ASSESSING THE POTENTIAL FOR SOLAR ENERGY UTILIZATION IN MALAWI

BY

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I45/69981/2013

A RESEARCH PROJECT SUBMITTED IN PARTIAL FULFILLMENT FOR THE AWARD OF THE DEGREE OF POSTGRADUATE DIPLOMA IN METEOROLOGY, UNIVERSITY OF NAIROBI

JULY, 2014
DECLARATION

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

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This research project has been submitted with our approval as university supervisors.

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SIGN. ______________________________ DATE: 12/08/2014

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DEDICATION

With heartfelt appreciation, I dedicate this study to my family who has labored tirelessly with patience and perseverance during the entire period of my absence.
ACKNOWLEDGEMENTS

First and foremost, I would like to pass my sincere gratitude to the ALMIGHTY GOD for the gift of life and having given me the strength and sound mind through the process of my study.

Secondly, I pass gratitude to my supervisors, Dr. Christopher Oludhe and Dr. R.E Okoola for their invaluable guidance and tireless support during the entire project period.

I would also pass my gratitude to the entire staff of University of Nairobi Department of Meteorology, Chiromo Campus, and all colleagues for their contribution towards my study.

It is wealthy for me to extend my gratitude to Malawi government through Department of Climate Change and Meteorological Services (DCCMS) for granting me the scholarship to study Meteorology at University of Nairobi.

Finally, I wish to thank my family and friends for their encouragement and support throughout this course.
ABSTRACT

Energy is very important for the development of any country in this world and Malawi is not exceptional. Malawi depends mainly on the Hydro Electric Power, fossil fuels and biomass on its energy sources for social economic and industrial activities. Due to increase in demand, Electricity Supply Corporation of Malawi (ESCOM) has more pressure to supply the power to increased number of industry and domestic use which lead to more frequent blackouts throughout the country. In this regard there is need for an alternative source of energy, and solar energy is the most common and easy to get.

The main objective of this study is to assess the potential for solar energy generation over Malawi, results of which would lead to harnessing solar energy in the country. The monthly mean sunshine hours and solar radiation values for the period of 30 years from 13 sites were analyzed in this study.

Monthly and seasonal variations of sunshine hours and solar radiation were determined. Long time trend were also determined. The analysis has shown that there is higher solar energy potential in the Northern, Lakeshore, Central areas and the Southern tip of southern region. The analysis has also shown that most of the areas in the Southern highlands of Malawi have low solar energy potential. The study further show that there is seasonal variation of solar radiation within the season of the year; March, April, May, August, September, October and November being the months of highest solar radiation utilization while December, January, June and July has lower solar radiation utilization potentials.

This research recommends the people in the area of study to put into consideration in this form of energy. They should invest and use solar energy as a reliable source of energy more especially in the rural areas where only 1% of the population has access to Electricity. More research needs to be done in order to get accurate estimate of available solar energy in Malawi more especially at regional and districts levels.
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</tr>
<tr>
<td>CAB</td>
<td>Congo Air Boundary</td>
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<td>DC</td>
<td>Direct current</td>
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<td>Department of Climate Change and Meteorological Services</td>
</tr>
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<td>Electricity Supply Corporation of Malawi</td>
</tr>
<tr>
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<td>Global Domestic Product</td>
</tr>
<tr>
<td>ICT</td>
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</tr>
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<td>InterTropical Convergence Zone</td>
</tr>
<tr>
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CHAPTER ONE

1. INTRODUCTION

1.1 Background
Renewable energies are the forms of energy which are inexhaustible, clean and they can be used in a decentralized way, that is to say; they can be used in the same place as they are produced. They have the additional advantage of being complimentary, the integration between them being favorable. These energies are also known as green or alternative energies. Solar energy is a notable example of renewable energy resources. Solar Energy involves harnessing the radiant light energy emitted by the sun and converts it into electrical current. The main source of this energy is the Sun. The Sun provides light, heat and radiation to the Earth and other planets. Among other uses, solar Energy can be used for lighting, heating, drying and generating electricity.

Malawi being located in the tropics where there the intense heating exits on earth can have a great opportunity as far as the utilization of the resource is concerned. This energy can supplement the exiting Hydro Electrical power, which is currently the main source of power. The population of Malawi is now 14.9 million, with an estimated growth rate of 2.8%. Only 9.8% of population has access to electricity. 87% of energy is from biomass in form of firewood, therefore serious deforestation and Environmental degradation. Regarding Electricity, the total installed power generation capacity is 287MW. The majority of this power is generated from hydro Electrical power station (99%) mainly from Shire River. Power transmission is at 132kV and 66kV and only extends to major cities. Power distributed to rural areas is done through 33kV and 11kV lines. Nationally, electricity access rate is at 8% while in rural areas, access rate is less than 1%.

1.2 Solar Energy systems
There are many ways in which people can tap the sun as an energy source. They can use the sun’s rays to heat things such as the water for their homes through solar thermal energy. They can use solar energy to turn light from the sun directly into electricity using photovoltaic (PV). Two other ways include daylighting, which is the practice of using natural light to illuminate indoor spaces, and passive solar space heating, which captures the sun’s heat within the building’s elements and releases that heat during periods when the sun is not shining.
The most common solar energy installations used for homes are solar electric systems (PV) and solar hot water heaters.

1.2.1 Solar Hot Water Systems
Solar hot water systems can be a cost-effective way to generate hot water for anyone’s home. Due to the cold winters, homeowners can use an “active” and “closed loop” solar hot water system. Active systems use electric pumps to circulate a fluid with a low freezing point through specially-designed collector panels on a roof building. The fluid is heated by the sunlight as it passes through the collector panels and then directed to a heat transfer unit where it warms the cool water heading into the household hot water tank. The “closed loop” means that the special fluid then returns to the pump and again flows into the solar collector on a roof building without ever mixing with the home’s water.

1.2.2 Solar Electric Systems
Solar electric systems provide clean and safe electricity for a lot of people’s home. Solar panels are installed on a northern-exposed roof to maximize their sun exposure, and they convert sunlight into direct current (DC) electricity. The panels then route power through an inverter to convert it into alternating current (AC) electricity and distribute the power throughout the people’s home. Solar electric systems are durable: typical PV systems have 25-year warranties and may last 40 years with minimal maintenance.

1.3 Problem Statement
Malawi depends mainly on the Hydro Electric Power, fossil fuels and biomass on its energy sources for social economic and industrial activities. Due to increase in demand, Electricity Supply Corporation of Malawi (ESCOM) has more pressure to supply the power to increased number of industry and domestic use which lead to more frequent blackouts throughout the country. The blackouts have negative impacts on the day to day life and the development of Malawi as a Country. Due to climate change which has resulted to the occurrence of drought, the power generation had been reduced because of the reduction of water levels in the Lake Malawi, Shire River and Nkula dam. To solve the current power shortage problem, venturing into renewable energy resources more especially solar energy will increase the power production, and reduced deforestation and Environmental degradation which is there due to the use of firewood and charcoal.
1.4 Objective of the Study
The main objective of this study is to assess the potential for solar energy generation over Malawi.

The specific objectives are as follows,

(i) To determine the temporal variability of solar radiation and sunshine hours over the area of study
(ii) To determine the spatial distribution of solar radiation and sunshine hours over the area of study
(iii) To determine the trend of both sunshine and solar radiation.
(iv) To map potential areas where the solar energy can be harnessed over the area of study.

1.5 Justification of the Study
Malawi as a country experiences a massive blackouts. This is due to insufficient power from Hydro-Electrical Power Station at Nkula. The use of biomass sources such as charcoal and firewood lead to serious deforestation and Environmental degradation. Climate change, energy security and looming energy gaps that exits between rural and urban areas are all driving the research and development into clean, renewable energy supplies and solar energy is the most common and easy to get. Nowadays, engineers and scientists are finding out on the ways to harness the sunlight to help meet the demand for electricity demand to mitigate all of these potential problems.
1.6 Area of Study
1.6.1 Geography of the Study Area

Malawi, officially the Republic of Malawi, is a landlocked country in southeast Africa that was formerly known as Nyasaland. It is lying between latitudes 9 and 17°S and longitudes 32 and 36°E. It is bordered by Zambia to the northwest, Tanzania to the northeast, and Mozambique on the east, south and west. The country is separated from Tanzania and Mozambique by Lake Malawi. Malawi is over 118,000 km$^2$ with an estimated population of more than 14,900,000.

*Figure 1: Geographical position of Malawi from the map of Africa.*
1.6.2 Climatology of the Study Area

Malawi experiences a tropical type of climate with two seasons, namely the rainy season and the dry season. The rainy season is experienced from November of one year to April of the next year while the dry season is experienced from May to October. Summers are generally hot and wet while winters are cool and dry. The warm-wet season, 95% of the annual precipitation takes place. In a cool, dry winter season the country experience the mean temperatures varying between 17 and 27 degrees Celsius, with temperatures falling between 4 and 10 degrees Celsius. A hot, dry season lasts from September to October with average temperatures varying between 25 and 37 degrees Celsius. Humidity ranges from 50% to 87% for the drier months of September/October and wetter months of January/February respectively.

During winter Malawi is influenced by a divergent southeasterly airmass driven by high pressure cells southeast of Africa. A strong high pressure cell over the eastern South African coast draws a cool moist easterly airmass into the country causing overcast conditions with drizzle over highlands and east facing escarpments near Lake Malawi, locally called "chiperoni". These weather conditions usually last for two to three days.

In summers, Malawi is usually being affected by a broad belt of a strong convective activity during the rainy season. This belt is known as InterTropical Convergence Zone (ITCZ), which is the main rain bearing system, marks the converging point of northeasterly monsoon of the Northern Hemisphere and the southeasterly trade winds of the Southern Hemisphere. The belt invades the country from the north on its southwards movement to its southern limit in February and then moves back to the north. The other main rain bearing system for Malawi weather during the rainy season is the Congo Air Boundary (CAB) which marks the confluence between the Indian Ocean southeast trades and recurved South Atlantic air that reaches Malawi as northwesterly airmass through the Democratic Republic of Congo. This system brings well-distributed rainfall over the country and even floods may be experienced in some areas especially if it is associated with the ITCZ. There are times when the country is affected by tropical cyclone originating from the Indian Ocean. Depending on its position over the Indian Ocean, a cyclone may result in having either a dry or a wet spell over Malawi. The other weather features of significance are easterly and westerly waves, and temperate weather systems. The extra tropical waves are normally active during the start and end of the rainy season.
CHAPTER TWO

2.0 LITERATURE REVIEW

The energy from the sun is in the form of low heat intensity and light. A lot of studies have been done on solar resources and the potential of harnessing it. From early 1970’s due to the energy crisis which had faced the whole world, this had accelerated research into alternative sources of energy besides the conventional types.

Energy is the main driver of social economic development of any country. It is important as it plays an essential role in the Gross Domestic Product (GDP) of most of the country, Malawi inclusive. The sun is the source of virtually all the energy that we use every day. The energy we derive from wood fuel, paraffin, hydroelectricity and even our food originates indirectly from the sun (Hankins, 1991).

The importance of energy in development that has raised an increased interest in renewable energy in the region due to is the crises faced by most power utilities in the region. For example, in year 2000, Ethiopia, Kenya, Malawi, Nigeria and Tanzania faced unprecedented power rationing which adversely affected their economies. The rapid development of renewable energy is often mentioned as an important response option for addressing the power problems faced by the region (Karekezi, 1997).

The total amount of solar power reaching the surface of the earth in one hour on a cloudless day is about 6.46X10^{20}J which is equivalent to 1.9X10^{13}Kg of charcoal; we are assuming that in one hour 1 Kg of charcoal supplies 3.4X10^{7}J. In tropical areas throughout the year, it is approximately that 900 watts of solar radiation falls on one square meter on a cloudless day (Kivaisi, 1977). This is typical in tropical areas through the year.

Lack of electricity has contributed to the lack of internet facilities in rural areas. Mobile phone service providers hesitate to build capacity in rural areas. “Underutilization of solar energy is depriving rural areas of an opportunity to access information through ICT. Social and economic development is inseparable from scientific and technological advances. Africa has lagged behind in technology and harvesting solar energy to use development programs.” (Munyeme, 2003).
In his findings Okoola, (1982) on his solar energy project work over Kenya, he concluded that the availability of solar energy country wide is enough for it to be utilized for solar Energy power models. The solar radiation which is available on the earth’s surface is confined to be in shortwave radiation of range $3 \times 10^{-6} \text{m}$- $2.5 \times 10^{-6} \text{m}$.

Solar energy is a very large, inexhaustible source of energy. The power from the sun intercepted by the earth is approximately $1.8 \times 10^{11} \text{MW}$, which is many thousands of times larger than the present consumption rate on the earth of all commercial energy sources. Thus, in principle, solar energy could supply all the present and future energy needs of the world on a continuing basis. This makes it one of the most promising of the unconventional energy source. In addition to its size, solar energy has two other factors in its favour. Firstly, unlike fossil fuels and nuclear power, it is an environmental clean source of energy. Secondly, it is free and available in adequate quantities in almost all parts of the world where people live (Sukhatme, et al., 1996).

The use of solar Energy is widely available today; this is due to the fact that the sun will always shine on earth. What we need is the devices that can capture the sun’s rays and convert those rays into energy. It is also a need for us to store the solar energy for future use. The only problem that exits with the solar energy is if a day is cloudy (overcast) or it is night, you don’t have power (Twidell and Weir, 2005). However, the energy is best utilized with other backup systems such as battery (lead or acid).

These views, findings and facts can significantly help us to see that there is a high potential of solar energy in the tropics and Malawi inclusive.
CHAPTER THREE

3.0 DATA AND METHODOLOGY

3.1 Data
The data used in this study include observed monthly sunshine hours and solar radiation for the period of 30 years. The period covers from 1983 to 2013. The sources of the data are stated in the following subsections.

3.1.1 Sunshine hours data
Monthly sunshine hours data from 1983 to 2013 was considered. The data was obtained from Department of Climate Change and Meteorological Services (DCCMS) Headquarters in Malawi from 13 stations. The Table 1 below shows the stations.

Table 1: Table of Sunshine and solar radiation stations

<table>
<thead>
<tr>
<th>NO.</th>
<th>NAME OF STATION</th>
<th>SYNOPTIC CODE</th>
<th>LATITUDE</th>
<th>LONGITUDE</th>
</tr>
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<tr>
<td>3</td>
<td>NKHOTAKOTA</td>
<td>67591</td>
<td>-12.92</td>
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</tr>
<tr>
<td>4</td>
<td>SALIMA</td>
<td>67597</td>
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</table>
3.1.2 Solar radiation data
Monthly solar radiation data were obtained from National Aeronautics and Space Administration (NASA) data archives freely available at http://power.larc.nasa.gov/cgi-bin/cgiwrap/solar/timeseries.cgi?email=daily@larc.nasa.gov for daily solar radiation and https://eosweb.larc.nasa.gov/cgi-bin/sse/interann.cgi?email=skip@larc.nasa.gov for Monthly averaged solar radiation from 1983 to 2013. The coordinates in Table 1 above were used to extract the data from the archives.

3.2. Data Quality Control
Meteorological and climatological data need to meet certain standards for it to be effectively used. This involves looking for errors in the acquired data ranging from storage media problem to data inhomogeneity and inconsistency. Single mass curve analysis was used to test for homogeneity or consistency of the data records. For the purpose of eliminating data contamination; the outlier detection, keypunch errors, illegal data filter programs, detection of outliers sample and detection leverage points in sample linear regression was used. The common sources of errors are due to Observation, recording and station condition.

3.2.1 Estimation of Missing Data
The missing data in this study was estimated using arithmetic mean method that involves replacing missing record with the average values for a given station. For the efficient results to be achieved the estimated data did not exceed 10% of the total data. The following formula was used.

\[ \bar{X} = \frac{1}{n} \sum_{i=1}^{n} X_i \]  \hspace{1cm} (1)

The equation (1) above; \( \bar{X} \) is the long term mean of solar radiation or sunshine hours; and \( n \) is the number of years, i.

3.2.2 Mass Curve Analysis
In testing solar radiation and Sunshine Hours data, the single massive curve was used. Cumulative values (\( Y_t \)) of observation (\( X_t \)) plotted against time, t. For homogeneous records, \( Y_t \) values produced a single straight line. If \( X_t \) values were heterogeneous, more than one line could be fitted to the \( Y_t \) scatter diagram. The method is used to deal with inhomogeneous and was used to extrapolate the months or years missing data. It also provided the correlation factor of the data.
3.3 Methodology
In order to successfully achieve the main objective of this study, as outlined in section 1.4, the following methods were used.

3.3.1 Time Series Analysis
A time series is a collection of observations of well-defined data items obtained through repeated measurement over time. It represents the set of data at equal interval of specific time. It was used to study the variability of mean monthly solar radiation and average monthly sunshine characteristics by detecting trend within seasons. Examination of the trend component in any time series analysis is significant since it will show whether the time series is stationary or non-stationary. The mean monthly radiation values and also average monthly sunshine were computed from the daily radiation records. Mathematically, time series can be expressed as values of a given variable with respect to time.

\[ Y_t = F(t) \] ...... .......................................................... .......................................................... .......................................................... .......................................................... .......................................................... .......................................................... .......................................................... .......................................................... ................................... (2)

The equation (2) above; \( Y_t \) are the values of mean monthly solar radiation and average monthly sunshine for time \( t \) from the year 1983 to 2013. Upon plotting, the \( Y \) against time \( t \) gives a time series graph that shows the variation of \( Y \) with time.

3.3.2 Trend Analysis
Most naturally-occurring time series in Meteorological and Climatological data are not at all stationary. Instead they exhibit various kinds of trends, cycles, and seasonal patterns. The equation below will be used to establish the patterns.

\[ Y(t) = \alpha + \beta X \] ...... .......................................................... .......................................................... .......................................................... .......................................................... .......................................................... .......................................................... .......................................................... ................................... (3)

The equation (3) above; \( t \) is the time index. The parameters alpha and beta (the "intercept" and "slope" of the trend line) are usually estimated via a simple regression in which \( Y \) is the dependent variable and the time index \( t \) is the independent variable.

3.3.2.1 Trend Significance
The significance of the observed trends for the sunshine hours and solar radiation were tested using the student t-test method. The equation for student t-test is shown below.
\[
t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}
\]

The equation (4) above, \(\bar{X}_1\) is the mean of first set of values, \(\bar{X}_2\) is the mean of second set of values, \(S_1^2\) is the standard deviation of first set of values, \(S_2^2\) is the standard deviation of second set of values, \(n_1\) is the total number of values in first set, \(n_2\) is the total number of values in second set.

### 3.3.3 Correlation Analysis

Correlation analysis measures the relationship between two Variables. It was used to investigate the strength of the relationship between the average monthly sunshine and monthly solar radiation intensity for all the months. The measure of degree of association between these two data sets is the correlation coefficient which can also be used in determining the characteristics of solar radiation. A strong, or high, correlation means that two or more variables have a strong relationship with each other while a weak, or low, correlation means that the variables are hardly related. The equation below was used.

\[
r_{XY} = \frac{s_{XY}}{S_X S_Y}
\]

The equation (5) above, \(r_{XY}\) is the correlation coefficient;

\(S_{XY}\) is the covariance (X, Y), and is expressed as:

\[
s_{XY} = \frac{1}{n} \sum_{i=0}^{n} (x_i - \bar{x})(y_i - \bar{y})
\]

\(S_x\) is the standard deviation of \(X_i\), and is expressed as:

\[
S_x = \left( \frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2 \right)^{\frac{1}{2}}
\]

\(S_y\) is the standard deviation of \(Y_i\), and is expressed as:

\[
S_y = \left( \frac{1}{n} \sum_{i=1}^{n} (y_i - \bar{y})^2 \right)^{\frac{1}{2}}
\]
The equation (6) above; $x_i$ is mean monthly solar radiation in kWh/m$^2$/day, $\bar{x}$ is the long term mean for the solar radiation, $y_i$ is average monthly sunshine in hours and $\bar{y}$ is long term mean for monthly sunshine, $n$ is the number of years, $i$ for all variables from 1 to $n$.

### 3.3.3.1 Correlation Significance
The correlation significance of the sunshine hours and solar radiation data were tested using the student t-test method. The equation for student t-test as follows:

$$t = \sqrt{\frac{(n-2)}{\sqrt{1-r^2}}}$$

The equation (9); $t$ is the computed t value, $r$ is the correction coefficient, $n$ is the number of observation years.

### 3.3.4 Spatial Analysis and Mapping
Mapping the potential areas, the Surfer computer application Software was used. Surfer is a sophisticated interpolation engine that transforms XYZ data into publication-quality maps. It provides more gridding methods and more control over gridding parameters, including customized variograms.
CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

This chapter contains discussion of the results obtained from the various analyses which were used in this study.

4.1 Data quality control

4.1.1 Estimation of missing data
In this study there were missing data in the sunshine hours and solar radiation data sets which contributed to less than 10% of the total observations. Estimation of missing data was therefore necessary and therefore Arithmetic Mean Method was applied.

4.1.2 Homogeneity test of Sunshine and solar radiation data
After filling in the missing data, the data sets were then subjected to homogeneity test. Test for homogeneity for all the sunshine hours stations and solar radiation therefore were done using the single mass curve method where cumulated data of sunshine hours or solar radiation were plotted against time in years. The results obtained are as follows.

The Figure 2 below represents the single mass curves for Chitipa. The graphs show that the data used were homogenous and therefore fit for further statistical analysis.

![Figure 2: Sunshine and Solar radiation Single mass curves for Chitipa.](image)
The Figure 3 below represents the single mass curves for Mzimba. The graphs show that the data used were homogenous and therefore fit for further statistical analysis.

**Figure 3: Sunshine and Solar radiation Single mass curves for Mzimba.**

The Figure 4 below represents the single mass curves for Nkhotatota. The graphs show that the data used were homogenous and therefore fit for further statistical analysis.

**Figure 4: Sunshine and Solar radiation Single mass curves for Nkhotakota.**
The Figure 5 below represents the single mass curves for Salima. The graphs show that the data used were homogenous and therefore fit for further statistical analysis.

**Figure 5: Sunshine and Solar radiation Single mass curves for Salima.**

The Figure 6 below represents the single mass curves for Chitedze. The graphs show that the data used were homogenous and therefore fit for further statistical analysis.

**Figure 3: Sunshine and Solar radiation Single mass curves for Chitedze.**
The Figure 7 below represents the single mass curves for Dedza. The graphs show that the data used were homogenous and therefore fit for further statistical analysis.

![Figure 7: Sunshine and Solar radiation Single mass curves for Dedza.](image)

The Figure 8 below represents the single mass curves for Makoka. The graphs show that the data used were homogenous and therefore fit for further statistical analysis.

![Figure 8: Sunshine and Solar radiation Single mass curves for Makoka.](image)
The Figure 9 below represents the single mass curves for Mangochi. The graphs show that the data used were homogenous and therefore fit for further statistical analysis.

Figure 9: Sunshine and Solar radiation Single mass curves for Mangochi.

The Figure 10 below represents the single mass curves for Chichiri. The graphs show that the data used were homogenous and therefore fit for further statistical analysis.

Figure 10: Sunshine and Solar radiation Single mass curves for Chichiri.
The Figure 11 below represents the single mass curves for Mimosa. The graphs show that the data used were homogenous and therefore fit for further statistical analysis.

**Figure 11: Sunshine and Solar radiation Single mass curves for Mimosa.**

The Figure 3 below represents the single mass curves for Bvumbwe. The graphs show that the data used were homogenous and therefore fit for further statistical analysis.

**Figure 12: Sunshine and Solar radiation Single mass curves for Bvumbwe.**
The Figure 13 below represents the single mass curves for Chileka. The graphs show that the data used were homogenous and therefore fit for further statistical analysis.

Figure 13: Sunshine and Solar radiation Single mass curves for Chileka.

The Figure 14 below represents the single mass curves for Ngabu. The graphs show that the data used were homogenous and therefore fit for further statistical analysis.

Figure 14: Sunshine and Solar radiation Single mass curves for Ngabu.
4.2 Data analysis results

4.2.1. Results for determining the temporal variability of solar radiation and sunshine hours over the area of study.

The analysis was done to examine the temporal variability of both the sunshine hours and solar radiation over the study area. Time series analysis was used. The total monthly average for the period of 30 years; 1983 to 2013 were obtained and being plotted as follows.

![Graph showing solar radiation and sunshine hours temporal variations for Chitipa.]

**Figure 15: Sunshine and Solar radiation Temporal variations for Chitipa.**

The Figure 15 above shows that there more solar radiation and sunshine hours in other months comparing to other months. September, October and November records highest amount of solar radiation while December, January, February, June and July indicates the lowest. In terms of sunshine hours December, January, February and March have lowest number of sunshine hours. There is an increase in sunshine hours from April to August. The graph further shows decrease in sunshine hours in September and pick up August.
**Figure 16:** Sunshine and Solar radiation temporal variations for Mzimba.

The Figure 16 above shows that there more solar radiation and sunshine hours in other months comparing to other months. August, September, October and November records highest amount of solar radiation while December, January, June and July indicates the lowest. In terms of sunshine hours December, January, February and March have lowest number of sunshine hours. There is an increase in sunshine hours from April to May. The graph further shows decrease in sunshine hours in July and pick up from August to November.

**Figure 17:** Sunshine and Solar radiation temporal variations for Nkhotakota.
The Figure 17 above shows that there more solar radiation and sunshine hours in other months comparing to other months. August, September, October and November records highest amount of solar radiation while December, January, February, June and July indicates the lowest in terms of radiation. In terms of sunshine hours December, January, and February have lowest number of sunshine hours. There is an increase in sunshine hours from March to May. The graph further shows a constant flow in May, June and July and pick up from August to November.

**Figure 18: Sunshine and Solar radiation temporal variations for Salima.**

The Figure 18 above shows that the solar radiation has two picks; the first and smaller pick in March and April and the highest pick in August to November. The graph indicates December, January, February, June and July as the period of low solar radiation. In terms of sunshine hours December, January, and February have lowest number of sunshine hours. There is an increase in sunshine hours from March to May. The graph further shows a drop in sunshine hours in July and pick up from August to November.
Figure 19: Sunshine and Solar radiation temporal variations for Chitedze.

The Figure 19 above shows that the solar radiation has two picks; the first and smaller pick in March and April and the highest pick in August to November. The graph indicates December, January, February, June and July as the period of low solar radiation. In terms of sunshine hours December, January, and February have lowest number of sunshine hours. There is an increase in sunshine hours from March to May. The graph further shows a drop in sunshine hours in June and July and pick up from August to November.

Figure 20: Sunshine and Solar radiation temporal variations for Dedza.
The Figure 20 above shows that the solar radiation has two picks; the first and smaller pick in March and April and the highest pick in August to November. The graph indicates December, January, February, June and July as the period of low solar radiation. In terms of sunshine hours December, January, and February have lowest number of sunshine hours. There is an increase in sunshine hours from March to May. The graph further shows almost constant sunshine hours in May, June and July and pick up from August to November.

\[\text{Figure 21: Sunshine and Solar radiation temporal variations for Makoka.}\]

The Figure 21 above shows that the solar radiation has two picks; the first and smaller pick in February to April and the highest pick in August to December. The graph indicates January, June and July as the period of lower solar radiation. In terms of sunshine hours December, January, and February have lowest number of sunshine hours. There is an increase in sunshine hours from March to May. The graph further shows decrease in sunshine hours in June and July and pick up from August to November.
Figure 22: Sunshine and Solar radiation temporal variations for Mangochi.

The Figure 22 above shows that the solar radiation has two picks; the first and smaller pick in February to April and the highest pick in August to December. The graph indicates January, June and July as the period of lower solar radiation. In terms of sunshine hours December, January, and February have lowest number of sunshine hours. There is an increase in sunshine hours from March to May. The graph further shows decrease in sunshine hours in June and July and pick up from August to November.

Figure 23: Sunshine and Solar radiation temporal variations for Chichiri.
The Figure 23 above shows that the solar radiation has two picks; the first and smaller pick in January to May and the highest pick in August to December. The graph indicates June and July as the period of lower solar radiation. In terms of sunshine hours December, January, and February have lowest number of sunshine hours. There is an increase in sunshine hours from March to May. The graph further shows decrease in sunshine hours in June and July and pick up from August to November.

![Graph showing solar radiation and sunshine hours](image)

**Figure 24: Sunshine and Solar radiation temporal variations for Mimosa.**

The Figure 24 above shows that the solar radiation has two picks; the first and smaller pick in January to May and the highest pick in August to December. The graph indicates June and July as the period of lower solar radiation. In terms of sunshine hours December, January, February and March have lowest number of sunshine hours. There is an increase in sunshine hours from April to May. The graph further shows decrease in sunshine hours in June and July and pick up from August to November.
Figure 25: Sunshine and Solar radiation temporal variations for Bvumbwe.

The Figure 25 above shows that the solar radiation has two picks; the smaller pick in January to May and the highest pick in August to December. The graph indicates June and July as the period of lower solar radiation. In terms of sunshine hours December, January, February and March have lowest number of sunshine hours. There is an increase in sunshine hours from April to May. The graph further shows decrease in sunshine hours in June and July and pick up from August to November.

Figure 26: Sunshine and Solar radiation temporal variations for Chileka.
The Figure 26 above shows that the solar radiation has two picks; the smaller pick in January to May and the highest pick in August to December. The graph indicates June and July as the period of lower solar radiation. In terms of sunshine hours December, January, and February have lowest number of sunshine hours. There is an increase in sunshine hours from March to May. The graph further shows decrease in sunshine hours in June and July and pick up from August to November.

![Figure 26: Solar Radiation and Sunshine Temporal Variations for Ngabu.](image)

**Figure 27: Sunshine and Solar radiation temporal variations for Ngabu.**

The Figure 27 above shows that the solar radiation has two picks; the smaller pick in January to April and the highest pick in August to December. The graph indicates May, June and July as the period of lower solar radiation. In terms of sunshine hours December, January, and February have lowest number of sunshine hours. There is an increase in sunshine hours from March to May. The graph further shows decrease in sunshine hours in June and July and pick up from August to November.
4.2.2. Correlation analysis
Correlation was done to determine the degree of relationship between Sunshine hours and solar radiation.

4.2.2.1 Correlation analysis for the stations
The correlation analysis for sunshine hours and solar radiation was done in all the station in all the months. Below is the bar graph showing the stations with their correction coefficients.

![Bar graph showing stations with their correction coefficients.](image)

**Figure 28: Correlation analysis of sunshine and solar radiation for all stations.**

The Figure 28 above shows how the sunshine hours and solar radiation correlates per station. To interpret the correlation significance the t-Test was used and below is the results.
Table 2: t-Test results of correlation significance of sunshine and solar radiation over years

<table>
<thead>
<tr>
<th>Station</th>
<th>Correlation coefficient</th>
<th>Tabulated T-Value at 95% confidence level</th>
<th>Computed T-value</th>
<th>Significance results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chitipa</td>
<td>0.704369</td>
<td>2.048</td>
<td>5.25063026</td>
<td>High</td>
</tr>
<tr>
<td>Mzimba</td>
<td>0.608322</td>
<td>2.048</td>
<td>4.05563798</td>
<td>High</td>
</tr>
<tr>
<td>Nkhotakota</td>
<td>0.525798</td>
<td>2.048</td>
<td>3.27083474</td>
<td>High</td>
</tr>
<tr>
<td>Salima</td>
<td>0.498147</td>
<td>2.048</td>
<td>3.0399255</td>
<td>High</td>
</tr>
<tr>
<td>Chitedze</td>
<td>0.518242</td>
<td>2.048</td>
<td>3.2064919</td>
<td>High</td>
</tr>
<tr>
<td>Dedza</td>
<td>0.367561</td>
<td>2.048</td>
<td>2.0913382</td>
<td>High</td>
</tr>
<tr>
<td>Mangochi</td>
<td>0.368197</td>
<td>2.048</td>
<td>2.09548497</td>
<td>High</td>
</tr>
<tr>
<td>Makoka</td>
<td>0.500765</td>
<td>2.048</td>
<td>3.06124674</td>
<td>High</td>
</tr>
<tr>
<td>Chileka</td>
<td>0.319227</td>
<td>2.048</td>
<td>1.78240791</td>
<td>Low</td>
</tr>
<tr>
<td>Chichiri</td>
<td>0.389751</td>
<td>2.048</td>
<td>2.23945791</td>
<td>High</td>
</tr>
<tr>
<td>Bvumbwe</td>
<td>0.498271</td>
<td>2.048</td>
<td>3.0409808</td>
<td>High</td>
</tr>
<tr>
<td>Mimosa</td>
<td>0.338635</td>
<td>2.048</td>
<td>1.9043726</td>
<td>Low</td>
</tr>
<tr>
<td>Ngabu</td>
<td>0.509612</td>
<td>2.048</td>
<td>3.13410666</td>
<td>High</td>
</tr>
</tbody>
</table>

It can be seen that the significance of correlation is high in most stations like Chitipa, Mzimba, Nkhotakota, Salima, Chitedze, Dedza, Mangochi, Makoka, Chichiri, Bvumbwe and Ngabu while low correlation in only two stations namely; Chileka and Mimosa.

The results clearly show that sunshine correlated highly with solar radiation.

4.2.3. Results for determining the trend of both sunshine hours and solar radiation over the area of study.

This is the general pattern that the sunshine and solar radiation appears to follow over a long period of time. The analysis focuses the period of 30 years from 1983 to 2013.
4.2.3.1 Trend analysis of Sunshine and Solar radiation

The graphs below show sunshine hours and solar radiation trend of annual totals for Chitipa.

![Graph showing sunshine hours and solar radiation trend for Chitipa](image1)

**Figure 29: Sunshine and Solar radiation trends for Chitipa.**

To interpret the trends the t-test was used, and the results are in the Table 3 below. From the t-Test results it can be seen that the trend was significant for both sunshine and solar radiation.

The graphs below show sunshine hours and solar radiation trend of annual totals for Mzimba.

![Graph showing sunshine hours and solar radiation trend for Mzimba](image2)

**Figure 30: Sunshine and Solar radiation trends for Mzimba.**
To interpret the trends the t-test was used, and the results are in the Table 3 below. From the t-Test results it can be seen that the trend was significant for both sunshine and solar radiation.

The graphs below show sunshine hours and solar radiation trend of annual totals for Nkhotakota.

![Sunshine and Solar radiation trends for Nkhotakota.](image1)

**Figure 31: Sunshine and Solar radiation trends for Nkhotakota.**

To interpret the trends the t-test was used, and the results are in the Table 3 below. From the t-Test results it can be seen that the trend was significant and it is an increasing trend of both sunshine and solar radiation. This is due to cloudless sky due to Lake Malawi influence.

The graphs below show sunshine hours and solar radiation trend of annual totals for Salima.

![Sunshine and Solar radiation trends for Salima.](image2)

**Figure 32: Sunshine and Solar radiation trends for Salima.**
To interpret the trends the t-test was used, and the results are in the Table 3 below. From the t-Test results it can be seen that the trend was significant for solar radiation and it is an increasing trend but it was not significant for both sunshine.

The graphs below show sunshine hours and solar radiation trend of annual totals for Chitedze.

**Figure 33: Sunshine and Solar radiation trends for Chitedze.**

To interpret the trends the t-test was used, and the results are in the Table 3 below. From the t-Test results it can be seen that the trend was no significant for both sunshine and solar radiation.

The graphs below show sunshine hours and solar radiation trend of annual totals for Dedza.

**Figure 34: Sunshine and Solar radiation trends for Dedza.**

33
To interpret the trends the t-test was used, and the results are in the Table 3 below. From the t-Test results it can be seen that the trend was no significant for both sunshine and solar radiation.

The graphs below show sunshine hours and solar radiation trend of annual totals for Makoka.

![Figure 35: Sunshine and Solar radiation trends for Makoka.](image)

To interpret the trends the t-test was used, and the results are in the Table 3 below. From the t-Test results it can be seen that the trend was significant for sunshine hours and it is an increasing trend but it was not significant for solar radiation.

The graphs below show sunshine hours and solar radiation trend of annual totals for Mangochi.

![Figure 36: Sunshine and Solar radiation trends for Mangochi.](image)
To interpret the trends the t-test was used, and the results are in the Table 3 below. From the t-Test results it can be seen that the trend was not significant for both sunshine hours and solar radiation.

The graphs below show sunshine hours and solar radiation trend of annual totals for Chichiri.

**Figure 37: Sunshine and Solar radiation trends for Chichiri.**

To interpret the trends the t-test was used, and the results are in the Table 3 below. From the t-Test results it can be seen that the trend was not significant for both sunshine hours and solar radiation.

The graphs below show sunshine hours and solar radiation trend annual totals for Mimosa.

**Figure 39: Sunshine and Solar radiation trends for Mimosa.**
To interpret the trends the t-test was used, and the results are in the Table 3 below. From the t-Test results it can be seen that the trend was not significant for both sunshine hours and solar radiation at the station.

The graphs below show sunshine hours and solar radiation trend of annual totals for Bvumbwe.

![Graph of Sunshine and Solar radiation trends for Bvumbwe.](image)

**Figure 38: Sunshine and Solar radiation trends for Bvumbwe.**

To interpret the trends the t-test was used, and the results are in the Table 3 below. From the t-test results it can be seen that the trend was not significant for both sunshine hours and solar radiation.

The graphs below show sunshine hours and solar radiation trend of annual totals for Chileka.

![Graph of Sunshine and Solar radiation trends for Chileka.](image)

**Figure 40: Sunshine and Solar radiation trends for Chileka.**
To interpret the trends the t-test was used, and the results are in the Table 3 below. From the t-Test results it can be seen that the trend was not significant both for sunshine hours solar radiation.

The graphs below show sunshine hours and solar radiation trend of annual totals for Ngabu.

![Graph showing sunshine hours and solar radiation trend](image)

**Figure 41: Sunshine and Solar radiation trends for Ngabu.**

To interpret the trends the t-test was used, and the results are in the Table 3 below. From the t-Test results it can be seen that the trend was not significant both for sunshine hours solar radiation.
Table 3: t-Test results on the trend of sunshine and solar radiation over years

<table>
<thead>
<tr>
<th>Station</th>
<th>Weather Element</th>
<th>Mean1</th>
<th>Mean2</th>
<th>t Stat</th>
<th>T Critical one-tail</th>
<th>T Critical two-tail</th>
<th>Trend Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chitipa</td>
<td>Sunshine</td>
<td>93.77</td>
<td>96.80</td>
<td>-1.89</td>
<td>1.69</td>
<td>2.04</td>
<td>No Significant</td>
</tr>
<tr>
<td></td>
<td>Radiation</td>
<td>64.31</td>
<td>63.89</td>
<td>0.52</td>
<td>1.69</td>
<td>2.04</td>
<td>No Significant</td>
</tr>
<tr>
<td>Mzimba</td>
<td>Sunshine</td>
<td>92.14</td>
<td>92.11</td>
<td>0.01</td>
<td>1.69</td>
<td>2.04</td>
<td>No Significant</td>
</tr>
<tr>
<td></td>
<td>Radiation</td>
<td>69.24</td>
<td>68.34</td>
<td>1.20</td>
<td>1.69</td>
<td>2.04</td>
<td>No Significant</td>
</tr>
<tr>
<td>Nkhotakota</td>
<td>Sunshine</td>
<td>97.91</td>
<td>102.05</td>
<td>-2.99</td>
<td>1.69</td>
<td>2.04</td>
<td>Increasing</td>
</tr>
<tr>
<td></td>
<td>Radiation</td>
<td>62.62</td>
<td>65.40</td>
<td>-2.34</td>
<td>1.71</td>
<td>2.06</td>
<td>Increasing</td>
</tr>
<tr>
<td>Salima</td>
<td>Sunshine</td>
<td>101.07</td>
<td>103.97</td>
<td>-1.66</td>
<td>1.70</td>
<td>2.05</td>
<td>No Significant</td>
</tr>
<tr>
<td></td>
<td>Radiation</td>
<td>62.69</td>
<td>65.04</td>
<td>-2.19</td>
<td>1.70</td>
<td>2.06</td>
<td>Increasing</td>
</tr>
<tr>
<td>Chitedze</td>
<td>Sunshine</td>
<td>90.86</td>
<td>92.88</td>
<td>-1.06</td>
<td>1.70</td>
<td>2.06</td>
<td>No Significant</td>
</tr>
<tr>
<td></td>
<td>Radiation</td>
<td>67.28</td>
<td>66.77</td>
<td>0.65</td>
<td>1.69</td>
<td>2.04</td>
<td>No Significant</td>
</tr>
<tr>
<td>Dedza</td>
<td>Sunshine</td>
<td>86.26</td>
<td>89.18</td>
<td>-1.27</td>
<td>1.70</td>
<td>2.05</td>
<td>No Significant</td>
</tr>
<tr>
<td></td>
<td>Radiation</td>
<td>69.82</td>
<td>69.69</td>
<td>0.13</td>
<td>1.69</td>
<td>2.04</td>
<td>No Significant</td>
</tr>
<tr>
<td>Makoka</td>
<td>Sunshine</td>
<td>83.94</td>
<td>89.59</td>
<td>-3.23</td>
<td>1.70</td>
<td>2.05</td>
<td>Increasing</td>
</tr>
<tr>
<td></td>
<td>Radiation</td>
<td>64.53</td>
<td>65.06</td>
<td>-0.69</td>
<td>1.70</td>
<td>2.05</td>
<td>No Significant</td>
</tr>
<tr>
<td>Mangochi</td>
<td>Sunshine</td>
<td>98.71</td>
<td>100.66</td>
<td>-1.01</td>
<td>1.70</td>
<td>2.05</td>
<td>No Significant</td>
</tr>
<tr>
<td></td>
<td>Radiation</td>
<td>65.20</td>
<td>65.85</td>
<td>-0.82</td>
<td>1.67</td>
<td>2.04</td>
<td>No Significant</td>
</tr>
<tr>
<td>Chichiri</td>
<td>Sunshine</td>
<td>86.16</td>
<td>86.28</td>
<td>-0.06</td>
<td>1.71</td>
<td>2.06</td>
<td>No Significant</td>
</tr>
<tr>
<td></td>
<td>Radiation</td>
<td>64.53</td>
<td>65.03</td>
<td>-0.67</td>
<td>1.70</td>
<td>2.05</td>
<td>No Significant</td>
</tr>
<tr>
<td>Mimosa</td>
<td>Sunshine</td>
<td>83.87</td>
<td>85.36</td>
<td>-0.84</td>
<td>1.70</td>
<td>2.04</td>
<td>No Significant</td>
</tr>
<tr>
<td></td>
<td>Radiation</td>
<td>64.72</td>
<td>65.01</td>
<td>-0.41</td>
<td>1.70</td>
<td>2.04</td>
<td>No Significant</td>
</tr>
<tr>
<td>Bvumbwe</td>
<td>Sunshine</td>
<td>83.95</td>
<td>84.96</td>
<td>-0.43</td>
<td>1.71</td>
<td>2.06</td>
<td>No Significant</td>
</tr>
<tr>
<td></td>
<td>Radiation</td>
<td>64.53</td>
<td>65.03</td>
<td>-0.64</td>
<td>1.70</td>
<td>2.04</td>
<td>No Significant</td>
</tr>
<tr>
<td>Chileka</td>
<td>Sunshine</td>
<td>92.85</td>
<td>92.74</td>
<td>0.06</td>
<td>1.69</td>
<td>2.04</td>
<td>No Significant</td>
</tr>
<tr>
<td></td>
<td>Radiation</td>
<td>64.31</td>
<td>63.89</td>
<td>0.52</td>
<td>1.69</td>
<td>2.04</td>
<td>No Significant</td>
</tr>
<tr>
<td>Ngabu</td>
<td>Sunshine</td>
<td>92.14</td>
<td>92.11</td>
<td>0.02</td>
<td>1.70</td>
<td>2.05</td>
<td>No Significant</td>
</tr>
<tr>
<td></td>
<td>Radiation</td>
<td>66.34</td>
<td>66.48</td>
<td>-0.21</td>
<td>1.70</td>
<td>2.05</td>
<td>No Significant</td>
</tr>
</tbody>
</table>
4.2.4. Results for determining the spatial distribution of both sunshine hours and solar radiation over the area of study.
The spatial analysis was done in order to find out which area have more in terms of yearly average of sunshine hours and solar radiation in the period of study; from 1983 to 2013. All the 13 stations involved in this study were analyzed. The Results are shown as below.

4.2.4.1 Spatial distribution for sunshine hours
The figure 42 below shows the spatial distribution in terms of sunshine hours in the area of study.

![Figure 42: Spatial distribution of Sunshine hours over the study area](image)

4.2.4.2 Spatial distribution of solar radiation
The figure 43 below shows the spatial distribution in terms of sunshine hours in the area of study.
4.2.5. Results showing the mapping of the potential areas where the solar energy can be harnessed over the area of study.

The analysis using surfer software was done to determine the potential area where solar energy can be harnessed over the study area. The results come from the spatial distribution in the section 4.2.4.2 above. The map of Malawi below shows the spatial distribution of solar radiation.

**Figure 43: Spatial distribution of solar radiation over the study area.**
Figure 44: Map of Malawi showing areas where the solar energy can be harnessed

The Figure 44 above shows that other areas have more potential in solar energy comparing to other areas. Northern part of Malawi has the highest potential seconded by Lakeshore and Central areas. The map further shows that there also high potential in the very Southern tip of Malawi. The map also shown that most of the areas in the Southern highlands of Malawi have low solar energy potential.

However, the minimum average of 5.32 kWh/m²/day is very good as far the utilization of the solar energy is concerned as most of the PV systems accommodate up to the minimum of 3.8 kWh/m²/day.
CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary
All Meteorological and climatological data need to meet certain standards for it to be effectively used. The data used in this study passed all the data quality controls. From the analyses of this study, it has been shown that the solar energy utilization is possible in Malawi. The 30 year average indicates the minimum of 5.32 kWh/m$^2$ day of solar radiation which is very good as far the utilization of the resource is concerned. The climatologically base map created by surfer has shown the areas which have high potential of solar energy utilization. The analysis has shown that there are higher solar energy potentials in the Northern, Lakeshore, Central areas and the Southern tip of southern region. The analysis has also shown that most of the areas in the Southern highlands of Malawi have low solar energy potential. The study further show that there is seasonal variation of solar radiation within the season of the year; March, April, May, August, September, October and November being the months of highest solar radiation utilization while December, January, June and July has lower solar radiation utilization potentials. The relationship between sunshine hours and solar radiation has been shown to be significant.

5.2 Conclusion
It has been shown from the results of the study that there is abundant solar radiation resource which is not being utilized in Malawi. This abundant solar radiation can be harnessed and be put into various uses such as water heating, cooking and electricity generation by the use of PV systems.

5.3 Recommendations
This research recommends the people in the area of study to put into consideration in this form of energy. They should invest and use solar energy as a reliable source of energy more especially in the rural areas where only 1% of the population has access to Electricity. The energy sector should take the utilization of the resource seriously as it real and possible in Malawi. The sector should sensitize people on this readily available source of energy. Further research need to be done more especially at regional and district levels.
6.0 REFERENCES

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