UNIVERSITY OF NAIROBI

SCHOOL OF BIOLOGICAL AND PHYSICAL SCIENCES

DEPARTMENT OF METEOROLOGY

ASSESSING THE SOLAR ENERGY RESOURCE POTENTIAL IN TRANS-NZOIA COUNTY FOR DECENTRALIZED DOMESTIC POWER GENERATION

By

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A project report submitted in fulfillment of one of the prerequisites necessary for the award of the Postgraduate Diploma in Meteorology.

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DECLARATION

This project is my original work and has not been submitted elsewhere for examination or publication. Proper acknowledgement and referencing has been exercised where other people's work have been quoted, in accordance with the University of Nairobi's requirements.

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ABSTRACT

The main economic activity in Trans-Nzoia County is maize farming. The cost of farming has been rising annually while the yield and maize price keep fluctuating thus making life hard for the people there. Considering that Trans-Nzoia county is within the equatorial region which receives solar radiation throughout the year, this study was therefore necessary to assess the possibility of utilizing this natural source of energy. The objective of this study was to assess the solar resource energy potential in Trans-Nzoia County for decentralized domestic power generation.

The data used in carrying out this study include sunshine hours, cloud data (0600Z and 1200Z) and solar irradiance for Kitale meteorological station. The data was sourced from the Kenya meteorological department headquarters. Quality control was performed by plotting single mass curves for the data. The single mass curves clustered about a straight line indicating that the data used was homogeneous.

Time series plots for sunshine hours showed that the area receives an average of 8.1 hours of sunshine daily. The solar radiation plots showed that the area receives an average of 6.1 kwh/m^2/day. The solar energy resource potential was computed and found to be 632.5GW but 126.5GW is extractable when the efficiency of photovoltaic panels is factored in. These values are an indication that the area is endowed with enormous solar energy resource that can be extracted for domestic power generation. Cloud analysis results is in agreement with the sunshine hours analysis for they both confirmed that December-January-February and June-July-August seasons are the seasons with maximum and minimum transparency of solar radiation respectively.

From the study, it is recommended that the residents of Trans-Nzoia County should tap into this naturally occurring resource since it is a cleaner and cheaper source of power. Further studies should also be carried out in this area to capture the effects of topography on the available solar energy.

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List of Acronyms

A: area

CO: carbon monoxide

CO_2: carbon dioxide

DJF: December-January-February season

E_{A} : available solar power

E_E: extractable solar power

E_S: average solar intensity

GW: giga watt

h: hour

H_2S: .hydrogen sulphide

j: joule

JJA: June-July-August season

$kWh/m^2/day$: kilowatt hours per square metre per day

KNBS: .Kenya National Bureau of Statistics

KPLC: Kenya Power and Lighting Company

MAM: March-April-May season

$Mj/m^2/day$: mega joules per square metre per day

M^2: square meter

pv: photovoltaic

r: solar panel efficiency

RCEP: Africa EU Renewable Energy Cooperation Programme

SWERA: Solar and Wind Energy Resource Assessment

SON: September-October-November season

W: Watt

List of equations

CHAPTER ONE

1.0 INTRODUCTION

The main sources of energy in rural parts of Kenya are biomass that is; firewood, charcoal and agricultural waste and kerosene. These sources are not only getting depleted but emit harmful gases such as carbon dioxide (CO_2) that contribute to global warming and climate change. Use of charcoal emits carbon monoxide (CO) which is an indoor pollutant that can cause death since it depletes a poorly ventilated room of oxygen.

Very few households are connected to the national electricity transmission grid in the rural parts of Trans-Nzoia County. Electricity generation in Kenya is mainly from the following resources: hydro, geothermal and fossil fuel. Fossil fuel contributes to global warming through emission of CO_2 and the cost of importing oil is ever rising thus weakening the shilling in the international money market. With a weakened currency, inflation is inevitable. The hydro resources on the other hand keeps fluctuating due to climate variability and change that has resulted in a change in rainfall patterns, whereby prolonged dry spells and insufficient rainfall during the rainy season fail to recharge the water reservoirs to the required levels for power generation.

Setting up of geothermal power plants is very expensive and can degenerate to conflicts between the government and the communities where the power generating plants are located because of displacement. Geothermal power plants contribute to air pollution through emission of hydrogen sulfide (H_2S) which is very poisonous, corrosive and flammable.Power outages are also frequent in Trans-Nzoia County, especially during the rainy seasons and hence electrical energy from KPLC is sometimes unreliable.

1.1 Problem Statement

The residents of Trans-Nzoia County derive their livelihood mostly from peasant farming and informal employment such as casual labor in maize farms and jua kali businesses.
With the effects of climate variability and change, crop yield and animal production has dropped. The residents are therefore unable to cater for the cost of getting connected to the national

electricity grid and payment of monthly electricity bill to Kenya power. Also the size of land owned by families has decreased due to subdivision among the family members and selling to cater for school fees payment for their children. With the decrease in land size per household, it becomes extremely hard for the residents to set aside land for planting trees to be cut for firewood. For this reason the use of wood energy is unsustainable since the rate of deforestation is higher than reforestation.

Since Kenya is an importer of oil, use of renewable energy resources will help in reducing the demand of foreign currency. Kerosene lamps on the other hand emit smoke that irritate the eye and soot that deposit on roof ceilings making them ugly and dirty. The light from these kinds of lamps is very dim and the users strain their eyes in using them. Use of charcoal in poorly ventilated rooms can lead to death due to emission of CO which depletes oxygen in the rooms.

1.2 Objectives of the study

The overall objective of this study was to assess the solar energy resource potential in Trans-Nzoia County for decentralized domestic power generation.

1.2.1 Specific Objectives

The specific objectives of this study were as follows:

i. To determine the temporal characteristics of solar radiation intensity and sunshine hours in Trans-Nzoia county.
ii. To determine the seasonal characteristics of sunshine intensity and sunshine hours.
iii. To determine the temporal characteristics of cloud cover over Trans-Nzoia County.
iv. To determine the solar power potential by computing the available and extractable solar power in Trans-Nzoia County.

1.3 Justification

Very few families are connected to the national electricity grid in rural parts of Trans-Nzoia County; other households depend on kerosene lamps for lighting and firewood for cooking, warming their houses during cold seasons and heating water. These sources of energy emit smoke that contributes to domestic internal air pollution and the dim light from kerosene lamps contribute to eye problems because of straining to see especially when reading. Soot emitted by use of firewood deposits on roof ceiling thus making them dirty and ugly. The smoke emitted make staying in such rooms uncomfortable since the eyes get irritated.

According to 2009 national population census carried out by Kenya National Bureau of Statistics (KNBS), poverty rate in Trans-Nzoia county is about 50.1% and this, therefore, implies that half the population is unable to raise the amount of money required to get connected to the national grid and monthly payments of electricity bill. Even for the few who have been connected to the national grid, there are frequent blackouts and power interruptions especially during the rainy season.

The population density is increasing and so is the demand for energy. Trans-Nzoia population growth rate was 3.8% in the 1999 (according to Kenya National Bureau of Statistics census carried out in August, 2009). Consequently the rate of deforestation exceeds that of reforestation due to the ever decreasing size of lands owned by households. Decreasing forest cover poses a threat to the ecosystem and rivers for the Cherang'any catchment area and Sitatunga Game Park.
The adoption of solar energy for domestic power generation will therefore help minimize internal air pollution from use of kerosene lamps, decrease the global warming effect resulting from overreliance on fossil and biomass fuel. Solar energy also comes in handy during the frequent and prolonged power outages in the area. With the improved reliability, efficiency and comfort students can carry out their studies at home without much inconveniences and will therefore boost their academic performance in school which.The solar energy resource tapping technologies for instance photovoltaic (PV) solar panels have been developed and are readily available in the market for use.

1.4 Area of Study

The focus area of the study was Tran-Nzoia county found in the former Rift-Valley province about 380 km North West of Nairobi within geographical coordinates 0°48’50’’N, 1°17’1’’N and 34°34’34E, 35°23’13E. It is situated within a geographical area of 249,5500,000 m^2 bordering the republic of Uganda to the North West ,Bungoma to the West and South West ,Kakamega and Uasin Gishu to the South East, Elgeyo Marakwet to the East and West Pokot to the North. The region is located between Mount Elgon (4321m above sea level) and Cherang'any hills (about 3500m above sea level). The population estimate of the county was 818,757 people in 2009 according topopulation census carried out by Kenya National Bureau of Statistics (KNBS). The County is found within the subtropical region and therefore solar radiation is available throughout the year.

Figure 1: Map of the study area extracted from Googlemaps.

CHAPTER TWO

2.0 LITERATURE REVIEW

Use of Photovoltaic system to harness solar energy is basically either by an on-grid solar system or off-grid solar systems. Off grid solar system are suitable for rural areas where there is no access to transmission grids, in such systems electricity is generated by solar photovoltaic (PV) and stored in batteries to be used at night when there is no irradiance. On-grid solar systems are integrated to the grid and power generated by solar PV is fed to the grid (Solar Direct, 2015).

According to global status report on renewable energy of 2012, only 51% and 4% of Kenyans living in the urban and rural areas respectively have access to electricity. Direct normal irradiance of 6.0kWh/m^2/day will provide heat for institutions, households and industry (SWERA- Country Report, 2008).

Approximately 70% of the land area in Kenya has a potential of receiving about 5kWh/m^2/day throughout the year. However there are spatial and temporal differences in the solar energy resource of the country (RCEP- Africa EU Renewable Energy Cooperation Programme) https://www.africa-eu-renewables.org/about-recp/.The insolation reaching the surface of the earth varies with the season. In Kenya seasons are classified into December-January-February (DJF), March-April-May (MAM), June-July-August (JJA) and September-October-November (SON) (Omwando L.M et.al, 2014)

Meteorological factors; cloud depth and cover, wind, relative humidity, e.g.also affect the amount of solar energy reaching the earth's surface, thereby affecting the potential of solar energy resource. (Nakella H, 2016).Solar energy resource tapping for rural domestic use is possible in most parts of Kenya and may contribute a lot inlimiting environmental pollution and health problems associated with CO_2 emissions due to burning biomass fuel (Marigi, 2017).Solar energy is mostly used in cooking, drying clothes and agricultural produce, water sterilization, power generation and heating, Thimo L. (2014).

CHAPTER THREE
DATA AND METHODOLOGY

3.0 Introduction.

This section covers the data sets and sources that were used in carrying out the study and how the same was analyzed.

3.1 Data

Data used in analyzing this study comprised of Monthly average total cloud cover at 0600Z and 1200Z for the years 2008 through 2017; Monthly average solar radiation for the years 2008 to 2017; And Monthly average sunshine hours for the years 2008 to 2017.The above data for Kitale Meteorological Station was extracted from Kenya Meteorological Department (KMD) synoptic registers stored in the climate section.

3.2 Methodology

3.2.1 Data quality control

Data quality control entails checking for errors in the collected data sets, heterogeneity or inconsistence. Data quality control was carried out by applying range validation and use of single mass curves.Range validation involves identification of extreme values. Observed data that falls below or above the minimum or maximum extreme value ever recorded were carefully examined to check if they were incorrect.

$$y_{min} \leq y_o \leq y_{max}$$

Where; y_{min} is the minimum climatological extreme value.

y_o is the observed value.

y_{max} is the maximum climatological extreme value.

In single mass curve, the cumulative data records were plotted against time. Data was considered to be of good quality if straight line plots resulted.

3.2.2 Estimation of missing data

Missing data was estimated by use of arithmetic mean method. This method involves considering seasonal averages for a pair of correlating stations as in the following equation. For this study Eldoret station was taken as the correlating station.

Arithmetic mean

$X_m = (X/Y) \times Y_m$……………………………………………………Equation 1

Where, X_m= estimated value.

X= seasonal mean for the station

Y= seasonal mean for the correlating station

Y_m= value for the correlating station at the corresponding time of missing record

3.2.3 Time series.

Ten years' trend of solar radiation intensity and sunshine hours were investigated. Monthly variation of solar radiation, sunshine hours and cloud were investigated through time series plots to identify months with least and maximum potential of solar energy.The December-January-February, March- April-May, June-July-August and September-October-November seasonal irradiance were also compared by plotting bar graphs. This was done to investigate how solar radiation changes with seasons.

3.4 Solar energy resource potential.

Power amount of power generated by photovoltaic (pv) panel depends on its surface area (A), efficiency (r)and the solar radiation incident on its surface. (https://photovoltaic-software.com/principle-resources/how-calculate-solar-energy-power-pv-systems/ Photovoltaic software, 2018).

3.4.1 Conversion of solar irradiance from mj/m^2/day to W/m^2

Solar radiation data was converted from mj/m^2/day to W/m^2 using the following equation.

1 mj/m^2/day = $\frac{1{,}000{,}000}{24\times3600} = 11.574 \mathrm{W/m^2}$……………………..……………Equation 2

3.4.2 Computation of the solar resource potential

The equation below was used to estimate the available solar power in the area of study.

$E_A = E_S \times A$…………...…………………………………………….…………Equation 3

Where E_A= Available solar power in watts (W)

E_S=Average solar intensity in W/m^2

A = area in m^2

3.4.3 Computation of the extractable solar power

$E_E = r \times E_A$………Equation……………………………………………………………4

Where, E_E = the extractable solar power in watts (W)

r = conversion efficiency of the solar panel i.e. the ratio of incident energy to that of the output energy. r is approximately 20% (www.greenmatch.co.uk/blog/2014/11/how-effient-are-solar-panels/)

E_A= Available solar power in watts (W)

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 INTRODUCTION

This section presents the results of the various analyses carried out on data and the corresponding discussion of the results. Figures 2 to 5 show single mass curves for sunshine hours, solar radiation, and cloud cover at 0600Z and 1200Z data sets.

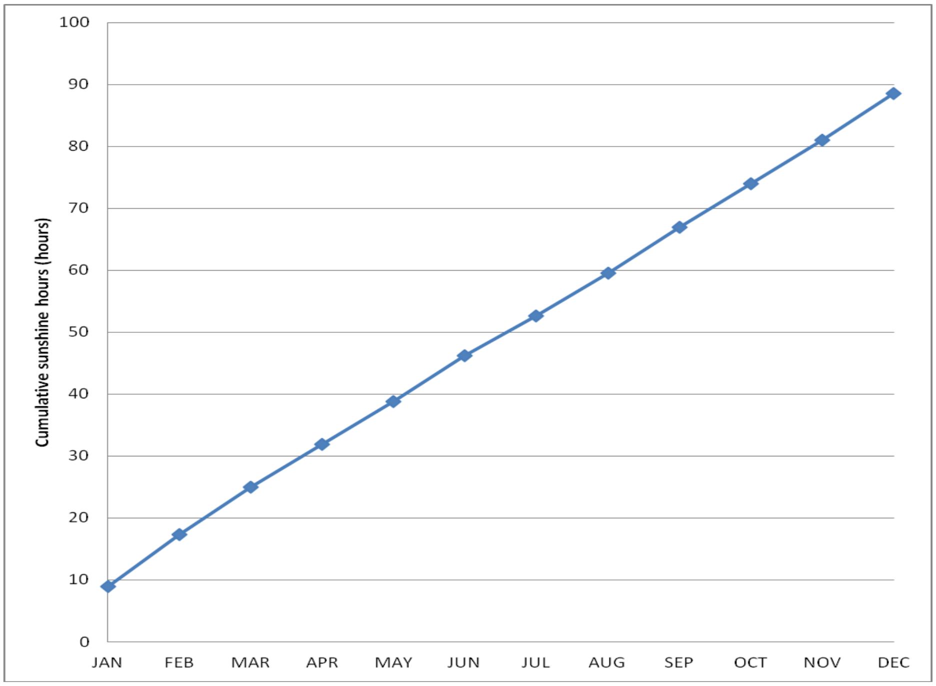

Figure 2: Sunshine hours single mass curve.

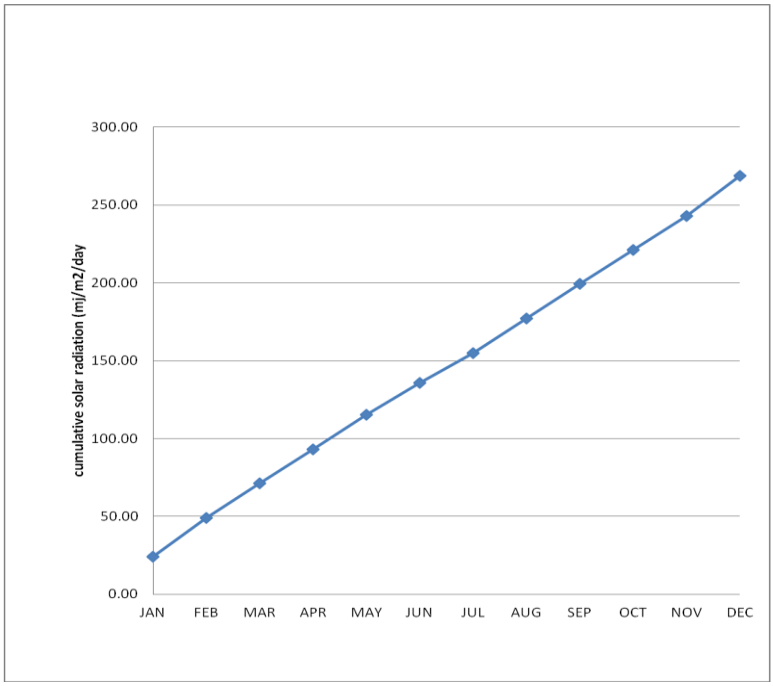

Figure 3: Solar radiation simple mass curve.

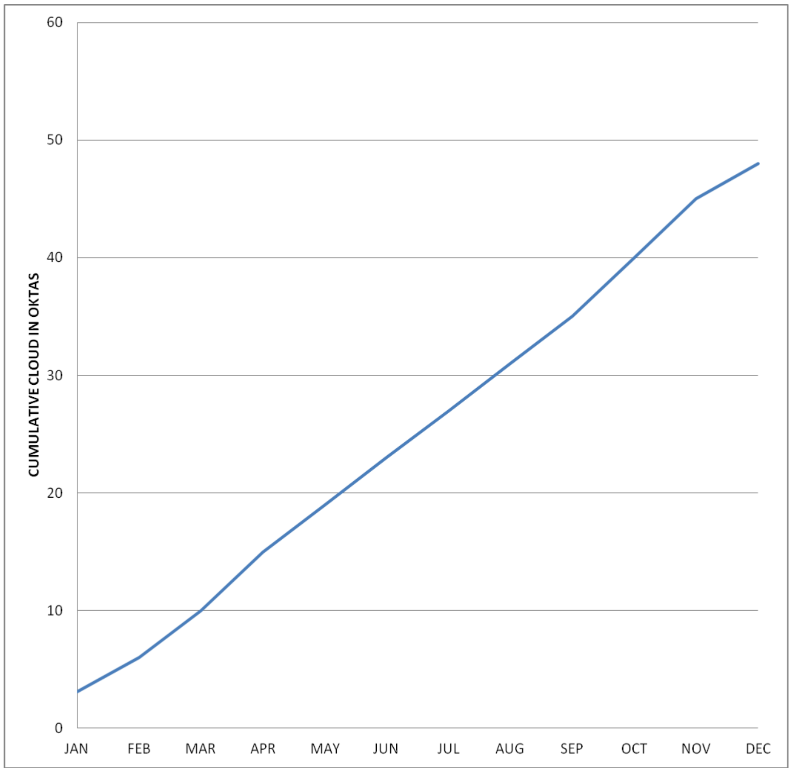

Figure 4: Cloud single mass, 0600Z

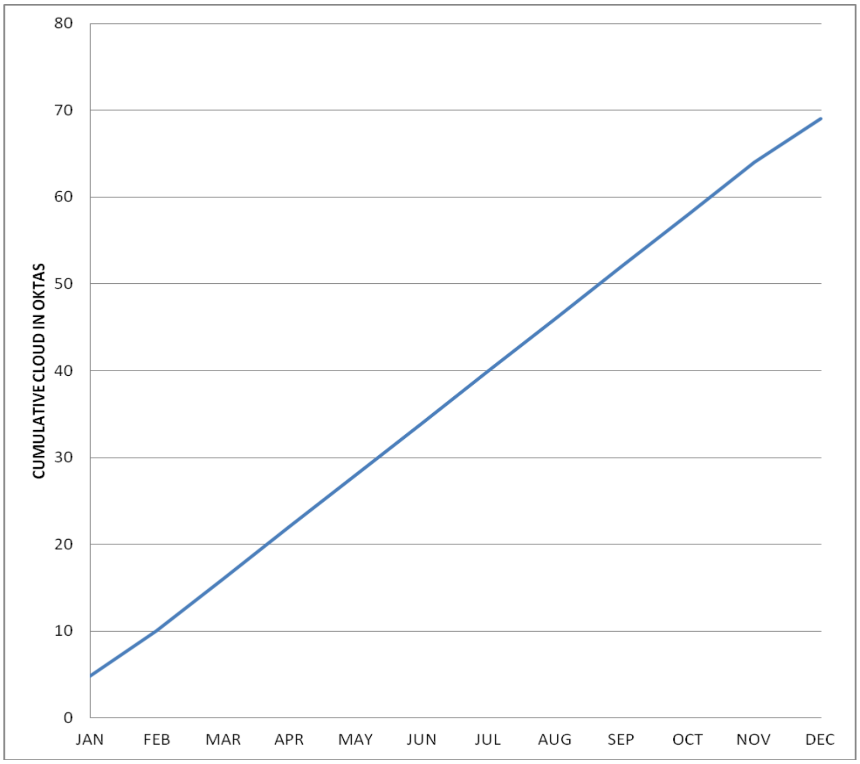

Figure 5: Cloud single mass curve 1200Z

Figures 6 to 9 present time series plots for average monthly solar radiation intensity, sunshine hours, cloud cover at 00600Z and 001200Z.

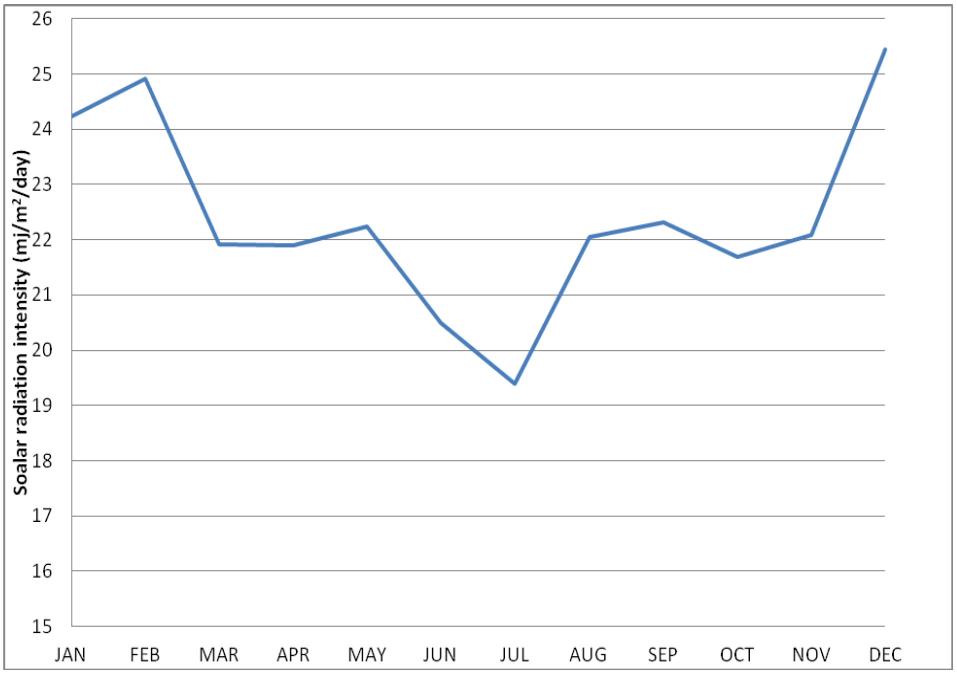

Figure 6:Average Monthly Solar Radiation Intensity.

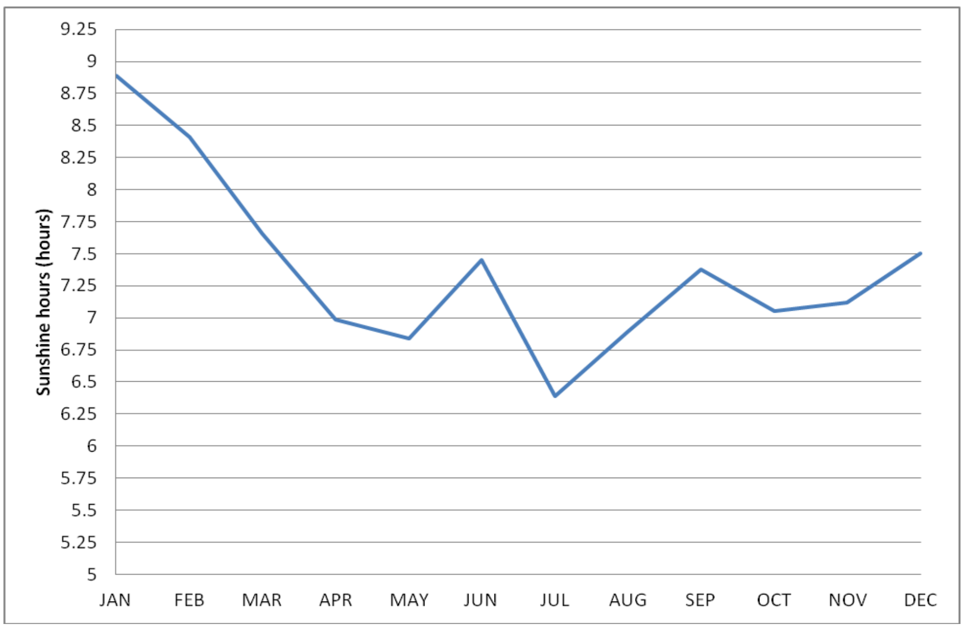

Figure 7:Average Monthly Sunshine Hours.

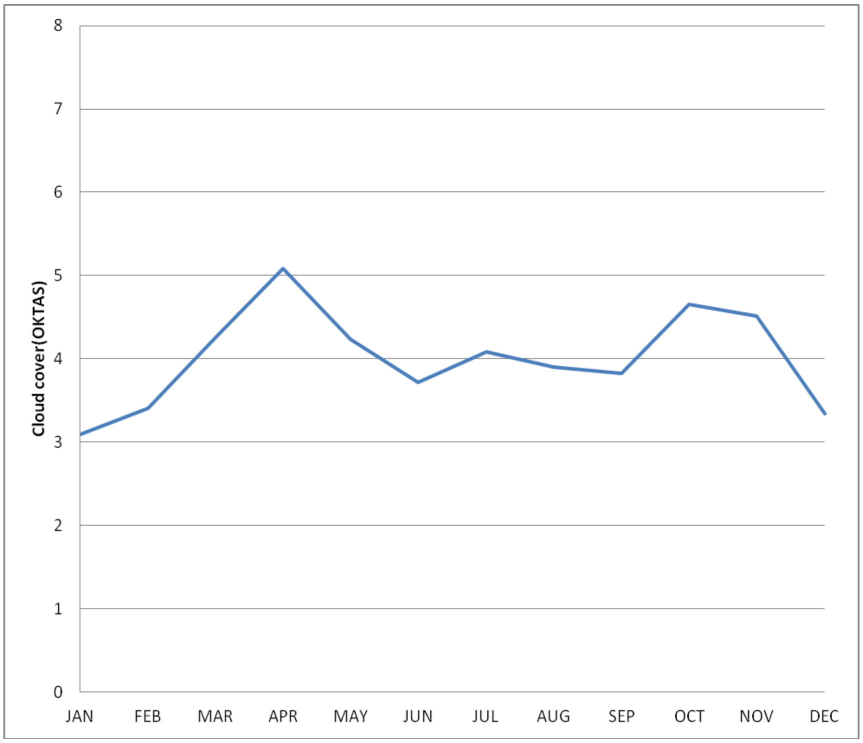

Figure 8: Average Monthly Cloud Cover, 0600Z

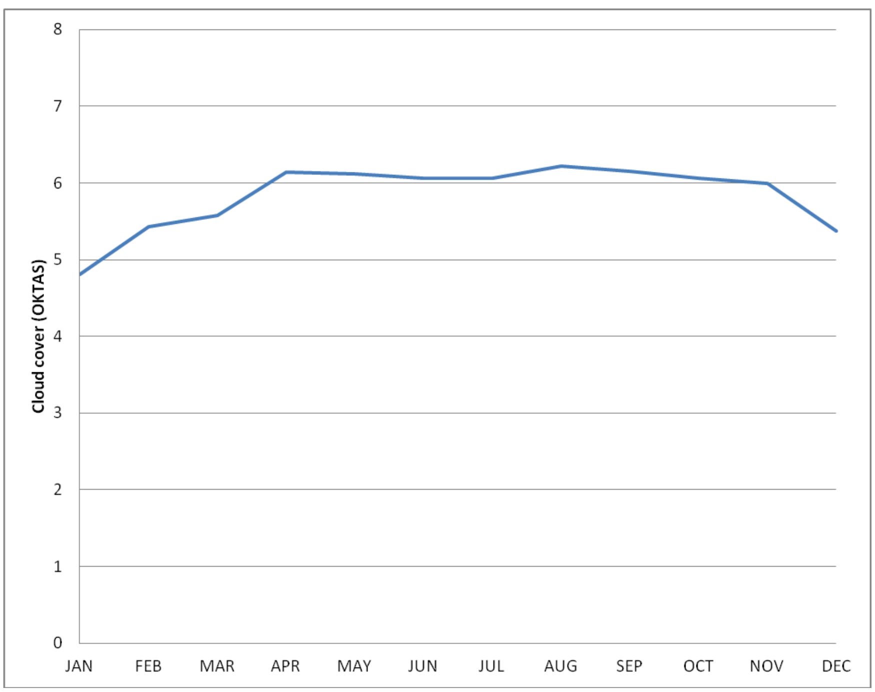

Figure 9: Average monthly cloud cover 1200Z.

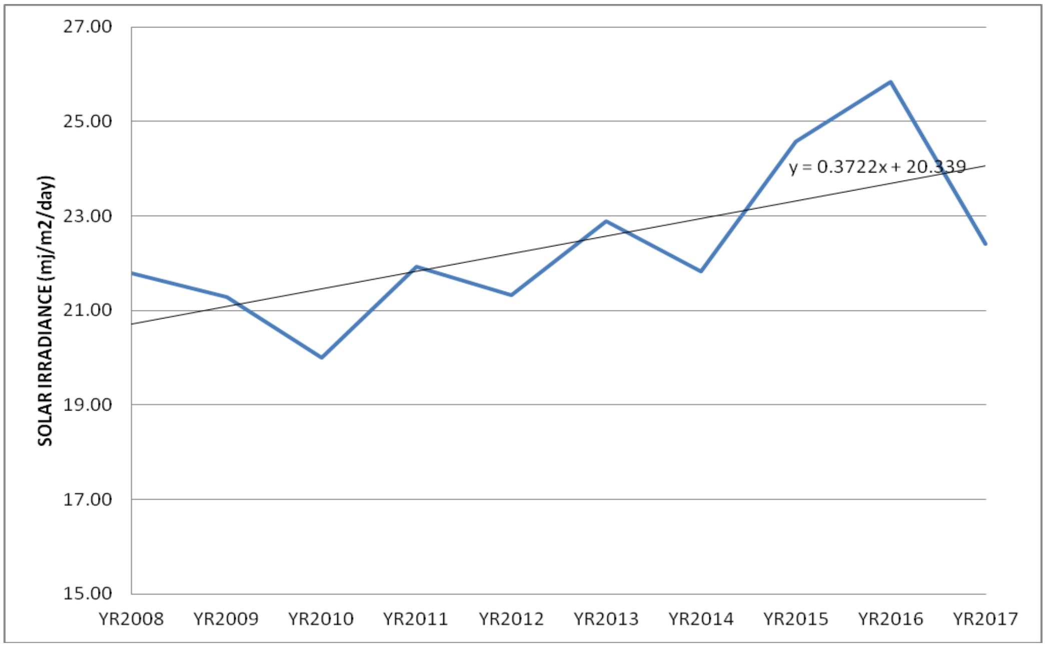

Figure 10: Yearly average solar irradiance

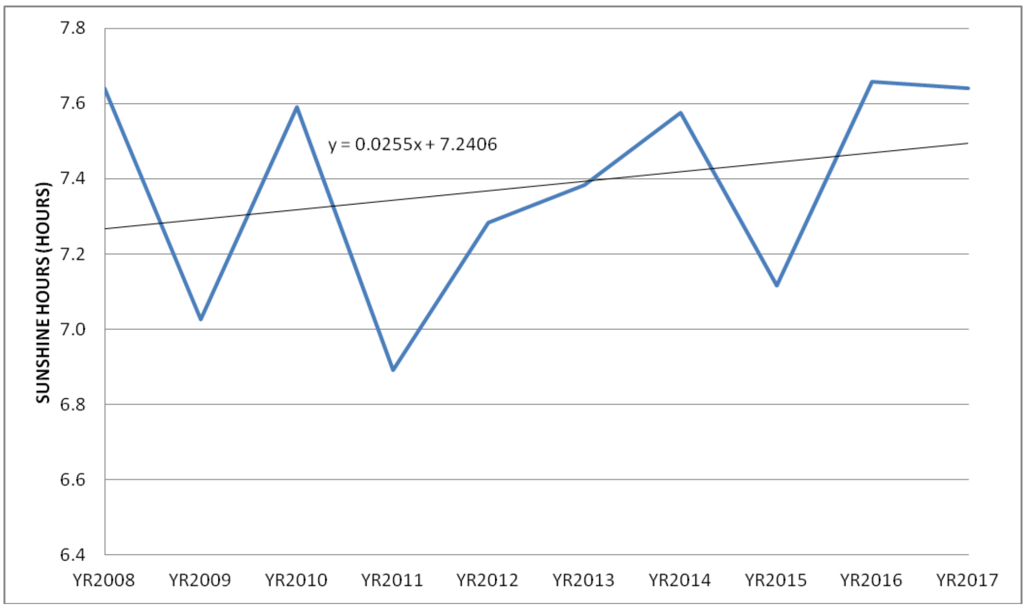

Figure 11: Yearly average sunshine hours.

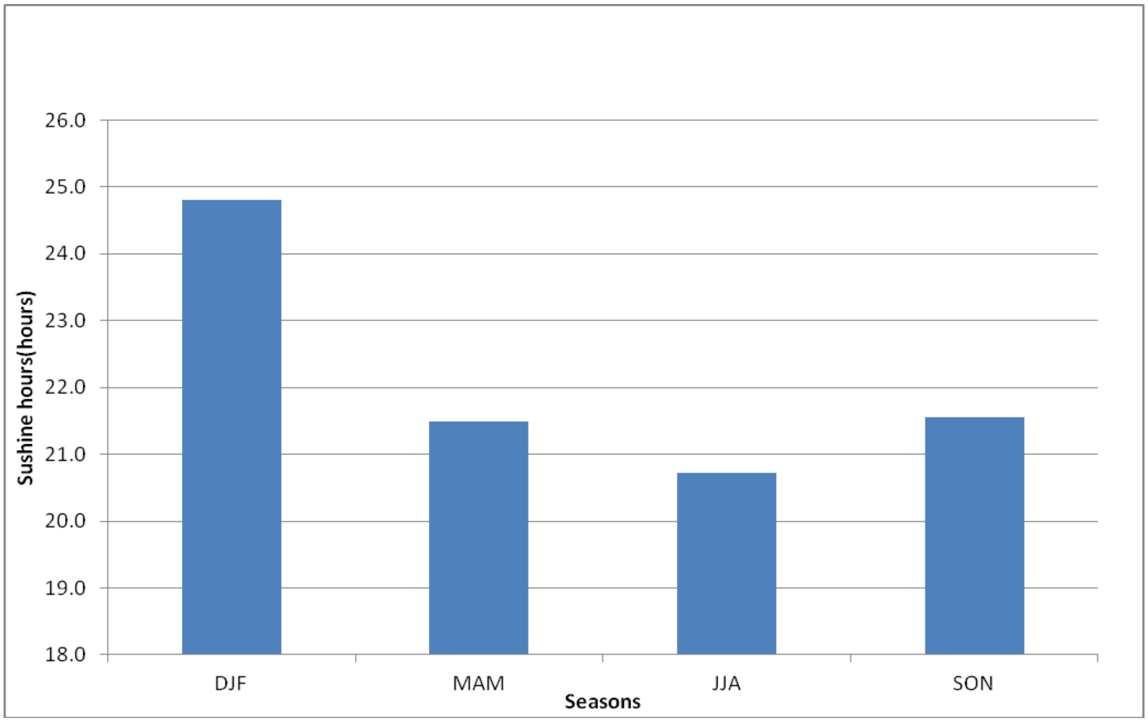

Figure 12: Seasonal sunshine hours

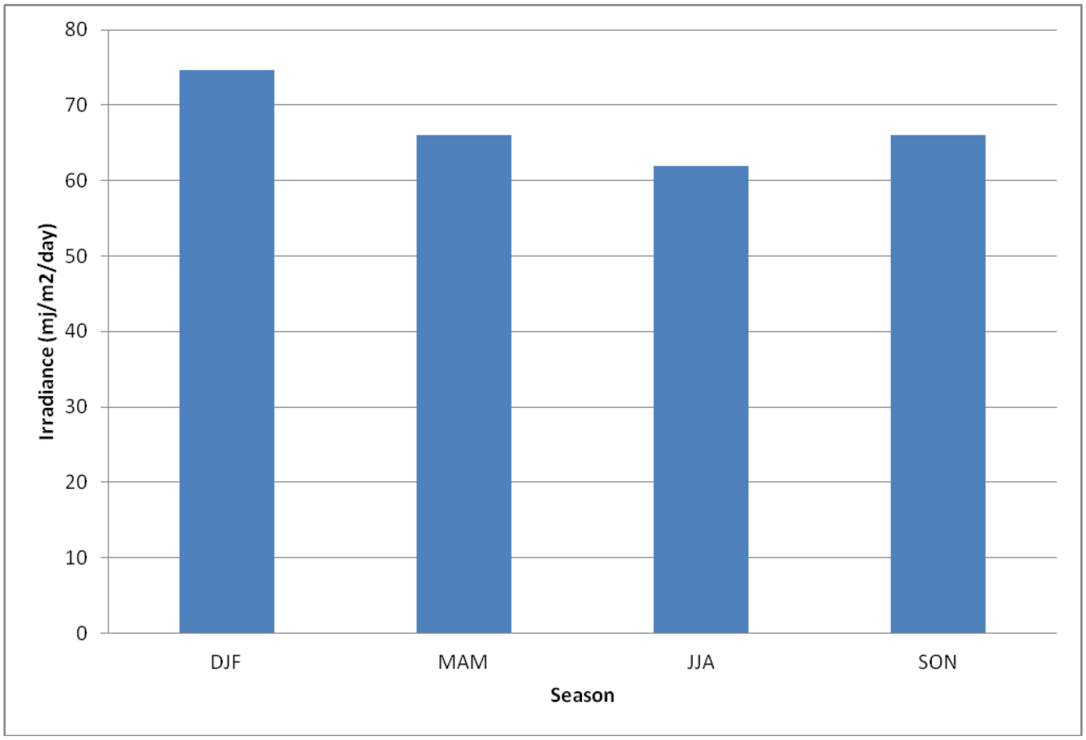

Figure13: Seasonal irradiance

4.4 Discussion

The data used in this study is homogeneous since the single mass curve plots clustered along a straight line except cloud data at 0600Z. The heterogeneity in 0600Z cloud data can be attributed to human error in estimation of the cloud amount. Apart from few stations with automatic Weather Stations (AWS) in other meteorological stations in Kenya cloud assessment is carried out by mere estimation. There are no instruments for measuring cloud amount and height and this can be subjective. The least irradiance (19.4Mj/m^2/day) was observed in July and the highest (25.4 mj/m^2/day) was observed in December. The average insolation per day for the ten years was 21.9 Mj/m^2/day. December-January-February (DJF) records the highest solar irradiance and least in June-July-August (JJA).

It was also observed that average sunshine hours and solar irradiance has been increasing from the year 2008 to 2017.The average available solar power E_A, for the area of study is 21.9×11.574×2.4955GW=632.5GW while the extractable solar power E_E, is 0.2×632.5=126.5GW.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

In this chapter the findings of the study and conclusions arrived at are discussed. Recommendations for further studies are also captured in the chapter.

5.1 Conclusions

The average available and extractable solar power in Trans-Nzoia County was computed and found to be 632.5GW and 126.55GW respectively. It was therefore concluded that the county is endowed with enormous solar energy resource.

5.2 Recommendations

Because of the abundance of the solar energy resource, it is recommended that the residents of Trans-Nzoia County be encouraged to adopt solar energy techniques instead of relying on kerosene, firewood and charcoal for lighting. This enormous resource can also be harnessed for preservation of farm produce (drying grains and chilling milk), cooking, lighting and warming of houses during cold seasons.

Because of the least sunshine hours and solar radiation in JJA season, the households should have rechargeable solar accumulators to store charge to be used during this season and at night throughout the year.

While great potential for harnessing solar radiation in the county exist, more studies should be carried out to investigate the spatial distribution of solar irradiance over the county to capture the topographical variability within the county.

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