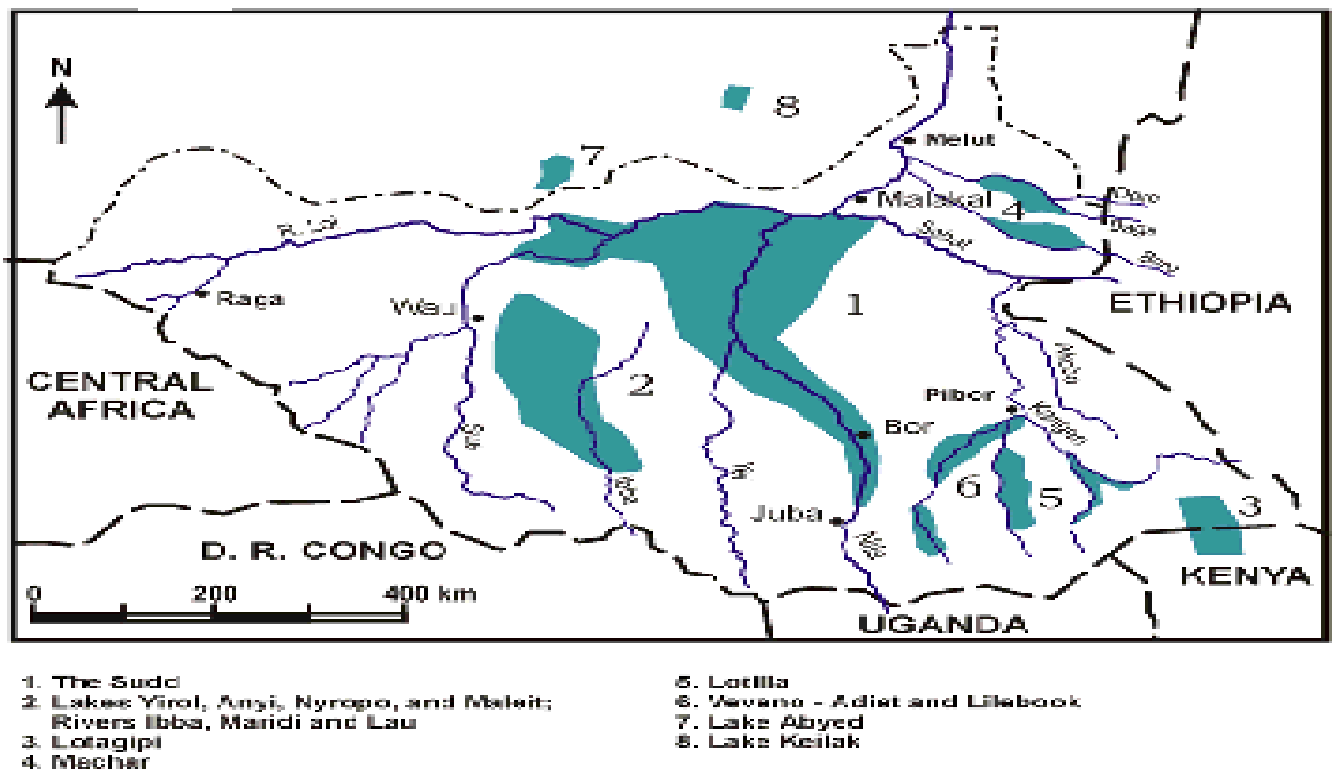


Figure 1.1: South Sudan Water Resources (MWRI, 2010)

The foreseen backbone of South Sudan's economy is and shall always be its water potential from which agricultural sector shall determine to a great extent the economic performance of its economy. The expected high load in such a great sector needs a reliable power supply (RPS). Hydro electrical

energy is being considered by the government of South Sudan as one of the most reliable sources of power supply. Currently, there is a negligible contribution of hydro into the consumption loop but with the greatest potential.

1.2.1 Energy and South Sudan economy

South Sudan is and shall always be a market for the neighboring countries such as Uganda, Kenya, Congo, Ethiopia, Eritrea, Rwanda, Tanzania, Burundi and Sudan because of its riches. The country will need Technical and professional expertise. Economic Development of South Sudan will provide an overview of the South Sudanese economy. The prominent sectors that could be given attention include but not limited to agriculture, industry, transport, education, health, energy, power, and trade, [11]-[14]. For this economic growth to take place, the country requires reliable source of Energy.

Investment in South Sudan is currently at its lowest levels. The investment performance of all three investor groups namely, the private sector, government and parastatals were geared towards the outcome of the referendum in South Sudan. There was a lot of uncertainty about the referendum, since the country has just come out of war, many investors were thinking there might be chaos and so a peaceful environment could be necessary for investments, [22]. No doubt to believe that there shall be a serious inrush for investors to South Sudan, since such independent shall be taken as the guarantee for peace and stability in spite of some little turbulence within and without the country. Government investment was kept in check by the tight fiscal policy while parastatal investment was constrained by lack of streamlined system. There are no government bilateral investments except individual foreign investments, [24]. Investment can always grow when there is stable power supply in the country. This report will help the government to venture in

new and reliable energy sources and be able to change the thermal power supply which cannot be able to attract major investments.

1.2.2 Energy and Population in South Sudan

The "Fifth Population and Housing Census of Sudan (FPHCS)" published in 2009, was conducted in April 2008. However the census results of South Sudan were rejected by South Sudanese officials as reportedly "the central bureau of statistics in Khartoum refused to share the national Sudan census raw data with South Sudan centre for census, statistic and evaluation. The census showed the South Sudan population to be 8.26 million; many southerners claimed that the South Sudanese population should be one-third of Sudan, while the census showed it to be only 22%. Many South Sudanese were also said to have not been counted "due to bad weather, poor communication and transportation networks, and some areas were unreachable, while many South Sudanese remained in exile in neighboring countries.

South Sudan Centre for Statistic and Evaluation (SSCSE) projected the population to be over 10 million, a number that was missed by a small margin during the voter registration for April 2010 election. This can therefore make us approximate the real number of South Sudanese wherever they are to be between 10 million to 15 million. In 2009 Northern Sudan started a new South Sudanese census ahead of the South Sudanese independence referendum, 2011, which is said to also include the South Sudanese in Diaspora. However this initiative was criticized as it was to leave out countries with a high share of the South Sudanese in Diaspora, and rather count countries where the Diaspora share was low. Over 8.26 million South Sudanese are in dire need of electrical energy for social and commercial activities. 83% of South Sudanese lives in rural areas, this number of people are using charcoal or fire

woods for cooking. As mentioned before the current little installed capacity of 30MW is concentrated in state capitals.

South Sudan is composed of more than 60 ethnic groups speaking languages found primarily within South Sudan with other languages from neighboring Kenya, Ethiopia, Uganda, Congo, Northern Sudan (Khartoum) and more. The official language is both English and National language is Juba Arabic, along with various local languages in states or cities. These ethnic communities are sparsely situated and shall be in need of power. This can only be achieved if power grids are constructed to reach all corners of our country or make use of solar arrays in these areas until a reliable energy source is established [9].

1.3 Thermal Energy in South Sudan

South Sudan has ten states whose capital cities are growing at a high rate. The estimated population growth in the 10 state capitals is 2% and is expected to double in the next five years. Catering to this extraordinary influx will require substantial investment in basic infrastructure including reliable energy sources – not only to upgrade the current towns but to provide developed land equivalent to double the existing built up area. It is estimated that only 10% of the population is urbanized. Even if the overall population doubles with the return of internally displaced persons (IDP) and returning refugees (RR), and if a significant part settles in the state capitals, the population should continue to be overwhelmingly rural within the foreseeable future. Rural Development is a national priority, yet it needs an operational urban system to provide essential supporting services in the cities especially the power [7].

Juba appeared to be more populated compared to other state cities of South Sudan. Juba being the commercial and government centre, it is growing in unimaginable speed. Foreign and local investors are doing their best to compete for the market. This population growth is an indication that the power demand will automatically be high in the next 5 years. Hydroelectric power will be reliable for this much growth in South Sudan. Electrical generation is currently done through Thermal energy source predominantly by using the diesel generators and the capacity of this source of supply is limited and notoriously expensive to operate and maintain. These generators are now down for major overhaul. This poses a big threat on the country's economy and on the entire progress in the power and investment sector.

A need to establish power supply will be the remedy for this region [15]. The expansion of electricity provision is a crucial factor in the ongoing development of South Sudan. Approximately 15,000 consumers currently have access to an electricity network. The Government of South Sudan after the signing of peace in 2005, a power project was initiated in juba with the intention of extending the same to other states. Juba emergency power Project (JEPP) was initiated by the government in order to meet the load in juba. 5MW diesel generators were installed by Electrowatts at the Juba power station. Cummins station was the first to be established in juba as part of juba emergency power project (**JEPP**) which was supervised by Gibb Africa. This capacity was stretched by the fast growing load in Juba and therefore the government decided to add 12MW more which were installed by Watsilla from Finland.

Depending on the increase of the load in Juba, the watsila station was installed next to Cummins to meet the demand. But still, the reality is, power needs/demands in juba and other states are too high and this demand cannot be met by using diesel generators which are very expensive to maintain. Egyptians saw the gap in power supply as well and tried to invest in installing diesel generators in

some states of South Sudan, namely; Bor, Rumbek & Yambio. Generally, power demand is now uncontrollable and there is a shortage of supply, [5]. The current estimated demand for Juba is 44MW and is expected to rise with time.

1.4 Solar Energy in South Sudan

Many investors have been trying to invest as independent power producers (IPP) in hybrid system, a combination of Biomass and Solar but the government has not been keen to give it attention since the initial capital is too high and it is not economical for instance, 1MW of solar unit covers an acre of land and as experienced in most cases, land in Africa is a primary resource and so this could be taken as misuse of land. It is too early to introduce this technology in a large scale in South Sudan. However, this technology is being utilized by international, National NGOs and individuals. Solar is good for rural electrification and in future, the government may consider it as a source of electricity for rural schools, health centers and administrative units. Solar potentials in the South are approximately 6.9 GJ/m²/year, or 436 W/m²/year. The region receives on average, 8 hours of sunshine daily, making it ideally placed to utilize solar energy resources. The potential has been recognized for use in street lighting, through LEDs. Solar energy currently powers some radio stations in the country, and approximately 45,000 households have some form of energy service derived from solar resources in South Sudan [25]-[31].

1.5 Wind energy

A research in the old Sudan showed wind power density in the Southern region to be ranging from 285 – 380 W/ m². Wind power generation is seen as a key investment opportunity by the government of

South Sudan. This potential is not exploited. Wind has a disadvantage of being uneconomical and unreliable especially when there is no wind. It could also be used for rural electrifications [34].

1.6 Biomass energy

78% of households in South Sudan depend on crop farming or animal husbandry as their primary source of livelihood. Traditional biomass fuels provide for the vast majority of the South Sudanese population's energy needs. An estimated 71.1 million hectares of biomass resource exists in the country, of which 29.3 million cubic metres are deemed to be the allowable cut. Agricultural residues, as well as animal wastes, could also hold significant potential [36]. .

1.7 Geothermal energy

The country is currently seeking assistance from the Kenyan Geothermal Development Company (GDC) to undertake a thorough assessment of its geothermal resource. Due to its geographical location, geothermal resources are expected to be developed, and the GDC has expressed a keen interest in lending South Sudan technical assistance and co-operation in the development of this resource. This is not yet started but the government of South Sudan feels that there is a great potential [35]-[37].

1.8 Problem Statement

Lack of new and renewable energy sources for power supply in South Sudan are major problems. The country is 100% dependent on thermal generation which suffers from limited unit capacity. The estimated demand in capital cities of ten states is 154MW. This demand is a way high and can't be met if there is no reliable energy source. In Juba for example, the installed capacity is 17MW and the

demand is estimated to be 44MW, Demand in Bor 15MW and installed capacity is 2MW and the same case applies to other capital cities. The gap between the demand and installed capacity is quite high and requires efforts to be doubled by exploiting the existing energy potential in South Sudan. In addition the government is incurring hefty losses in terms of money and man-hours. Grid system is not constructed and it is also vital to prepare for efficient transmission of high voltages that will be produced by Fula rapids of 40MW being constructed by Norwegian government. This power shall be transmitted to the national grid, to Juba and other cities.

1.9 Main objective

The main objective of this study is to determine energy status in South Sudan. To achieve this, five main and other minor energy sources were considered. These sources are Thermal Energy, Electrical energy, solar energy, Wind Energy, Geothermal, Biomass energy, Kerosene and Battery.

1.9.1 Specific objective

1. Determine the energy mix of South Sudan (A case study of Juba city)
2. Analyze the potential from hydro
3. Compare Hydroelectric power with other sources of electricity
4. Propose ways forwards/Recommendations for South Sudan.

1.10 Organization of the project

This project has five chapters as follows;

Chapter 1 is an introduction giving a survey of earlier work, statement of the problem, objectives and organization of the project.

Chapter 2, a presentation of literature survey, looked at the work done by different people in other part of the world on renewable energy and hydro power potential studies, energy current status in South Sudan and summary of literature review.

Chapter 3, the method used to carry out the data collection was presented.

Chapter 4 shows the discussions of the results found out of the study, both in graphical presentation and in narratives format.

Chapter 5, Conclusion and recommendations/ways forward were presented. Areas of further research also identified for future work.

This chapter gives a short review about the literature of energy status in South Sudan, review on hydropower potential calculations, where recent studies and projects around the world concerning energy mix and estimation of hydropower potential are discussed. Finally an overview of the status and history of hydropower potential estimations in South Sudan and the ways forwards.

2.1 Energy mix studies

Mahmud Z. & Zied T., 2004 [29] carried out energy mix studies in Sudan. The studies showed that, oil is a major source of Energy in both Sudan and South Sudan. It plays a major role in their economies. This is due to the large numbers of oil reserves available in the country. Currently, about 95% of these oil reserves fall within the South Sudan territory, areas of Muglad and Melut basins. According to studies by IMF in 2008, South Sudan, oil represents 98% of total revenues. South Sudan energy consumption mix has not yet been determined and it is assumed to have been dominated by oil (98%) and the rest comes from 100% thermal. Most of Renewable energy sources are currently not part of the country's energy consumption mix. In South Sudan, only 1% of the population has access to electricity. 83% of South Sudan population is rural and depends on charcoal, firewood paraffin etc. There is no national grid in South Sudan but only 11kV distribution network in the capital city. Hydro electrical energy is not enough to help in economic development as of now.

Joel G., 2001[31] did an analysis on South Sudan power sector, in his short studies he found out that this sector suffers from poor infrastructure. Biomass in South Sudan rural households has a great potential but not exploited. Most of individuals in towns and some businesses in rural towns use either

solar or small diesel fired-generators 100% thermal. This way of generating electricity is inefficient and expensive, and causes environmental problems. In many developing nations with a large rural population, the residential sector contributes most to final energy demand, due to the large amounts of fuel-wood used for basic energy needs. The government utility company, South Sudan Electricity Corporation (SSEC) established in 2007, is tasked with Generation, transmission, Distribution and Sales of Electricity. Attempts to invest in solar by independent power producers (IPP) is underway, if the government gives them chance, solar could be another source to be produced in large scale to the grid unlike now.

Bure Y, 2008 [14] elaborated the administration of the then South Sudan regional governments which paid lip service to development while starving the region of its resources. South Sudan as mentioned earlier has resources, the potential for development and the prospects for the future. One of the major natural features of South Sudan is the River Nile whose many tributaries have sources in the country. The region also contains many natural resources such as petroleum, iron ore, copper, chromium ore, zinc, tungsten, mica, silver and gold. South Sudan should take keen interest on available energy resources to unlock its potential.

2.2 Hydropower Potential

Chen J., 2005 [54] evaluated the capability of flowing water to produce power as a function of the discharge of the flow where the specific weight of the water and the head were presented.

Castellarin A. & Omar M.A., 2004 [16, 56] applied a distributed hydrological model (DHM) to capture the data through aerial view. This method determined the height of a river above sea level at a

full scale level. These two also performed discharge observation methods at a few sites in each catchment along the whole river network. The analysis showed that the main Influences in discharge measurement are runoff from rainfall, snowmelt and glacial melt, groundwater, evaporation and transpiration.

Chastain E., 2007 [15] applied a simulation in gauged catchments to acquire discharge information along the whole river network. This was necessary as the discharge is constantly changing with every tributary. This was not enough to give the correct discharge values since observation may not give exact values. In this study the current meter was used to measure the velocity of flowing water. The principle of operation is based on the proportionality between the velocity of the water and the resulting angular velocity of the meter rotor.

Jasper K., 2007 [32] used conceptual rainfall runoff models like HBV and WaSiM-ETH to estimate discharge. A flow duration curve (FDC) provides an estimate of the percentage of time a given runoff was equaled or exceeded over a defined period. In this FDC the word quartiles was used in connection to the FDC, where for example the 75% quantile represents the discharge that is equaled or exceeded 75% of the simulation period. However, this models are not common and very expensive, hence may not be applicable in South Sudan evaluation of hydro potential.

Viessman W. J & Lewis G. L., 2003 [34] further described how different quartiles of a FDC could be used to give vital discharge information and are often analyzed in order to summarize the hydrological frequency characteristics of river flow. FDCs can predict the availability and variability of discharge but do not represent the actual sequences of flows. FDCs can be useful when defining

available discharge for hydropower and proper size and type of turbine and to see if regulations are needed. It can be assumed that the entire upper part of the FDC (50-100%) is the low flow section, as it represents an index of groundwater contribution to stream flow.

Gupta J.B., 2010 [6] used unique approach of integrating gradient data with discharge information and the data set of potential hydropower barrier locations was developed at the start of the project and was based on in-river features. Different method and technique was used to study hydrological development. This technique uses computer based integrated system of Geographical Information System (GIS) and Remote Sensing (RS). This development further affect the methods of evaluating and mapping of potential hydropower with increase imaginary information from satellite and easiness of data in GIS environments.

Maidment D.R., Ritchie & Schmugge T., 2002 [26, 30] both applied Remote Sensing (RS) for hydrology, as it provides the possibility of observing hydrological state variables over large areas. Input data based on RS was used for modeling of evapotranspiration. However, this method is limited. Carroll (2004) described how GIS-based tools and RS data applied to hydropower survey studies around the world in order to locate and select hydropower opportunities of different types, such as run-of-the-river projects in US pumped hydroelectric energy storages in Ireland, storage capacity dams in India and South Africa.

Gagnon Y., 2011 [35] Utilized synthetic hydro network (SHN) created from digital elevation models coupled with annual base flow to map hydropower resource in New Brunswick. Bansal N.K (1985) described Gross Head (GH) and the Net head (NH) as the maximum available vertical fall in the water,

from the upstream level to the downstream level and actual/reduced head respectively. The reduction happens as a result of transfer of water into and away from the machine, this reduced head is the one that is seen by the turbine and head is the same parameter to be used in determining hydropower potential.

Kristofferson L.A *et al*, 1991[38] Calculated the heads by using the Digital Elevation Model (DEM) for the “river cells”, he found the head as a difference of elevation between the current and the immediately downstream cell.

Cherry S. J & Hall D.G., 2004 [41] did a study that provided estimates of the amount of low head/low power potential, in United States with Emphasis on Low Head/ Low Power Resources Power Potential (PRPP) in several power classes defined by power level and hydraulic head.

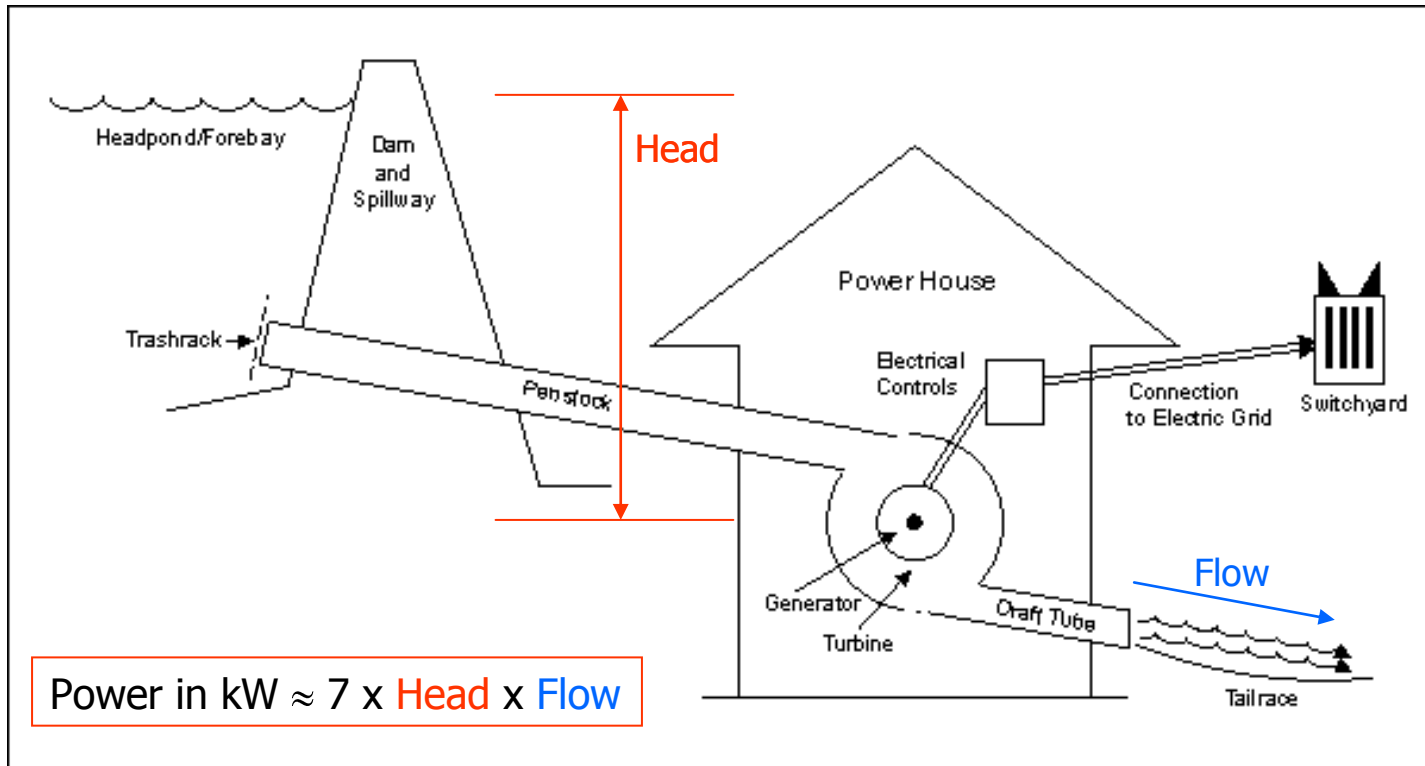


Figure 2.1: Example for Measurements of power (kW) in terms of flow rate and water head.

Source, (DIU, 2010)

Einar O. A., 2006 [44] Carried out studies for calculating hydro potential for small power plants in Norway. The potential for power plants under 1MW had been estimated to be 3 TWh and the assessment for plants between 1 and 10 MW was 7 TWh with estimations done in the 1980's and 1990's. Since there was no project evaluation behind these estimations, a new method was developed through a joint cooperation between NVE and GIS consultants. All rivers with a slope down to 1/25 were included in the estimation and the head was limited to range from 10 m to 600 m and mean flow in the range from 0.05 to 25 m³/s. For better understanding of these numbers, Table 1 shows the calculated power for minimum, Mean and maximum values of both discharge and head according to the Norwegian thresholds, using eq. (1). For minimum discharge (0.05 m³/s), necessary head to produce 50 kW power is 102 m and for minimum head (10 m), necessary discharge is 0.51 m³/s.

Table 2.1: Power calculated using eq. (1) for minimum, mean and maximum values of discharge and head according to the Norwegian thresholds. Source: (NVE, 2004)

Q [m³/s]	H [m]	P [kW]
0.05 min	10min	5
0.05 min	600 max	294
0.05 min	300 mean	147
25max	11 min	2,453
25max	600 max	147,150
25 max	300 mean	73,575
12.5 mean	10 min	1,226
12.5 mean	600 max	73,575
12.5 mean	300 mean	36,788

The power potential was then calculated with the equation of theoretical expression for hydropower with added factor of hydraulic efficiency (eq. (1)) with η equal to 0.815. Automatic calculations of head were made every 50 m tracing the river network from outlet to source by using the river network and the terrain model. The results were presented via internet on an interactive map, where every identified potential power plant with its theoretical calculated capacity is located.

2.3 Additional methods of evaluating hydro potentials

Weiss H. W & Faeh A. O., 1990 [48] both discussed various methods of determining hydro potential, though emphasize was given to keen interpretation of hydrologic background. Hydro potential constitutes one type of surface water resource on which renewed interest has been focused. Of the various methods in use for determining hydro potential, two are described in short as written below;

2.3.1 The area potential

Area potential was determined on the basis of conditions of topographic and hydrologic structure which formed the upper limit of the hydro potential. Mean annual precipitation was used to estimate hydro potential. For evaluation, a catchments area was subdivided into squares of equal area using a grid. The potential of each square was a function of the precipitation, the surface area of the square and its head difference to some predefined point of reference as shown in the figure 2.2

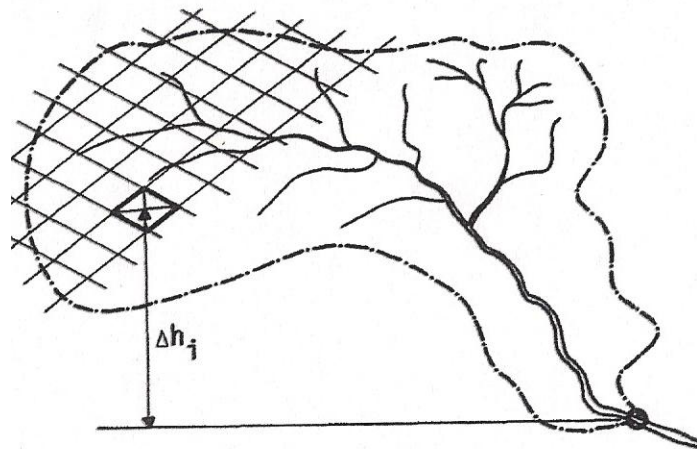


Figure 2.2: Basic method of determining hydro potential (Area potential)

2.3.2 Utilizable potential

Watt et al, [50] conducted a study on the hydro potential of Peru and Guatemala. In the case of Peru, 80 000 km of rivers in 111 separate basins were analyzed. The utilizable potential turned out to be approximately 30% of the theoretical (line) potential. This was also done by using available hydro power plant designs once construction and production costs have been estimated. The expression below clearly defines utilizable potential as illustrated in the figure 2.3 below;

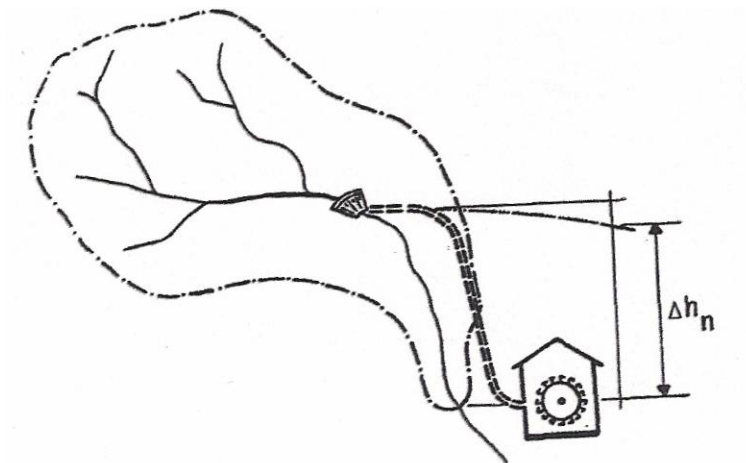


Figure 2.3: Basic method of determining hydro potential (Utilizable potential)

2.4 Current status in South Sudan

South Sudan is characterized by consistent rainfall that last for nearly three quarters a year. The mean annual rainfall ranges from 1mm in the desert to 1600mm in equatorial region. Geologically, South Sudan has mountains that are characterized by steeply dissected hilly and rolling terrain. For instant, Fula station has a reasonable head which is capable of supplying the whole country (South Sudan) with power. This geo-climatic combination causes a large number of streams to radiate from the upper

reaches of mountains. Small streams in the Upper catchments as well as major rivers shall be able to offer South Sudan a remarkable power supply.

The hydropower potential in South Sudan has been evaluated several times since 1970's. Another assessment was done in 2009 by SSEC's consultants and came up with the following summary of hydropower potential sites in South Sudan. With this data, a new method could be applied to assess and affirm the potential of hydro sites.

Table 2.2: Hydro potential sites in South Sudan, Source (SSEC, 2009)

River	Potential site	Capacity (MW)	Energy (MWh/y)
Bahr El Jebel	Fula	720	3900
	Shukoli	210	1430
	Lakki	210	1500
	Bedden	400	2600
	Juba	10	40
Tributaries	Sue	12	45
	Yei1	3	10
	Yei2, 3,4	0.3	2
	Kinyeti1-4	3.5	15
	Kaya	13.5	50
Total		1,582.3MW	9,589MWh/y

Currently, South Sudan is experiencing difficulty in meeting its demand due to limited generation capacity. In juba, only 1% of the population has an access to electricity. If the above potential is utilized, the country shall be in a better position to pick up in term of development.

2.5 Summary of Literature Review

Determination of energy status for South Sudan is necessary because the country is in dire need of a sustainable and reliable energy sources. There is a need to determine energy source that could be used for short term and long demands. The potential of hydro has been assessed in the past in the then Sudan and was not well completed. There is a need to apply a different method to get the potential values. From the above literature review, there shows good results in assessment of hydro power potentials done by individuals and that of other countries around the world. From this literature, Energy mix analysis that was used in Sudan and in the USA could be utilized in this study. The concept of area potentials and discharge analysis using energy meter will be applied in this research work.

3 METHODOLOGY

3.1 Determination of Energy mix for South Sudan

Data for energy sources in Juba was obtained by dividing Juba City into three sections according to the existing payams as shown in figure 3.1. Juba city covers an area of 18KM². Juba payam being the biggest, it covers up to 8KM², Munuki payam covers an area of 6KM² and Kator payam is 4KM². The division of the city was to make site survey for data collection easier. The data collection was carried out for two weeks from 1st October 2013 to 15th October 2013.

The main aim was to determine the energy sources that are in use in Juba for electricity supply. The three sections of Juba are; Kator, Munuki and Juba. Each Section was assigned five working days apart from weekends which were also utilized. Data collection was extensive, could start from 7:30AM to 01:00PM then from 01:30PM to 05:30PM every day and it could go to 06:00PM sometimes. Each section was assigned 150 sample size of energy sources to be assessed in random; this brings the total sample to 450 for the entire city of Juba.

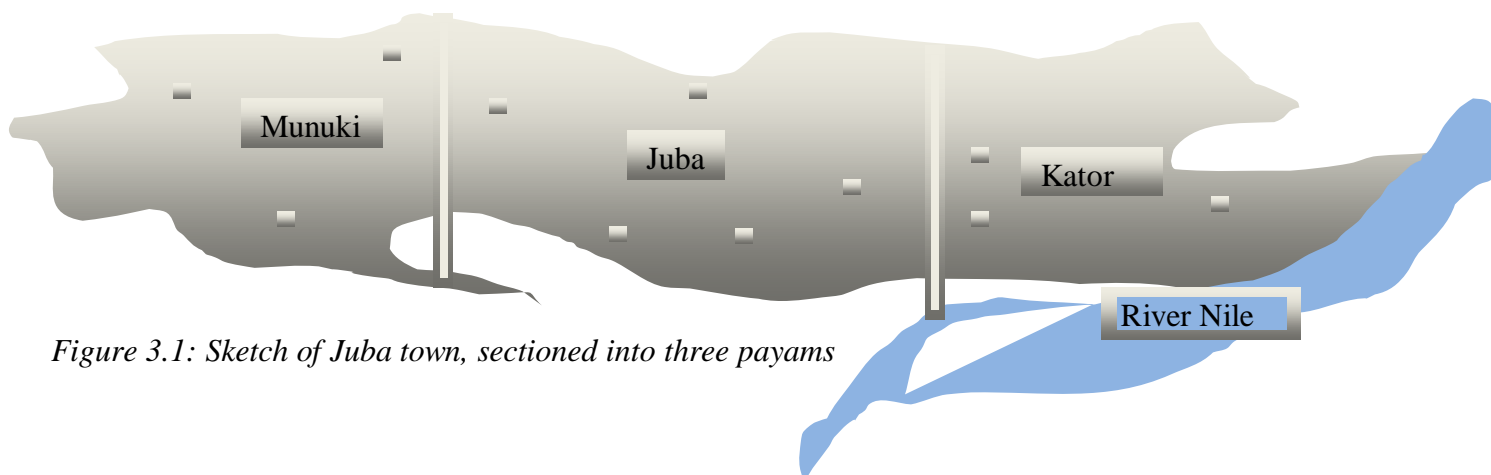


Figure 3.1: Sketch of Juba town, sectioned into three payams

From figure 3.1 above, the dotted spots represent households that are using at least one energy source in a payam.

3.2 Data

The data required to achieve the study objective was found as follows;

1. The data for energy sources was obtained by carrying out site survey. The site was divided into three sections (payams), namely munuki, kator and juba to make it easier to collect energy sources in use. This data covered a period of two weeks from 1st Oct 2013 to 15th Oct 2013 with a sample time of eight hours a day.
2. The data to determine Potential from hydro was obtained from data discharge taken from two hydro sites, Fula and Shukoli sites. The data was found by using current meter to measure the discharge in the river. The data was obtained for one month of river flow.
3. Water Elevation data was sourced from Sudan dam implementing unit and from ministry of water resources. This data was taken for two months from July 2009 to September 2009 using the aerial view.
4. Data for comparing Hydro power with other sources of energy was obtained from historical data in the ministry of Electricity and Dams and by using some books from different authors.

The potential from Hydro was estimated from the following expression;

$$P = \eta \gamma Q H \dots\dots\dots(1)$$

Where

P = Power (W)

γ = Specific weight (N/m³); $\gamma = g\rho$, Where g = Acceleration due to gravity (m/s²), ρ = Mass density (kg/m³)

η = Hydraulic efficiency

Q = Discharge (m³/s)

H = Head (m) The mass density is generally assumed constant at **1000 kg/m³** and gravitational acceleration **9.81 m/s²**. Only two remaining parameters (Head and Discharge) are needed to determine the hydropower potential for any site.

The head can be measured manually or with different automated methods measuring along the river system within a digital elevation model. The head can be classified in three groups; small head which is less than 50 m, average head which is 50-250 m and large head which exceeds 250 m.

4 RESULTS AND DISCUSSIONS

4.1 Energy Consumption mix in South Sudan

South Sudan energy consumption mix is dominated by oil which is 98% of South Sudan revenue and the rest of 2% comes from thermal. The total available Electrical energy in South Sudan is 70MW with 40MW being imported from Sudan and approximately 30MW installed in the state capital. Over 95% of this available energy is thermal. 100% of installed capacity mostly in state capital in South Sudan is thermal. Analysis of energy status in this research work shall concentrate on Juba city.

4.2 Energy mix in Juba

The energy mix data was obtained by dividing Juba city into three sections as explained in chapter 3. Table 4.1 gives the results of energy sources that were assessed in munuki, Juba and Kator.

Table 4.1: Data for assessed no. of energy sources in Juba from 1st October to 15th October 2013

S/N	Name of energy source	Munuki Payam	Juba Payam	Kator Payam
1.	Thermal	52	76	35
2.	Kerosene	34	8	30
3.	Batteries	8	5	6
4.	PV system	38	36	41
5.	Biomass	20	22	25
6.	Wind	0	0	0
7.	Geothermal	0	0	0
8.	Hydro power	0	0	0
	Total	152	147	137

From table 4.1, Munuki has the highest number of energy sources up to 152, followed by Juba with 147 then Kator with 137. The implication of this variation in the number of energy sources has something to do with standard of living. Majority of high class people stay in Juba payam according to national bureau of statistics assessment, 2011 and most of them are able to afford personal generators. Thermal energy constitutes of 52% of the total energy sources installed in Juba Payam and kerosene is 6% of the total.

Kator on the other hand has most of water bottling plants. The senior employees of these water bottling plants are situated around these areas and can manage to purchase generators. We can see that solar PV is about 30% of the energy sources in Kator. Munuki is mixed and it's composed of both classes. In the entire Juba, we have no trace of wind farm, Hydro station and Geothermal. Some of these energy sources have high potential.

Table 4.2: Data for Munuki energy sources in percentages

Thermal	Kerosene	Battery	PV system	Biomass	Wind	Geothermal	Hydro Power
34%	22%	6%	25%	13%	0%	0%	0%

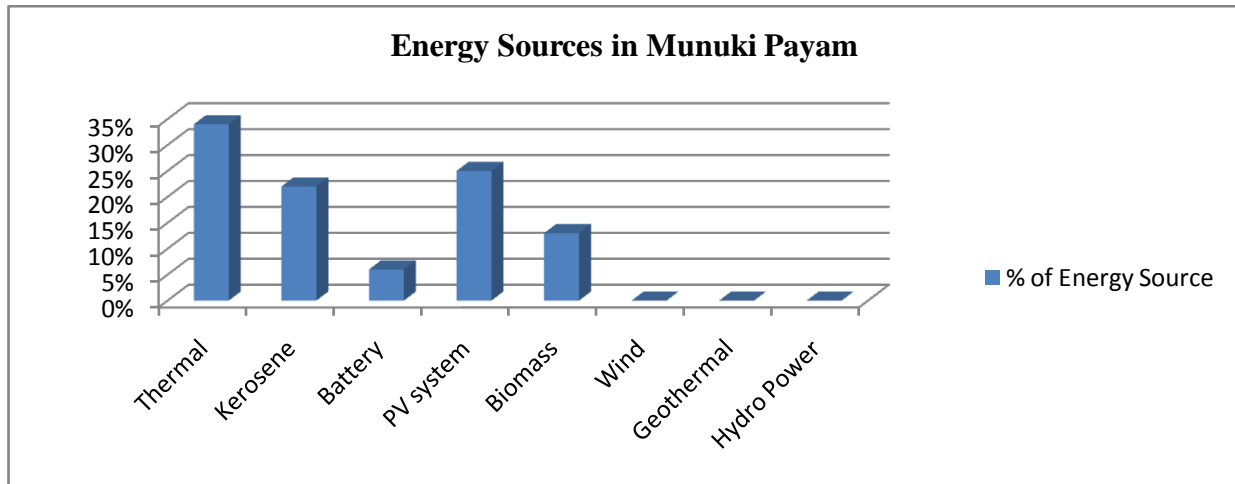


Figure 4.1: Graphical presentation of energy sources in Munuki Payam, Juba City

From figure 4.1, Thermal energy generation appear to dominate the consumption upto 34% in Munuki payam. Most of the residents in this area have personal generators and many of them are also using city power from diesel-fired Generators at Juba power station. Battery 6% are being used for entertainment and lighting but at the minimum rate. A reasonable number of residents are using solar arrays up to 25% of diffident sizes, ranging from 75W to 200W the common solar capacity in Juba but could go higher than 200W.

Most of returnees from Khartoum and many other neighboring countries for instance Kenya, Uganda, Ethiopia and DRC have settled here and are still using kerosene up to 22% of the total surveyed energy sources in this payam, Biomass gives 13%. Other sources of energy have no trace as yet. Wind, Geothermal and Hydro power are all zero as seen from the chart though; sources like wind and Hydro have high potential that is not yet exploited.

Table 4.3: Data for Juba energy sources in percentages

Thermal	Kerosene	Battery	PV system	Biomass	Wind	Geothermal	Hydro power
51%	5%	4%	25%	15%	0%	0%	0%

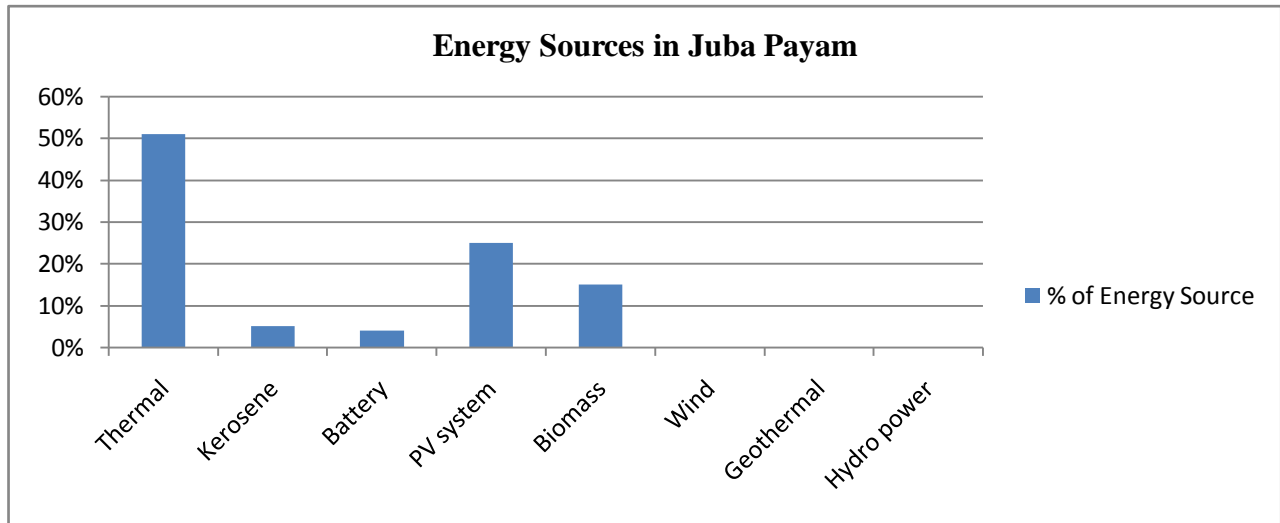


Figure 4.2: Graphical presentation of energy sources in Juba Payam, Juba City

Figure 4.2 presents a status of energy sources in Juba payam. Still thermal is at the higher level upto 51% compare to Kerosene 5%, Battery 4% , PV system 25%, Biomass 15%, Wind 0%, Geothermal 0% and Hydro 0%. Majority of residents in Juba payam are able to purchase city power as well own a generator and solar. Kerosene is at minimum since most of the people here don't need it. It is only used in some few areas within Juba payam.

Table 4.4: Data for Kator energy sources in percentages

Thermal	Kerosene	Battery	PV system	Biomass	Wind	Geothermal	Hydro Power
26%	22%	4%	30%	18%	0%	0%	0%

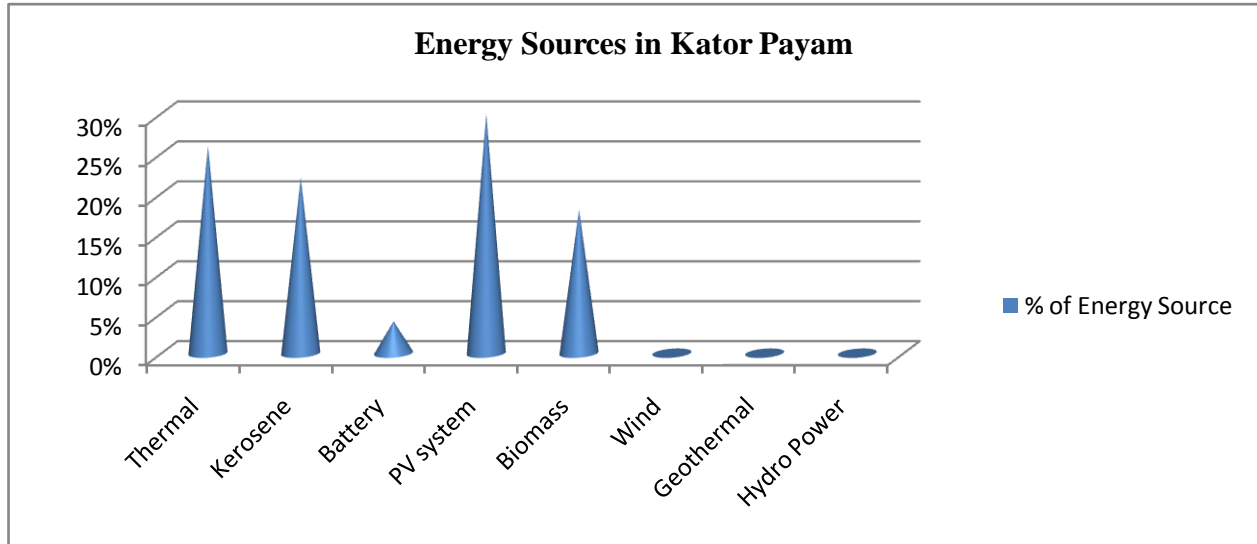


Figure 4.3: Graphical presentation of Energy Sources in Kator Payam, Juba City

Solar is rating higher by 30%, than thermal 26%, Kerosene 22%, Battery 4%, Biomass 18%, Wind 0%, Geothermal 0% and Hydro 0% as shown in figure 4.3 above. This shows that the able residents in kator payam prefer to use solar than buying personal generators. Some respondents said that generator is too noisy and expensive. Some of the residents here are using city power and some with few generators (thermal 26%) in Kator payam. the rest of other sources are also zero, indicating they are not exploited.

Table 4.5: Percentage (%) use of energy in Juba City

S/N	Thermal	Kerosene	Battery	PV System	Biomass	Wind	Geothermal	Hydro Power
Percentage (%)	36%	17%	5%	27%	15%	0%	0%	0%

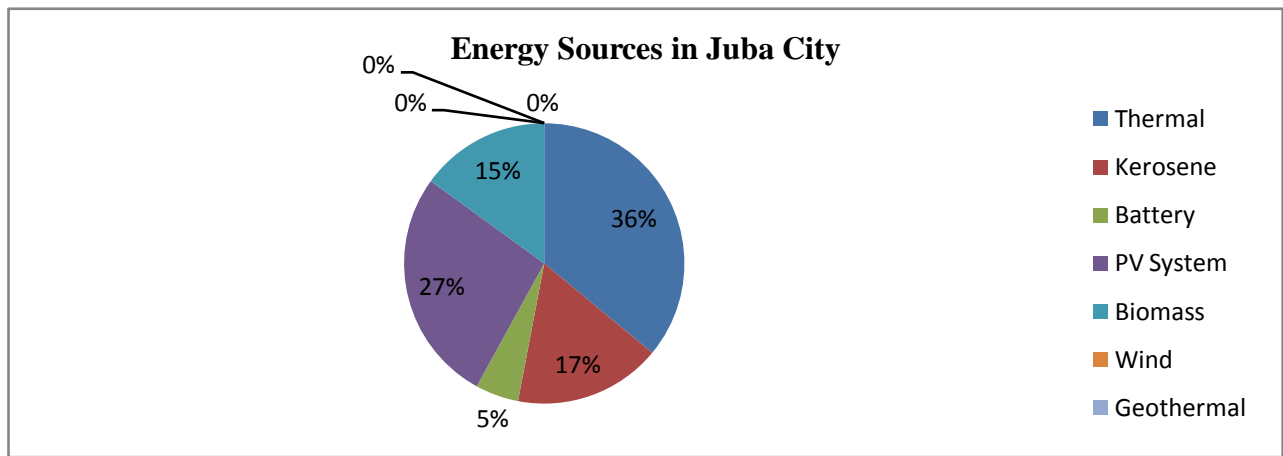


Figure 4.4: Percentage (%) of energy sources in Juba

In figure 4.4 above, the energy consumption in the entire city of juba is presented considering the 450 sample size. Thermal 36% takes the lead as the only source of energy being utilized in Juba widely. As we can see, the country is suffering for lack of reliable source of energy. Major sources of energy like, Hydro 0%, Wind 0% and Geothermal 0% are not yet exploited and social and economic development can never go ahead without such sources.

Solar energy 27% on the plot is clean and efficient but it is not economical in term of space. 1MW of solar covers an acre of land which if you install Hydro or any other source of power, can be enough for over 100MW. This justifies that solar is not economical, initial capital for solar is also too huge. Use of

Kerosene 17% indicates low class of living. Juba still has a large number of internal displaced persons (IDP) from Khartoum mainly and they have not yet settled well to be self-reliance therefore, a great number of them are still using kerosene and candles for lighting.

4.3 Determination of potential from Hydro

Potential from Hydro was determined through discharge and river elevation. River discharge was determined by multiplying velocity by summation of the area of cross-sections. Depth and width were obtained by sectioning the river as shown in figure 4.5. Area was calculated from depth by the width. The data was taken in the month of December 2012 and revised in October 2013. River elevation data was sourced from the ministry of dam implementing unit of Sudan and from ministry of irrigation and water resources of South Sudan. This data was taken for two months from July 2009 to September 2009 using aerial view.

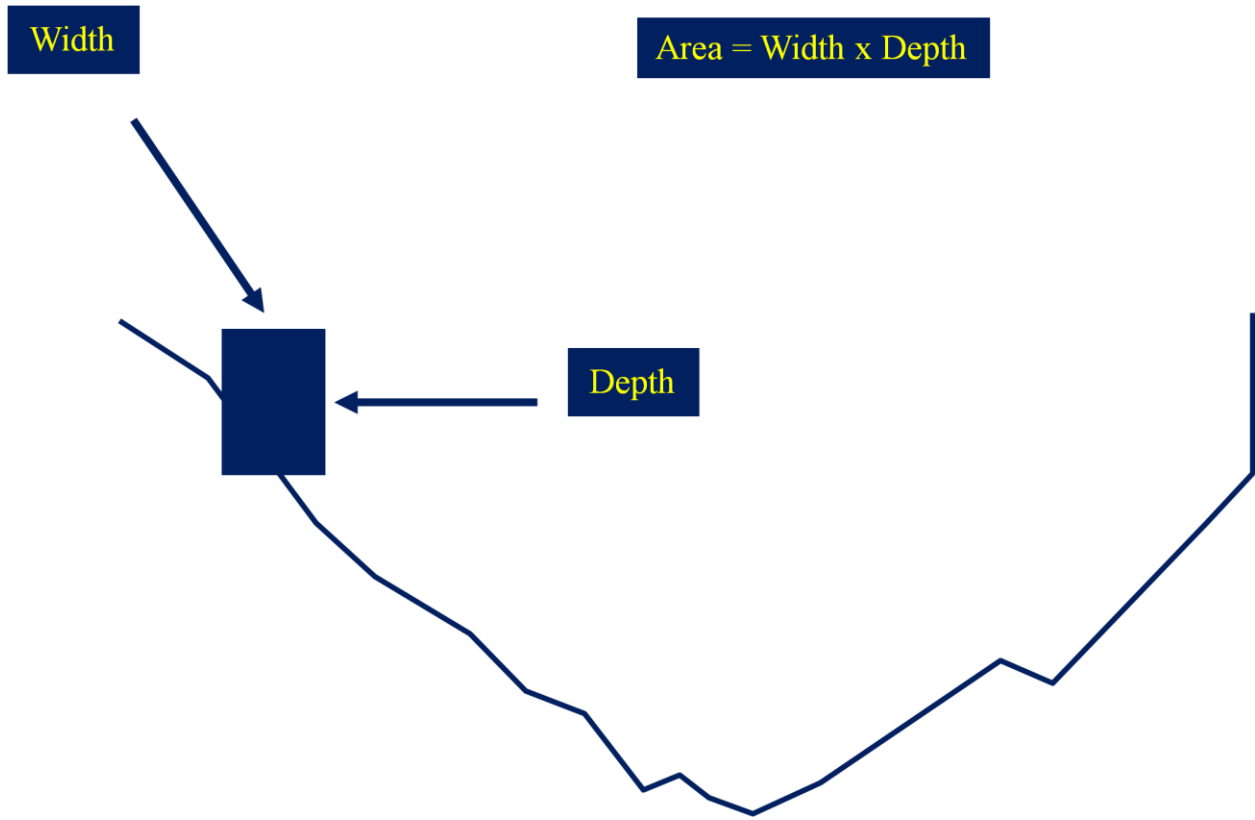


Figure 4.5: Area calculated by directly measuring width and depth of a river sectioned in cubes in series

4.3.1 Discharge

Discharge was determined through current meter measurements. The current meter was used to measure the velocity of flow, depth and width of water. The following formula was used to calculate the discharge based on figure 4.5.

$$\text{Total Discharge} = ((\text{Area}_1 \times \text{Velocity}_1) + (\text{Area}_2 \times \text{Velocity}_2) + \dots (\text{Area}_n \times \text{Velocity}_n)) \dots \dots \dots (2)$$

Table 4.6: Calculated discharge for Fula hydro site using current meter, data taken for one month from 1st Oct 2013 to 29th Oct 2013

S/N	Depth (m)	Width (m)	Area (m ²)	Velocity (m/s)	Discharge (m ³ /s)
1	4.0	5.0	20.0	8.0	160.0
2	4.5	5.7	25.7	8.5	218.45
3	5.0	6.4	32.0	12.0	384.0
4	7.0	5.0	35.0	14.0	490.0
5	8.0	5.4	43.2	16.0	691.2
6	10.0	5.1	51.0	18.0	918.0
7	10.2	5.4	55.08	21.0	1156.68
8	7.0	9.0	63.0	25.0	1575.0

Table 4.7: Calculated discharge for Laki hydro site using current meter, data taken for one month from 1st Oct 2013 to 29th Oct 2013

S/N	Depth (m)	Width (m)	Area (m ²)	Velocity (m/s)	Discharge (m ³ /s)
1	2.5	3.0	7.5	2.5	18.75
2	3.0	4.7	14.1	4.5	63.45
3	3.3	4.5	14.85	8.0	118.8
4	4.2	5.0	21.0	8.2	172.2
5	6.3	5.4	34.02	8.9	302.78
6	8.5	5.1	43.35	12.0	520.2
7	9.02	6.8	61.34	14.3	877.16
8	10.5	7.0	73.5	15.5	1139.25

Table 4.8: Calculated discharge for Shukoli ydro site using current meter, data taken for one month from 1st Oct 2013 to 29th Oct 2013

S/N	Depth (m)	Width (m)	Area (m ²)	Velocity (m/s)	Discharge (m ³ /s)
1	2.5	3.0	7.5	5.0	37.5
2	3.5	3.8	13.3	7.5	99.8
3	4.2	4.4	18.5	9.3	172.1
4	6.0	5.0	30.0	10.0	300.0
5	6.7	5.6	37.5	12.1	453.8
6	7.6	6.1	46.4	13.5	626.4
7	8.5	5.4	45.9	15.3	702.3
8	9.3	7.3	67.9	20.7	1405.5

Table 4.9: Calculated discharge for Bedden hydro site using current meter, data taken for one month from 1st Oct 2013 to 29th Oct 2013

S/N	Depth (m)	Width (m)	Area (m ²)	Velocity (m/s)	Discharge (m ³ /s)
1	3.5	5.0	17.5	6.0	105.0
2	3.9	5.5	21.45	7.5	160.88
3	4.3	6.4	27.52	10.0	275.2
4	5.5	6.8	37.4	12.0	448.8
5	6.3	5.4	34.02	13.0	443.26
6	7.2	5.1	36.72	15.0	550.8
7	7.9	6.4	50.56	17.0	859.52
8	8.5	9.0	76.5	19.7	1505.05

Table 4.10: Monthly river discharge data for the month of December 2012, taken again in October 2013 by using current meter

Fula (m³/s)	Laki (m³/s)	Shukoli (m³/s)	Bedden (m³/s)
160.0	18.75	37.5	105.0
218.5	63.45	99.8	160.88
384.0	118.8	172.1	275.2
490.0	172.2	300.0	448.8
691.2	302.78	453.8	443.26
918.0	520.2	626.4	550.8
1156.7	877.16	702.3	859.52
1575.0	1139.25	1405.5	1505.05

4.3.2 Water Elevation (FSL)

Water elevation data was sourced from the ministry of irrigation and water resources of South Sudan and from dam implementing unit of Sudan. This data was obtained by using elevation model and transferred from Arc geographical information system (ArcGIS) to excel sheet for computation. Table 13 shows the data of elevation from four hydro potential sites.

Table 4.11: Elevation data from July 2009 to September 2009

Fula Elevation (m)	Laki Elevation (m)	Shukoli Elevation (m)	Bedden Elevation (m)
543.0	488.532	463.0	526.7
545.0	492.186	463.8	527.5
545.6	493.158	464.2	528.8
546.3	494.628	464.7	528.0
547.0	496.467	465.3	528.3
547.5	497.943	465.8	528.6
548.2	499.105	466.5	529.0
549.9	501.392	467.9	530.1
550.3	502.766	468.6	530.8
551.3	505.970	460.9	531.9

Table 4.12: Discharge and head of three hydro potential sites for rating curves graphical presentation

Fula (m ³ /s)	Fula (m)	Laki (m ³ /s)	Laki (m)	Bedden (m ³ /s)	Bedden (m)
0.0	543.0	0.0	488.532	0.0	526.7
160.0	545.0	18.75	492.186	105.0	527.5
218.5	545.6	63.45	493.158	160.88	528.8
384.0	546.3	118.8	494.628	275.2	528.0
490.0	547.0	172.2	496.467	448.8	528.3
691.2	547.5	302.78	497.943	443.26	528.6
918.0	548.2	520.2	499.105	550.8	529.0
1156.7	549.9	877.16	501.392	859.52	530.1
1575.0	550.3	1139.25	502.766	1505.05	530.8

Zero discharge as recorded on table 4.12, means the point where meters above sea level (FSL) reads a value but no velocity measured and so the discharge at that point is zero and as we know, the total discharge comes from the area times the velocity of water and if the velocity is zero, we automatically get discharge to be zero at that level. From the table, **543m** is referred to as take off point elevation for Fula hydro potential site, **488.532m** is take off point elevation for Laki hydro potential site and **526.7m** is the take off point elevation for Bedden hydro potential site. These take off point elevations are indicated on the rating curve characteristics below;

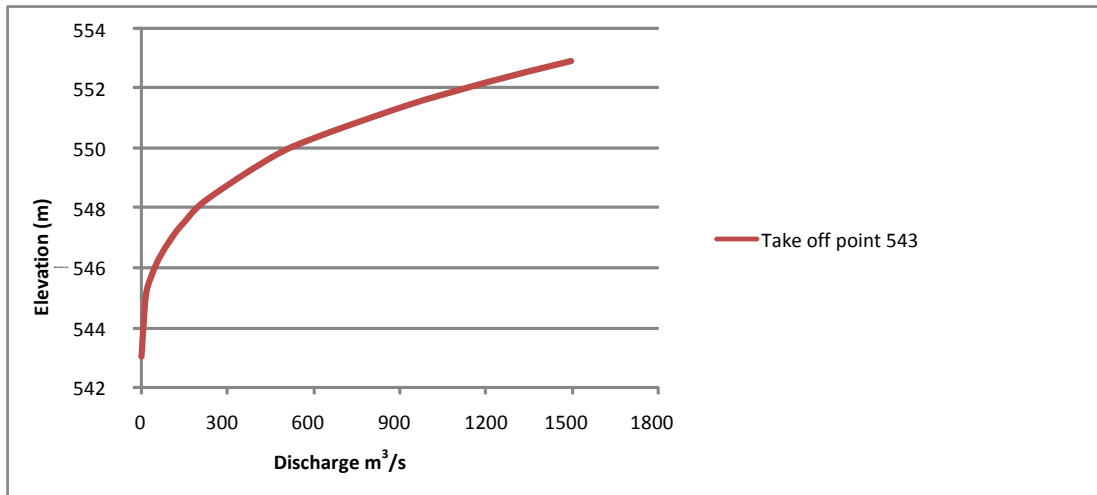


Figure 4.6: Fula rating curve characteristics

From figure 4.6, take off point elevation is found to be 543m. This elevation indicates the point where the discharge is zero. It is the point where the GIS measurement starts and no velocity measured. As shown from the curve above, this value is slightly above the 542m on the plot.

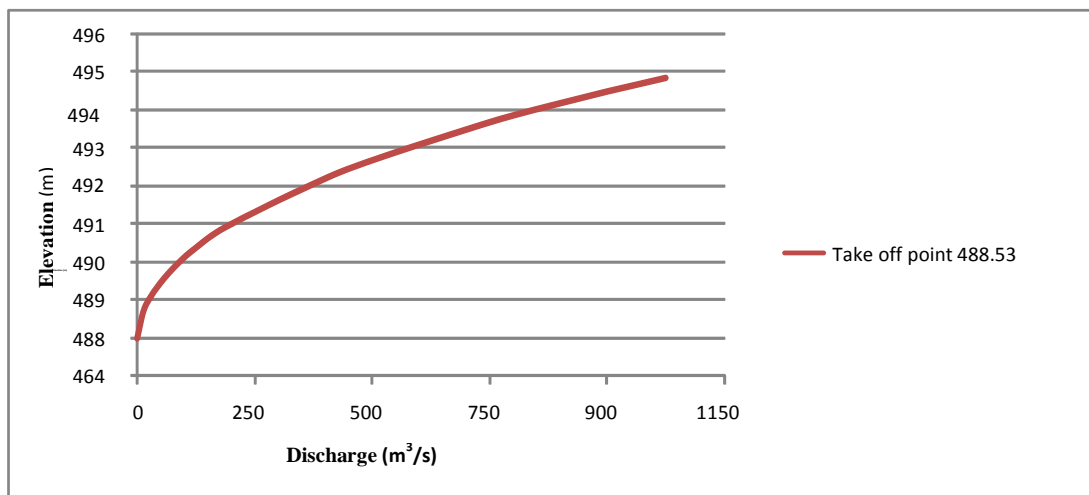


Figure 4.7: Laki rating curve characteristics

Figure 4.7, depicts a rating curve for laki hydro potential site along the River Nile. The take off elevation for laki is 488.53m coinciding with zero discharge on the curve.

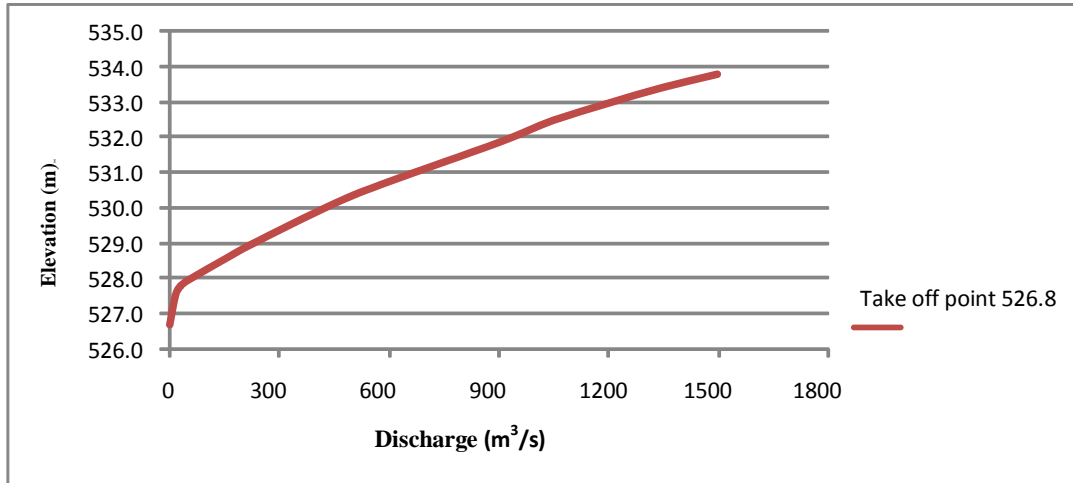


Figure 4.8: Bedden rating curve characteristics

The Take off point elevation for Bedden is 526.8m as shown on figure 4.8 above. This indicates the point where the discharge is zero.

4.4 Hydro potential calculations

The results were obtained as shown on table 4.13 using equation one (1), $P = \eta \gamma Q H$. Hydraulic efficiency and Discharge coefficient of 0.8 and 0.2 were used respectively. Acceleration due to gravity 9.81m/s^2 , Mass Density of water 1000kg/m^3 were also used in the calculation to get the capacity in MW as mentioned in chapter 3.

Table 4.13: Potential from hydro from four hydro potential sites,

Hydro Site	Discharge (m³/s)	Elevation (m)	Total Capacity (MW)
Fula	0.0 min	543	0.0
	118.1 mean	559.05	518.15
	315.0 max	561.3	1387.6
Laki	0.0 min	488.532	0.0
	47.498 mean	510.249	190.2
	227.85 max	515.970	922.6
Shukoli	0.0 min	473	0.0
	75.38 mean	477.2	282.3
	281.1 max	480.1	1059.1
Bedden	0.0 min	536.7	0.0
	89.2 mean	539.55	377.7
	301.1 max	541.8	1280.3
Total (Min)			0.0
Total (Mean)			1368.35
Total (Max)			4,649.6

As seen in table 4.13, the results of hydro potential are within the range of previous estimates that was done by South Sudan Electricity Corporation (SSEC) in 2009. SSEC was estimating the total capacity of fula, laki, Shukoli and Bedden as 720MW, 210MW, 210MW and 400MW respectively. Discharge coefficient of 0.2 was factored in the discharge values. Calculation was done by considering the

minimum, mean and maximum values of discharge and head. This was done to find the range of values of hydro potential in Fula, Laki, Shukoli and Bedden hydro sites.

As tabulated in table 4.13, the maximum capacity that Fula can produce is **1387.6MW**; Laki can produce a maximum of **922.6MW**; Shukoli on the other hand can produce a capacity of **1059.1MW** and Bedden can also produce up to a maximum **1280.3MW**. This could amount to a total expected capacity of **4649.6MW** from these four hydro sites only. South Sudan is rich in terms of water resources and this translates to a high potential of Hydro. Most of the rivers were not accessed during this research work due to lack of roads and insecurity. This potential shall be exploited when South Sudan becomes stable.

4.5 Table 4.14(continued): Comparison of hydro power and other sources of energy

S/N	Energy source	Characteristics of Energy Source
1	Hydro Power	<ul style="list-style-type: none"> • Needs no fuel since water is the source of energy, hence operating costs are low and there are no problems of handling and storage of fuel and disposal of ash • The plant is highly reliable and it is the cheapest in operation and maintenance • It can be run up and synchronized easily, • The rapid changing load can be varied and met without any difficulty, • Such plant has constant speed and constant frequency and therefore acute governing is possible, • Standby losses in hydro plant are minimal • Hydropower plants have longer life and its efficiency does not fall with age, • Since no smoke and ash is produced during operations, the

		<p>hydropower plant is clean and neat</p> <ul style="list-style-type: none"> • Highly skilled engineers are required only at the time of construction but at last, few experienced personal are required, • This plant can serve other purposes apart from generation of electricity; it can be used for irrigation, flood control and navigation among others.
2	Thermal Power	<ul style="list-style-type: none"> • Operating cost is high due to high cost of fuel • Maintenance and lubrication cost is also high as compared In the case of other plants, • Diesel plants cannot supply overloads continuously • Diesel unit's capacity is limited. These cannot be constructed in large size, • Noise from the exhaust is a serious problem • Diesel useful life is very short, it's about 10 years.
3	Solar Power	<ul style="list-style-type: none"> • The initial cost of purchasing and installing solar panel is high • Location of solar panels is important, areas that are cloudy cannot produce solar power unless you install more panels • PV panels are made up of silicon and other toxic metals like mercury, hence imminent environmental pollution which renders inequality in PV cells. Very high technology can avert the worst of this effects • 60% of the sunlight gets wasted and not harnessed since most of solar panels have 40% efficiency. This renders it inefficient • Solar is not reliable since it can be operated at night • Takes large space for big companies to install solar arrays
4	Wind Power	<ul style="list-style-type: none"> • Doesn't produce the same amount of power every day since the strength of wind is not constant • Difficult some times to get wind farm site since most of the people think country site should be left untouched for wind farm • Wind turbines are noisy • Some people see wind turbines to be generally ugly and therefore it

		<p>disfigure the country site</p> <ul style="list-style-type: none"> • Pollutants are produced during manufacturing of wind turbines • Limited in unit capacity hence required many unit to supply a high population
5	Geothermal Power	<ul style="list-style-type: none"> • Location of geothermal power is normally a problem since it has to be located near geothermal activity. • Another downside to geothermal energy production is that a hot spring for geothermal activity can suddenly shut off without any rhyme or reason. There is no way to predict this. In some cases, this shut off can last years, causing disaster to anyone relying upon energy produced by the spot. • Geothermal energy cannot be moved easily. Unlike oil or electricity, it cannot be transferred long distances • Along with the heat, there are other chemicals that can come up along with the energy. Among these are many hazardous chemicals such as mercury, hydrogen sulfide, and ammonia. These chemicals can pollute the air • In order to run a geothermal energy plant, there is the need for many pieces of advanced infrastructure. This equipment is often expensive and cutting edge. As a result, starting a plant can be an expensive endeavor • Geothermal technology can be expensive. While the cost of infrastructure has already been stated, there is also the cost of the initial drilling process, which can be rather expensive. Even prior to that is the cost of surveying for the proper area to build such a plant • Many people speculate that there is the possibility that extracting geothermal energy can cause earthquakes
6	Nuclear Power	<ul style="list-style-type: none"> • Generation of nuclear waste and difficulty to contain the waste • Increased insecurity with international terrorism • Although security systems are very advanced, nuclear fission

		<p>reactions generate some chain reactions that are toxic to human life</p> <ul style="list-style-type: none"> • Nuclear fusions are unfeasible because of the difficulty of heating the gas to such high temperatures and to maintain a sufficient number of nuclei for a time sufficient to obtain energy to liberate than necessary to retain heat and is highly expensive • The high cost of building nuclear facility and possibility of accidents • Nuclear power is very expensive and the time it takes to build is long, needs program for short term
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4.5.1 Catchments areas

Catchments areas as shown below are geographical areas around hydro potential sites (Fula, Laki, Bedden & Shukoli) drained by rivers and their tributaries. These areas are characterized by all runoff being conveyed to the same outlet. Land use authorities' have controlled activities in these areas to minimize *soil erosion* and the washing of *silt* and pollution into rivers and dams site. The table below shows the catchments areas around the study areas

Table 4.15: Sub-catchment areas of torrents between Nimule and Mongalla. Source; (DIU, 2009)

Location		Catchment Area (km ²)
From	To	
Nimule	Fula Hydro Site	31,040
Fula Hydro Site	Shukoli Hydro Site	609
Shukoli Hydro Site	Laki Hydro Site	841
Lakki Hydro Site	Bedden Hydro Site	7,460
Bedden Hydro Site	Juba	4,565
Juba	Mongalla	7,607
TOTAL		52,122

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The following conclusion can be drawn from this research work;-

1. The method used to carry out the research work was through side survey and random sampling of energy sources in the three payams of Juba City. It was found out that the main energy source that is currently in use in South Sudan in slightly large scale is Thermal which possesses great limitations. We can see from figure 4.4, Thermal energy gives the highest (36%) which is also negligible compare to the required demand of 44MW in Juba. The other main sources of energy such as Hydro power (0.0%), Geothermal (0.0%), winds (0.0%) among others are yet to be exploited. Solar is being used widely by individual who can afford it and it accounts for 27% of the total sources of energy that were assessed. There is no reliable power supply in Juba except the little thermal power that is not consistent.
2. Potential from Hydro was analyzed and the results found indicate a high potential to be exploited in those four sites. Fula Hydro potential site gives a maximum of 1387.6MW, Laki with 922.6MW, Shukoli 1059MW and Bedden 1280MW. If this potential is exploited, South Sudan could be able to export a bulk power to the neighboring countries. The calculation was done using the mean and maximum discharge and average water head. By using equation (2). The results cumulate to total technical hydro potential at different sites and sum up to get 4649.6 as the total maximum potentials that

can be exploited from all the four sites. Other small hydro potential sites in South Sudan were not included in this research work due to the condition of roads and insecurity. If the potential from all these other sides is exploited, there could be no doubt that South Sudan will be taken to be in possession of a huge potential of hydro. Solar energy on the other hand is being exploited but in a small scale mostly by individual. There is no plans for the government to establish solar in a large scale any soon due to hefty initial cost and also it is uneconomical in term of space, this is the same case to wind energy although it has a high potential to be exploited. Geothermal and nuclear require high technology and it could be taken to be too early for South Sudan to venture into.

3. On Comparison of Hydro power and other sources of energy, Hydro is merited more than the rest of energy sources. As stated in table 4.14, Hydro is clean and neat, can be easily synchronized compare to wind, Nuclear and Geothermal, standby losses are minimal, It is easy to run compare to nuclear that is dangerous to human life and aquatic, Hydro has longer life span compare to solar energy, It is more reliable in terms of operation since it uses water to energize the turbine compare to thermal which uses fuel that is expensive. These results will be useful for energy resources planning.

5.2 Recommendations

The following recommendations are made in reference to this study;

1. Data for six months would be more appropriate for the assessment of energy sources in Juba for the analysis of energy mix
2. Over five (500) sampling size from the city of juba would be appropriate instead of 450 households to analyze the sources in a wide range.

3. It shall be vital to use rainfall-runoff-modeling assuming that there shall be accurate and efficient rainfall data.
4. The Country should have hydrological database centre where gridded results could be transported to after it's captured with GIS.
5. Utilization of Hydrological model like WaSim used in Iceland, HBV used in Norway and Hydra HP used in India for hydro simulation could improve the quality of hydrological data.
6. Further researches are required in areas of simulation software for hydrological modeling.
7. Thermal energy is expensive and could remain as a short term solution to power need in South Sudan.
8. There is a need to exploited the huge potential of Hydro (4649.6MW) in South Sudan to match the fast growing demand
9. The only way for South Sudan to response to energy crises is by establishing hydro power supply for long term energy needs.
10. There is a need for South Sudan to import power from Ethiopia, DR Congo and Uganda

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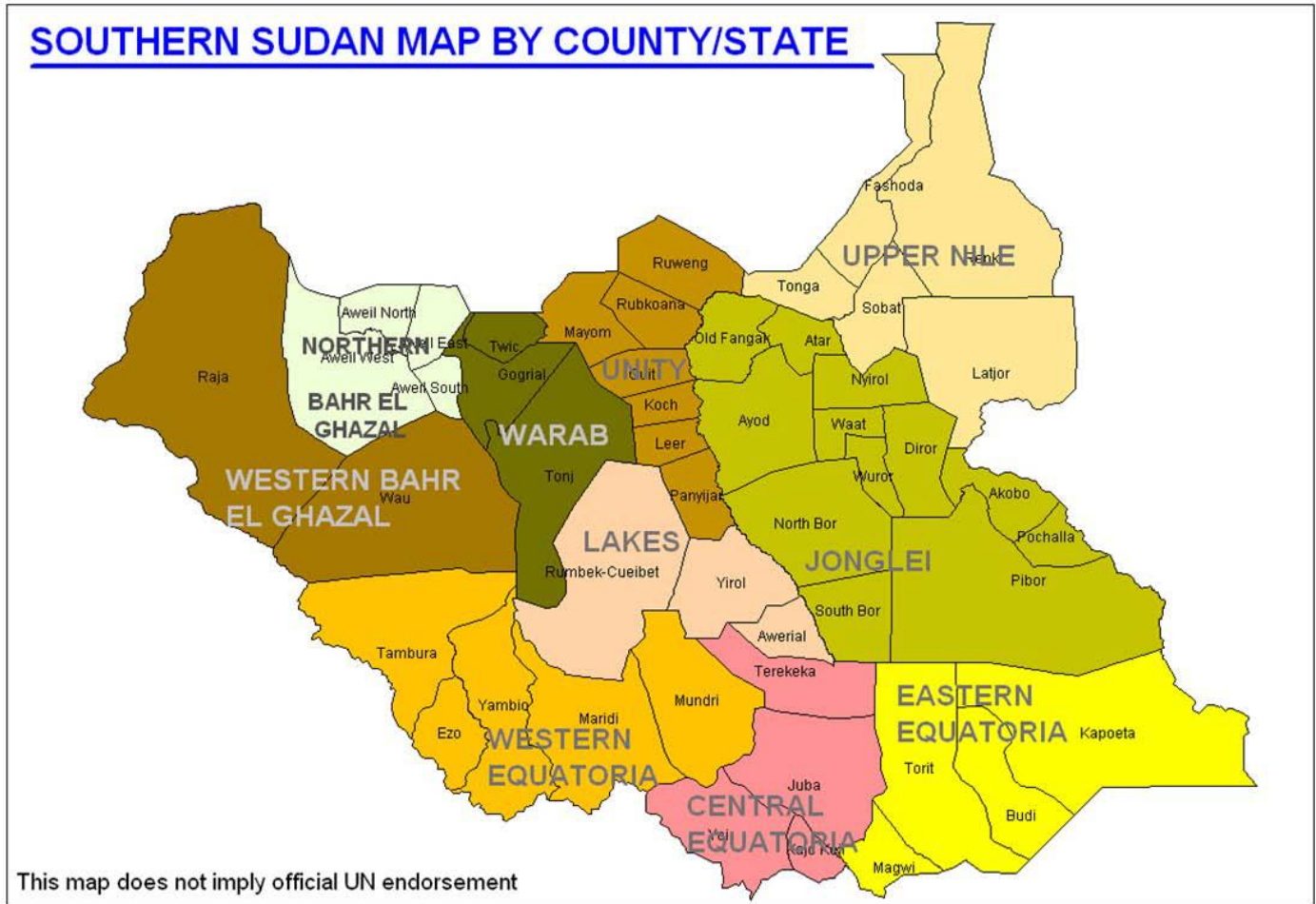
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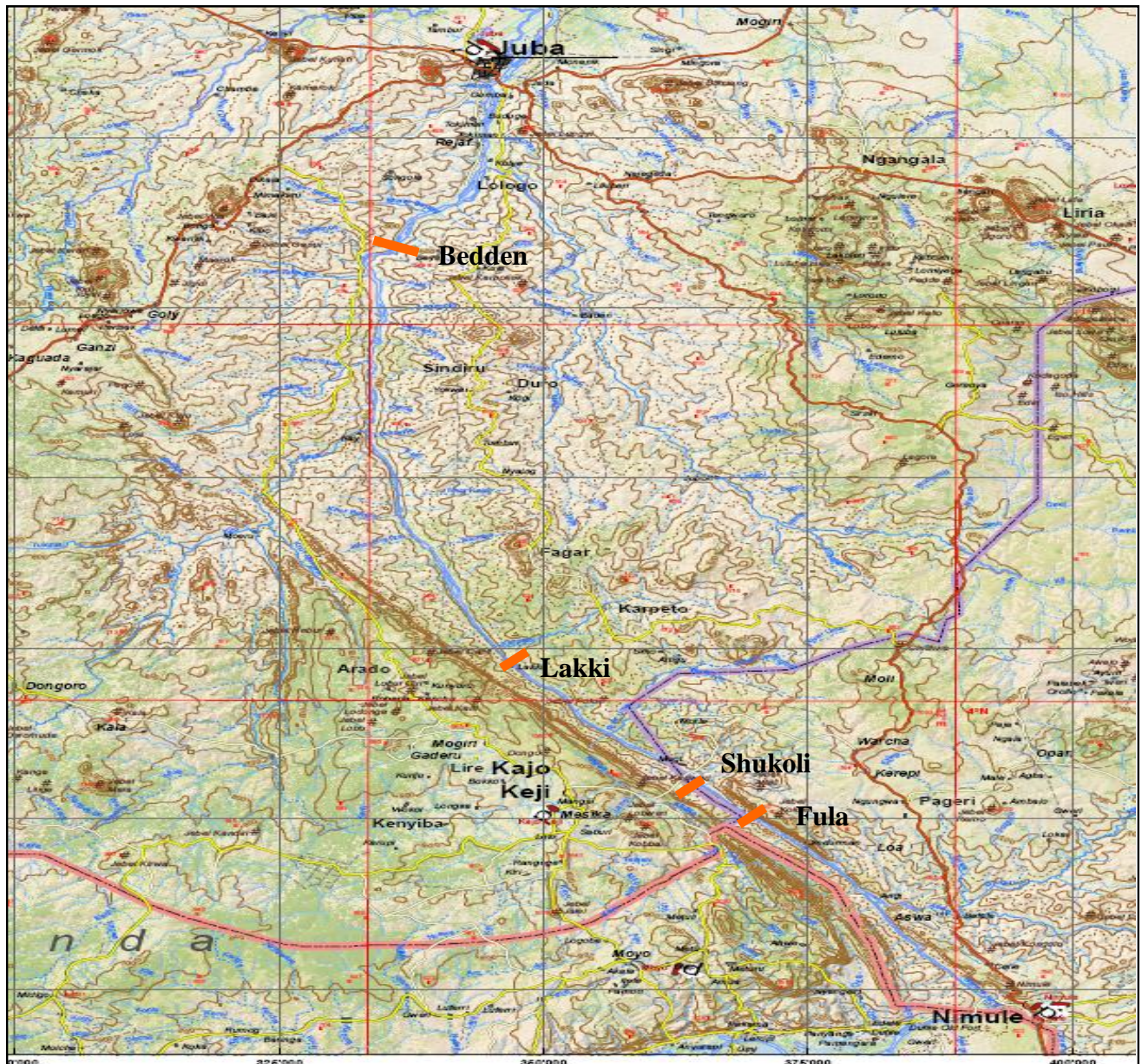
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Appendix 1



Appendix 2

Map of Hydro Potential Sites along the Nile



[Map Source: Central Equatoria State, Southern Sudan State Map Series, Federal Department of Foreign Affairs, Switzerland.]

Appendix 3

Bhar-el jebel/ River Nile



Photo taken on 12 July 2012

Appendix 4

Fula Rapids – a huge energy potential in the White Nile



Photo taken on the 12 July 2012

Appendix 5

Bedden Hydro Potential Sites

