

Assessment of Solar Energy Potential in Nakuru, Kenya

Lewis Mose Omwando

**A thesis submitted in partial fulfillment for the degree of Masters
of Science in Physics in the Jomo Kenyatta University of
Agriculture and Technology**

2012

DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

Signature: Date:

Lewis Mose Omwando

This thesis has been submitted for examination with our approval as University supervisors.

Signature: Date:

Dr. Robert Kinyua

JKUAT, Kenya

Signature: Date:

Dr. Ndeda O. H. Jared

JKUAT, Kenya

Signature: Date:

Dr. Samwel N. Marigi

**Institute for Meteorological Training
and Research, Kenya**

DEDICATION

I dedicate this thesis to my family, particularly to my lovely sons, Griffins Omwando and Finley Onyoni, my best friend & wife, Delvin Nyaboke. I also dedicate it to my mother Peris Kemunto Omwando and in loving memory of my father, Simion Omwando, who passed on whilst I was only a little boy.

ACKNOWLEDGEMENT

First and above all, I am grateful to the Almighty God for his boundless love, protection and help. He has been the source of my knowledge and wisdom; through Him, I have been able to overcome many challenges during this huge undertaking.

My gratitude goes to my supervisors, Dr Robert Kinyua, Dr Jared Ndeda and Dr Samuel Marigi for their critical reviews, invaluable guidance and comments. Their expertise as lecturers, scientist and experts in diverse fields are well appreciated at this point in time.

I could not possibly thank all the people in my life who have gotten me to this point. However, I must thank my family; my mother, brothers and sisters, for their ever-enduring support and love. Without this core group of people, I could neither be the person that I am now nor become the person I hope to be in the future. They give me a sense of purpose and a drive to succeed which has enabled me to have strength of self and a determination to accomplish goals. My Cousin Mobisa and his lovely family members are appreciated for accommodating me in their home irrespective of bad economic times. I must state that in this and all other regards, I also consider my other cousin and mentor, Joash Kerongo, to be an indispensable part of my life.

The Department of Physics, JKUAT has been helpful and supportive, right from the chairman Dr Ngaruiya, Dr Githiri (post graduate advisor) to the secretary Ms Lydia Gikonyo. Special thanks also go to all the lecturers from the department, the MSc course mates who always provided encouragement and valuable support.

Immeasurable gratitude goes to my employer, TSC for the sponsorship of my studies through a fully paid study leave, for without it; I would not have been able to complete my MSc programme or this thesis. I would also like to thank Mr. Ochieng of the KMD library and the KMD communities at large for allowing me to work with them during my attachment period and allowing me access the library resources and other research facilities in the course of my studies with little limitations.

Finally, and perhaps most importantly, I would like to thank my wife, Delvin Nyaboke, for her love, support and understanding since the beginning of my study until completion. The happiness that she brings to my life is unparalleled. She is supportive when I need support and enlightening when I need direction. She keeps me moving forward. This journey would have been more difficult without her support and encouragement. Last but not least, I shall forever be grateful to my lovely sons, Griffins and Finlay for bearing with my long absence during my studies despite being too young to understand. And to all, I say thank you!

TABLE OF CONTENTS

DECLARATION	ii
DEDICATION	iii
ACKNOWLEDGEMENT	iv
TABLE OF CONTENTS	vi
LIST OF TABLES	xii
LIST OF FIGURES	xiii
LIST OF ABBREVIATIONS	xv
LIST OF APPENDICES	xvii
LIST OF SYMBOLS	xviii
ABSTRACT	xx
CHAPTER ONE	1
1.0 INTRODUCTION	1
1.1 OVERVIEW	1
1.2 BACKGROUND.....	2

1.3	ENERGY DEMAND	6
1.3.1	General Overview	6
1.3.2	Wood Fuel	10
1.4	STATEMENT OF THE PROBLEM.....	12
1.5	JUSTIFICATION OF THE STUDY	13
1.6	HYPOTHESIS	14
1.7	OBJECTIVES OF THE STUDY	14
1.8	AREA OF STUDY	15
CHAPTER TWO		19
2.0	LITERATURE REVIEW AND THEORETICAL BACKGROUND.....	19
2.1	LITERATURE REVIEW	19
2.2	THEORETICAL BACKGROUND.....	21
2.2.1	SOLAR ENERGY	21
2.3	THE SUN.....	27
2.4	EARTH’S ATMOSPHERE	28
2.4.1	ATMOSPHERIC STRATIFICATION.....	28
2.5	MODELS FOR SOLAR ENERGY ESTIMATION.....	32
2.6	TECHNOLOGIES FOR THE CONVERSION OF SOLAR ENERGY	35
CHAPTER THREE.....		37

3.0	MATERIALS AND METHODS	37
3.1	INTRODUCTION.....	37
3.2	INSTRUMENTS FOR MEASURING SOLAR RADIATION.....	37
3.2.1	Pyranometer	38
3.2.2	Campbell-Stokes Tropical Sunshine Recorder.....	40
3.3	QUALITY CONTROL METHODS	42
3.3.1	Quality Control Tests	43
3.3.2	Range Validation	44
3.3.3	Mass Curve Analysis.....	44
3.3.4	One Sample Runs Test.....	44
3.4	THE SOLAR ENERGY RESOURCE.....	45
3.4.1	Characteristics of the Solar Energy Resource	45
3.4.2	Diurnal and Seasonal Solar Energy and Power Computations	45
3.4.3	Solar Energy Resource Reliability	46
3.5	COST ANALYSIS.....	47
3.5.1	Daily Energy Demand.....	47
3.5.2	Battery Storage.....	48
3.5.3	Solar Energy.....	48
3.5.4	Investment and Running Costs.....	49
3.6	EVALUATION OF THE EXTENT OF CLIMATE CHANGE MITIGATION.....	49
3.6.1	The Run Concept.....	49

3.6.2	Chemical Equations for Burning Fuels	50
CHAPTER FOUR.....		52
4.0	RESULTS AND DISCUSSION.....	52
4.1	INTRODUCTION.....	52
4.2	RESULTS FROM QUALITY CONTROL TESTS.....	52
4.2.1	Mass Curve Analysis.....	53
4.2.2	One Sample Runs-Test.....	54
4.3	TEMPORAL PATTERNS OF SOLAR RADIATION.....	54
4.3.1	Monthly Radiation Values.....	54
4.3.2	Global Dimming Phenomenon.....	56
4.3.3	Radiation Trends.....	57
4.4	SEASONAL RADIATION ANALYSIS.....	60
4.4.1	December - February Season.....	60
4.4.2	March - May Season.....	61
4.4.3	June - August Season.....	62
4.4.4	September- November Season.....	63
4.4.5	Seasonal Energy Trends/comparisons.....	64
4.5	SOLAR ENERGY RESOURCE RELIABILITY FOR NAKURU.....	65
4.5.1	Monthly Reliability Values.....	65
4.5.2	Seasonal Reliability Values.....	68

4.6	SURFACE TEMPERATURE TRENDS IN NAKURU.....	69
4.7	ENERGY DEMAND.....	70
4.7.1	Household Energy Demand.....	70
4.7.2	Rural Scenario.....	71
4.7.3	Urban Scenario.....	71
4.7.4	Battery Storage.....	71
4.7.5	Solar Energy.....	72
4.7.5.1	Rural.....	72
4.7.5.2	Urban.....	72
4.7.6	Investment and Running Costs.....	73
4.7.6.1	Yearly Investment Costs.....	73
4.7.6.2	Running Costs.....	73
4.8	EXTENT OF CLIMATE CHANGE MITIGATION.....	74
4.8.1	Seasonal Energy Insolation.....	74
4.8.2	Percentage of Fuel Savings and Carbon Dioxide Reduction.....	75
4.8.3	Rural Family’s Fuel Consumption and Environmental Pollution.....	76
4.8.4	Percentages of Fuel Savings and CO ₂ Reduction.....	77
4.9	WATER HEATING.....	78
	CHAPTER FIVE.....	80
5.0	CONCLUSIONS AND RECOMMENDATIONS.....	80

5.1	CONCLUSIONS.....	80
5.2	RECOMMENDATIONS.....	81
	REFERENCES.....	82
	APPENDICES.....	88

LIST OF TABLES

Table 1:	Number of customers served by KPLC between 2000 and 2008.....	9
Table 2:	Population growth for Nakuru.....	17
Table 3:	One sample runs-test results.....	54
Table 4:	Average daily radiation values in kWh/m ²	55
Table 5:	Daily and monthly radiation averages in kWh/m ² , 1986 to May 2010.....	57
Table 6:	Radiation average values for December – February season.....	60
Table 7:	Radiation values for March – May season.....	61
Table 8:	Radiation values for June - August season.....	62
Table 9:	Radiation values for September - November season.....	63
Table 10:	Computed monthly solar energy reliabilities values for Nakuru.....	67
Table 11:	Summary of computed seasonal reliabilities values for Nakuru.....	68
Table 12:	Rural/Urban household energy demand.....	70
Table 13:	Seasonal energy insolation analysis.....	74
Table 14:	Environmental pollution due to combustion of fuels.....	76
Table 15:	Carbon dioxide emissions (rural/urban household).....	77
Table 16:	Amount of fuel saving (kWh) and carbon dioxide (kg) reduction.....	77
Table 17:	Electricity tariffs in Kenya.....	79
Table 18:	Current market solar water heater capacity and prices.....	79
Table 19:	International SI unit prefixes.....	88

LIST OF FIGURES

Figure 1:	Kenya's population growth during the period 1969-2009	2
Figure 2:	Kenya's rural-urban population distribution by the year 2009.	3
Figure 3:	Total petroleum and kerosene demand in Kenya	6
Figure 4:	Electricity demand in Kenya 2004-2009	7
Figure 5:	Retail prices for LPG (in Kshs/13 kg cylinder).....	10
Figure 6:	Consumption of combustible renewables as a percent of total energy.	11
Figure 7:	Location of Nakuru on the map of Kenya.	16
Figure 8:	The solar spectrum.	24
Figure 9:	The Earth's Atmosphere.	29
Figure 10:	Pyranometer.....	40
Figure 11:	Campbell-stokes tropical sunshine recorder.....	42
Figure 12:	Mass curve for Nakuru radiation data	53
Figure 13:	Average daily solar radiation pattern measured at Nakuru (1986-2010)...	56
Figure 14:	Radiation max, mean and min value graphs for Nakuru.	58
Figure 15:	Graph of monthly average daily solar radiation pattern in kWh/m ²	59
Figure 16:	Average monthly insolation trend bar graph.	59
Figure 17:	December - February seasonal radiation bar graph.....	61
Figure 18:	March – May season bar graph.	62
Figure 19:	June - August season bar graph	63
Figure 20:	September- November season bar graph.....	64
Figure 21:	Seasonal energy trends/comparisons bar graph.....	65

Figure 22:	Observed annual temperature trends for Nakuru 1960-2008	69
Figure 23:	Radiation trend graph for January 1986-2010.....	89
Figure 24:	Radiation trend graph for February 1986-2010.....	89
Figure 25:	Radiation trend graph for March 1986-2010.....	90
Figure 26:	Radiation trend graph for April 1986-2010.....	90
Figure 27:	Radiation trend graph for May 1986-2010.....	91
Figure 28:	Radiation trend graph for June 1986-2010.....	91
Figure 29:	Radiation trend graph for July 1986-2010.....	92
Figure 30:	Radiation trend graph for August 1986-2010.....	92
Figure 31:	Radiation trend graph for September 1986-2010	93
Figure 32:	Radiation trend graph for October 1986-2010	93
Figure 33:	Radiation trend graph for November 1986-2010	94
Figure 34:	Radiation trend graph for December 1986-2010.....	94

LIST OF ABBREVIATIONS

A	Size of the solar energy conversion system
Av	Average
amu	Atomic mass units
BTU	British Thermal Unit
CBK	Central Bank of Kenya
d	Day
Ed	Energy demand
Es	Size of storage
EPP	Emergency Power Producers
FiT	Feed-in-Tariff
GoK	Government of Kenya
GWh	Gigawatt hours
Inv	Investments
IMTR	Institute for Meteorological Training and Research, Nairobi
IPP	Independent Power Producers
JKUAT	Jomo Kenyatta University of Agriculture and Technology
KMD	Kenya Meteorological Department
KIPPRA	Kenya Institute for Public Policy Research and Analysis
kWh	Kilowatt hour
KPLC	Kenya Power and Lighting Company
Kg	Kilogram
Kshs	Kenyan shilling

KITI	Kenya Industrial Training Institute
Km	Kilometre
KNBS	Kenya National Bureau of Statistics
Max	Maximum
Min	Minimum
MJ/m²/day	Mega joule per square metre per day
LPG	Liquefied Petroleum Gas
nm	Nanometer
sq	Square
SRHB	Solar Radiation Hand Book
TSC	Teacher Service Commission
TW	Terrawatt
US\$	United States Dollar
Vol	Volume
Wh	Watt hour
WMO	World Meteorological Organization
WOT	Working Group on Development Techniques
W	Watt
Y	Yotta

LIST OF APPENDICES

- APPENDIX 1:** International SI unit Prefixes
- APPENDIX 2:** Monthly Radiation Trend Graphs 1986 to 2010

LIST OF SYMBOLS

%	Percentage
<i>C</i>	Velocity of an electromagnetic wave
<i>v</i>	Frequency of an electromagnetic wave
λ	Wavelength of an electromagnetic wave
<i>O</i>₂	Oxygen
<i>O</i>₃	Ozone gas
<i>CO</i>₂	Carbon dioxide
<i>H</i>₂<i>O</i>	Water
<i>b</i>	Wien's displacement constant
<i>K</i>	Kelvin
<i>T</i>	Absolute temperature
<i>M</i>	Metre
<i>He</i>	Helium
<i>E</i>	Energy
ρ	Density
<i>R</i>_o	Sun's radius
^o<i>C</i>	Degree Celsius
δ_r	Reliability
<i>G</i>	Solar insolation
$\\$	Dollar
μ	Micro
τ	Number of observed runs.

∞	Infinity
\leq	Less than/equal to
Φ	Latitude of location
δ	Solar declination
Ω	Earth's speed about its axis

ABSTRACT

In this study, the potential of solar energy for utilisation in rural and pre-urban settings in Nakuru municipality was investigated. Global daily radiation intensity, air temperature records and household fuel consumption data were analysed. The study used global radiation intensity data from 1986 to 2010 while ambient temperature records were for the period 1960 to 2008. All these data sets were obtained from the archives of the Kenya Meteorological Department (KMD). The data sets were subjected to a number of statistical analyses including; Quality control and Homogeneity tests, temporal, time series as well as several empirical statistics to determine the characteristics of the resource. The characteristics examined include diurnal; seasonal and annual power expectations as well as resource reliability. The Renewable Energy Decision method was used to determine the sizes of the solar energy interceptors that would be required to replace the current conventional energy sources and the associated costs (capital costs and running costs) of the solar energy interceptors. Finally, appropriate chemical equations were applied to the conventional energy consumption values to determine the carbon dioxide and water vapour released during their use. Based on these values and the computed solar energy reliabilities, the percentage of carbon dioxide reduction and conventional energy savings were computed. Results revealed that Nakuru has a moderate to high solar energy potential region, with an average daily insolation of 6.9 kWh/m^2 . The energy reaching the surface in this area is season dependant with December-February season receiving the highest amount of 678 kWh/m^2 and September-November season receiving the least amount of 602.6 kWh/m^2 .

Reliability of this resource on an annual basis was found to lie between 55.5% and 85.5% depending on the temperature (high or moderate) required for the activity being carried out. Results have also indicated that although the initial investment on the resource is modest, it is worth it in the long run given the envisaged energy security, environmental preservation and potential climate change mitigation. The study concluded that Nakuru is endowed with abundant energy resources from the sun, favorable for tapping at both small and medium scale levels. These levels are quite convenient particularly for isolated households in the rural and pre-urban settings of the town. It is recommended that policies be put in place to harness this freely available, abundant, renewable and clean resource for the benefit of the inhabitants of Nakuru municipality.

CHAPTER ONE

1.0 INTRODUCTION

1.1 OVERVIEW

The sun is the driving force for all atmospheric processes. Solar radiant intensity is the expression of that input of energy upon the planet. Therefore, the ability to understand and quantify its value and distribution accurately is important in the initial understanding and modeling of any other thermodynamic or dynamic process in the earth-ocean-atmosphere system. However, little is known about the spatial and temporal distribution of incoming solar radiation (Kemp, 2007). A more complete and precise description of that distribution will prove useful in many fields of study that rely on atmospheric energy input, such as engineering (energy), agricultural planning, and architectural design.

The physics involved in the transfer of solar energy through the atmosphere at the global scale is well-understood. Ratios have been derived that describe the relative importance of transmission of radiation through the atmosphere both from the sun (shortwave) and from the surface (long wave). However, these ratios are not spatially or temporally consistent. Furthermore, the global energy budget is likely to change with a changing atmosphere. These complexities have led researchers to attempt to understand local variability in solar radiation with the aim of producing a more comprehensive view of both global and local energy budgets (Kemp, 2007).

It is on the basis of the aforementioned that an analysis of the solar radiation distribution in Nakuru municipality is both important and relevant.

1.2 BACKGROUND

Problems in energy and the environment are two of the greatest challenges that mankind face in the present world. Of the two, energy forms the most fundamental need for sustainable socio-economic development of any nation (WMO, 1981). Over the years, Kenya has experienced a growing demand for both modern and traditional energy owing to the increasing population and diversification of economic activities as evidenced in figures 1 and 2 (GOK, 2010).

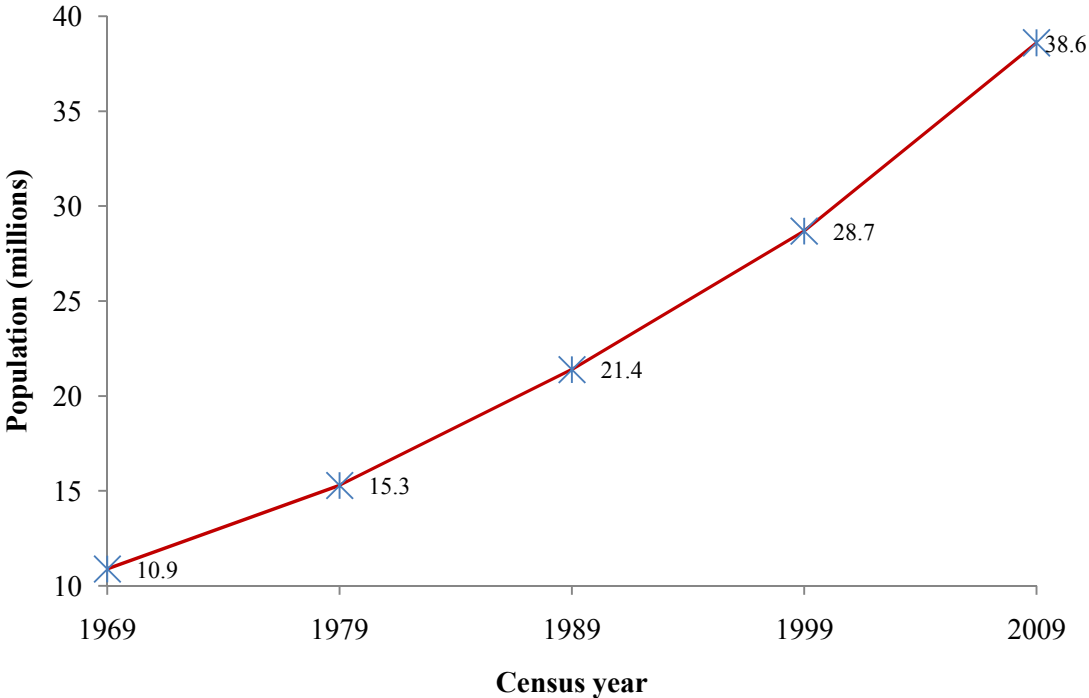


Figure 1: Kenya’s population growth during the period 1969-2009

The actual determinants of household, commercial and industrial energy consumption are found at the micro level where aggregate fuel demand is made up of the day-to-day decisions.

These are affected by budget and time constraints, opportunity costs of time and the relative accessibility of fuels (relative prices). Social and cultural factors have more influence on the aggregate demand at the household level (Osiolo, 2009).

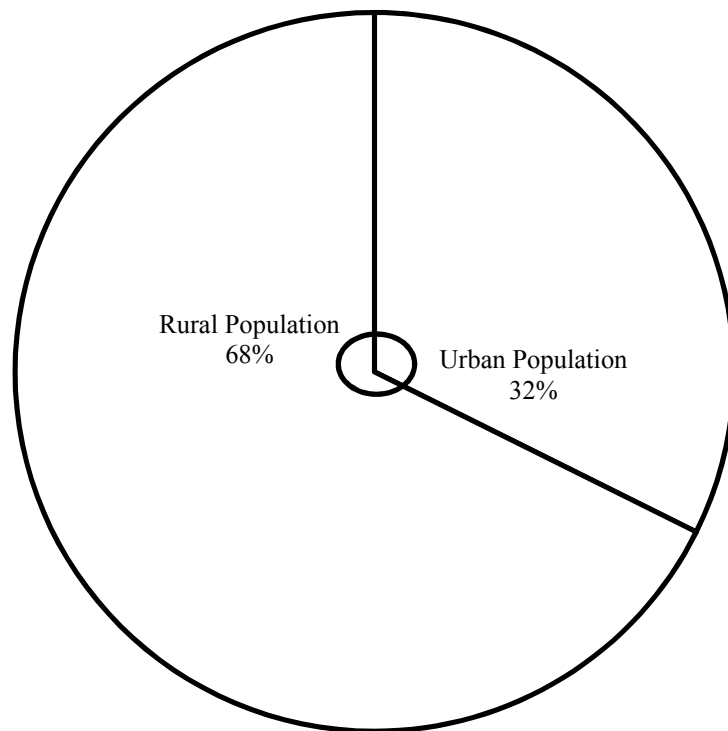


Figure 2: Kenya's rural-urban population distribution by the year 2009.

As the population grows, the demand for energy for household and industrial use also increases. In the Kenyan situation, hydroelectricity and petroleum are the two major sources of energy. At the moment, only marginal populations in rural areas of Kenya have access to modern sources of energy such as electricity. Rural communities therefore rely heavily on traditional energy sources such as wood fuel and agricultural/animal wastes. From the Kenyan census of 2009, it is noted that majority of the Kenyan population (68%) resides in the rural areas. Makokha, 1991 has estimated that biomass fuels account for over 75% of the total energy consumed in Kenya.

A simple global energy analysis reveals that Kenya is short of conventional energy sources especially oil-based products and lacks capital as well as technological know-how for expanding the domestic energy resource base. The country therefore heavily depends on imported conventional energy sources (Marigi, 1999). Due to a ten-fold increase in the prices of imported oil over the last three decades, the cost of oil based energy imports is now putting a crippling burden on Kenya's economy. This has resulted in heavy borrowings from international sources at prohibitive rates of interest (Asplund, 2008). Further, these sources are finite and are therefore likely to be depleted with time. The uncertainty regarding the future availability of oil based products (fossil fuels) as well as the negative impacts their utilization have on the environment have therefore led to a growing need to search for cheaper, renewable and environmentally friendly alternative energy sources. The alternative and renewable energy resources relevant to Kenya include hydropower, geothermal, solar, wind and biogas; all of

which, except geothermal and nuclear energies, are derived initially from solar energy (Natowitz and Ngo, 2009).

The energy from the Sun also drives almost every known physical and biological cycle in the Earth's system. These energies are also friendly to the environment, as they do not produce carbon dioxide. Other benefits of solar energy include: waste-free production; free fuel (sun); saves on foreign exchange. User installed solar systems provide distributed electricity to the owner and protects the owner from grid problems such as blackouts, and electricity price hikes. Also, solar equipments typically last for long, 25-30 years with minimal maintenance (Asplund, 2008).

Our use of energy has a major impact on our Environment. Since a huge amount of energy is consumed in the world, the impact is large, and can be on global or local scale, e.g. Nitrogen oxide emitted by the exhaust pipe of fossil fuel engines pollutes at local scale while the carbon dioxide emitted has an effect on global scale i.e. it's a major contributor to global warming. The development and promotion of renewable energy resources, specifically targeting the rural communities, may provide an alternative, sustainable and promising energy option that will alleviate problems related to deforestation, desertification, environmental pollution, green house gas emissions, global warming as well as potential climate alteration and over dependence on fossil based fuels among many other socio-economic problems.

1.3 ENERGY DEMAND

1.3.1 General Overview

The energy supply and demand balance has not seen major shifts in the recent past for both petroleum and electricity (KIPPRA, 2010). As can be seen from Table 1 and figure 3, the total petroleum demand increased from 2.85 million tonnes in 2004 to about 4.0 million tonnes in 2009, an increase of about 40%. The total electricity demand figure 4 (Republic of Kenya, 2009) increased from 4,234 GWh in 2004 to 5,429 GWh in 2009 which is an increase of about 28%. There was a sharp increase up to 2007 owing to growth in economic activities and some decline in 2008 which could be attributed to post election violence that Kenya underwent the previous year.

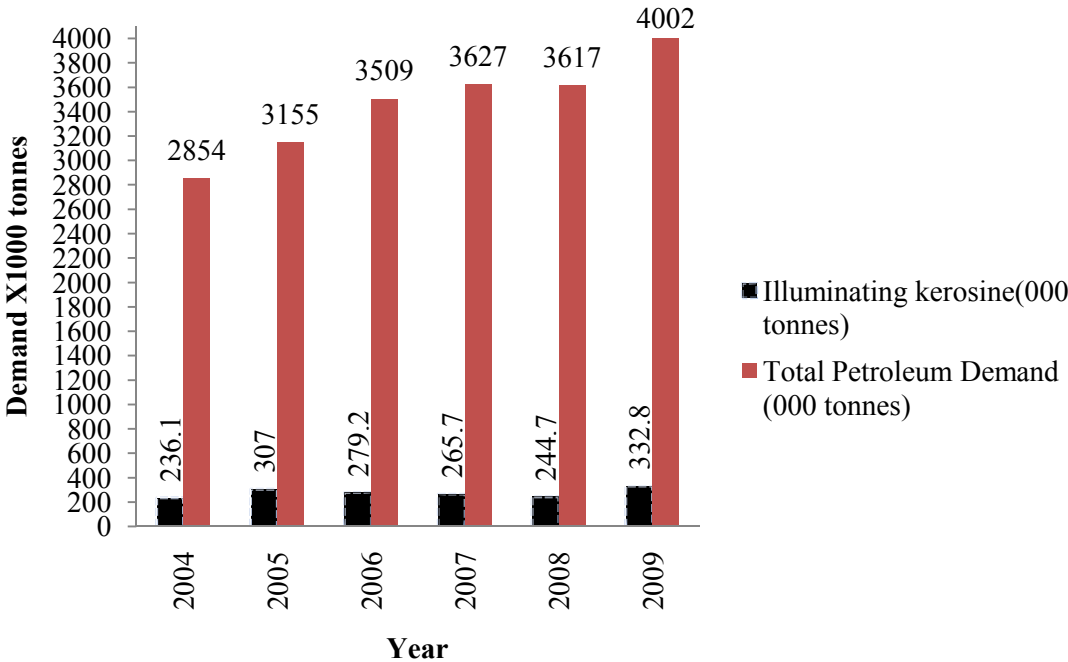


Figure 3: Total petroleum and kerosene demand in Kenya

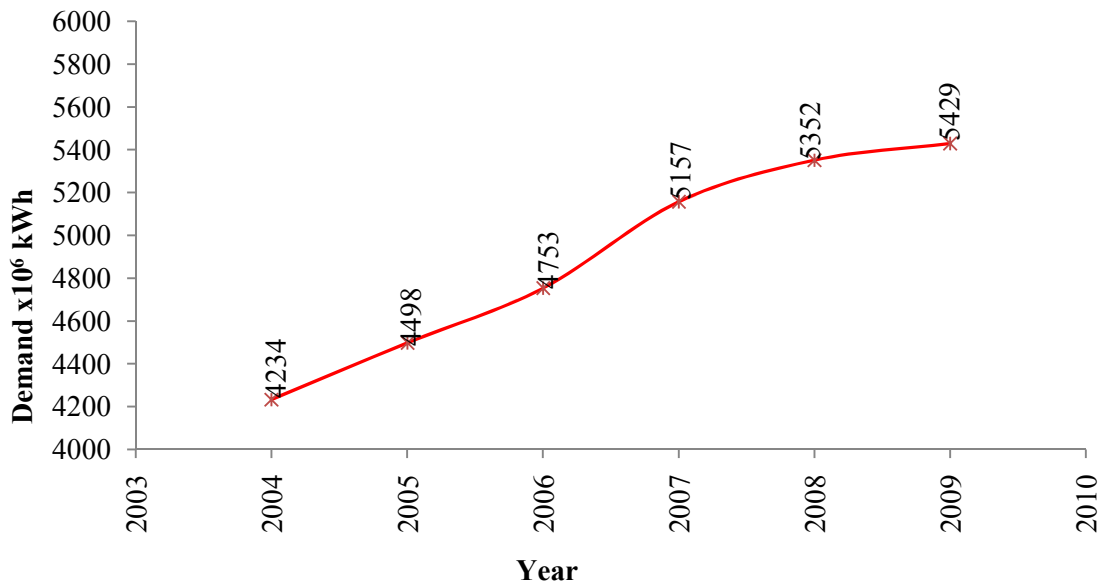


Figure 4: Electricity demand in Kenya 2004-2009

Electricity in many households is mainly used for lighting and powering various equipments/machines. In Kenya, electricity over the years has been generated from hydropower, fossil fuels (thermal), geo-thermal and wind (KIPPRA, 2010). The mix of electricity generation has varied over time and seasons. Hydropower generation has dominated the electricity sub sector since the 1970s when it accounted for 41.6% of all electricity used. Thermal power generation accounted for 25.9% of the total power consumed in the country then. However, in the 1980s and 1990s, it gained more prominence and achieved an all time high of 80% in late 1980s and early 90s before declining to about 50% today. Over the last three years, thermal generation has increased tremendously due to poor rains, which have led to an occasional drop in water levels in the main dams such as Gitaru and closure of others such as Masinga during some seasons. The nation has had, therefore, to rely heavily on thermal generation,

which has in turn increased the amount of diesel required to power these plants in order to generate enough power to meet current demand and avoid power failure (Republic of Kenya, 2009).

Although petroleum fuels have been used to generate power, the cost has been prohibitive which resulted to increased efforts to exploit geothermal electricity. Although initial costs of geothermal power exploitation and generation are high, it is clean and cheap in the long run. Geothermal power generation increased from 4.5% in 1981 to 14.5% in 1986, before falling to 6.9% in 1994. This was followed by a recovery to a maximum of 18.4%, ten years later. The advent of Independent Power Providers (IPP) and Emergency Power Producers (EPP) has improved the available power for use in institutions and industries.

In spite of very heavy investment in generation and transmission of electricity, only 8.7% of all Kenyan households were using electricity for lighting in 1989, with negligible numbers using it for cooking. This improved in 1999 to 13.5% and 15.6% in 2005; only 1.5% of all households were using electricity for cooking in 1999. Access to electricity has not kept pace with economic growth as evidenced by these data. However this notwithstanding, electricity consumption has been increasing over time as depicted in figure 5 above. Total domestic consumption of electricity grew by 8.5% in 2007 compared to a growth of 5.6% in 2006. All consumer categories recorded an increased demand in electricity with rural electrification increasing by 3.5%. The increase in demand reflects the increase in petroleum consumption to the year 2007.

This increased demand for electricity leads to an increase in generation capacity. However due to low hydro power generation as a result of persistent drought, decline in water levels in major dams or even closure of some power stations such as Masinga in September 1999, and mid-2008; the country has had to increase thermal power generation which is from fossil fuels. As a result this has led to increase in consumption of fuel oil. The number of new customers who get connected to the power lines has also been increasing over time, against Kenya's installed capacity as seen in Table 1(KIPPRA, 2010). This would explain the increased total domestic consumption over time.

Table 1: Number of customers served by KPLC between 2000 and 2008

Financial year	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08
Total Customers	537079	593621	643274	686195	735144	802249	924329	1060383
% increase p.a	6.2	10.5	8.4	6.7	7.1	9.1	15.2	14.7

Although the domestic power producers have managed to meet the country's total electricity demand, the heavy reliance on hydropower is a problem especially during periods of droughts when less electricity is produced. For example, in September 1999, and mid-2008, massive power rationing was put in place due to acute hydro generation shortfall. Rationing has negative effects in the productivity of most of the sectors of the economy and discourages additional investment in the economy.

Figure 5 (KIPPRA, 2010) shows the retail prices for Liquefied Petroleum Gas (LPG) in Kenyan shillings per 13 Kg cylinder from 1999-2009. The prices of LPG have been increasing. In 2009 the price stood at approximately Kshs. 1,900 per 13kg cylinder. The rise in retail prices has been steadily increasing since 2004 where price was about Kshs 1,264 per 13 kg cylinder.

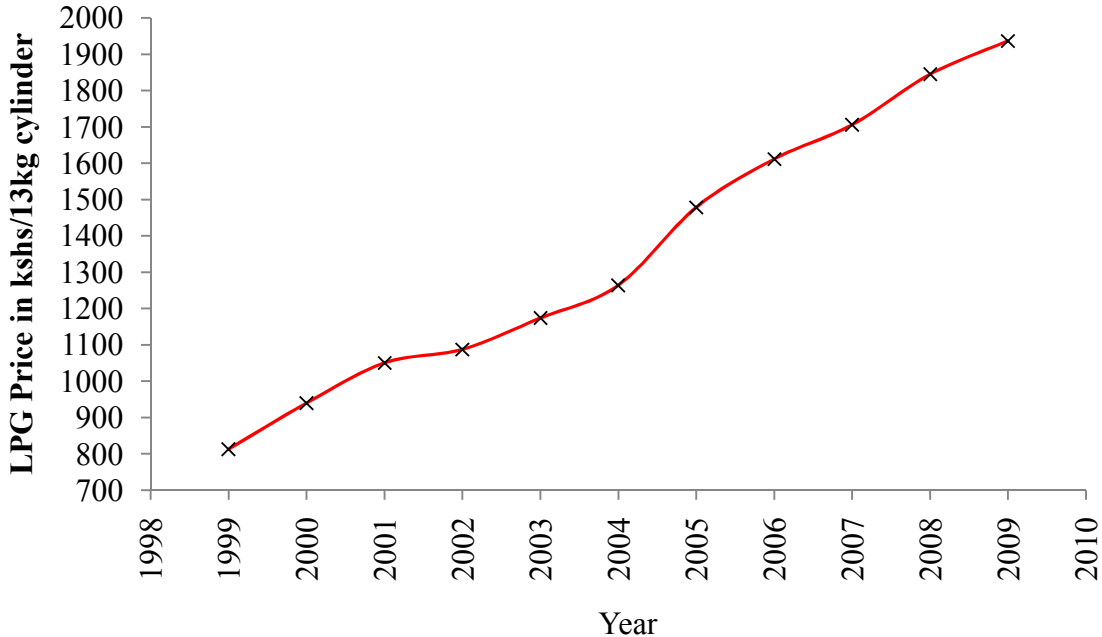


Figure 5: Retail prices for LPG (in Kshs/13 kg cylinder).

1.3.2 Wood Fuel

Wood fuel is the most popular source of energy in Kenya, supplying over 70% of Kenya's total energy requirements; hence the Kenyan population depends on wood fuel for domestic energy needs. In the rural areas, wood fuel is mainly used in the form of firewood whereas charcoal dominates in the urban areas. Figure 8 shows fuel wood consumption for the period 2001 – 2009 (KIPPRA, 2010).

As can be seen from Figure 6 (KIPPRA, 2010), consumption of combustible renewable, which include wood fuel, charcoal and material residual among others has not seen much growth. As a percent of total energy consumption, it recorded a high of over 81% in 2003 but has since declined to about 75% in 2009. Increased deforestation and environmental degradation have drastically reduced the forest cover and wood fuel is no longer readily available as it used be.

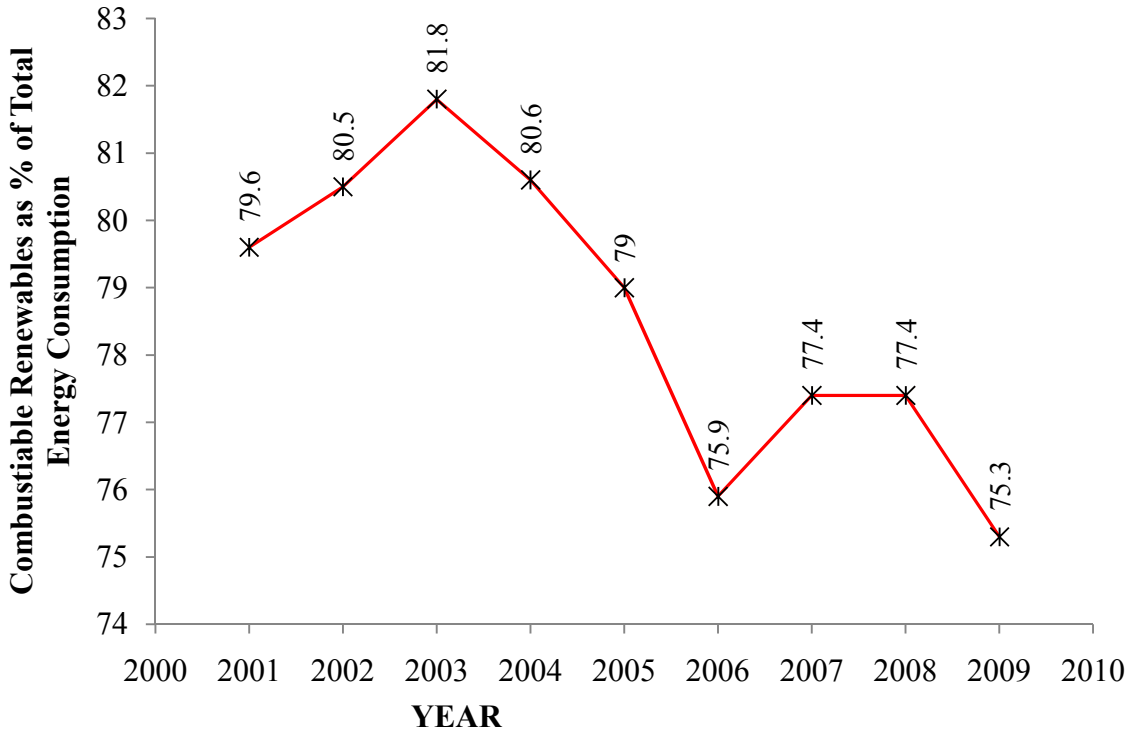


Figure 6: Consumption of combustible renewables as a percent of total energy.

In this study therefore, the focus is on the potential of solar energy resources with a view to improving access to adequate and stable energy supply to reduce reliability on imported fuel sources.

1.4 STATEMENT OF THE PROBLEM

Energy is an inevitable and essential input for all socio-economic development activities of a country. In the rural areas, much of the required energy is mainly for household activities such as cooking, lighting, water warming and to some extent, space warming. It should be noted that, the source of this energy is of biomass origin mainly in the form of wood fuel (firewood and charcoal) though there is appreciable use of kerosene particularly for lighting purposes. Demand for wood impacts the natural ecosystem through fuel harvesting and disruption of the natural nutrient cycling. Indoor air pollution from traditional cooking methods has serious health implications. High levels of fuel smoke exposure have been linked to acute respiratory infection in particular Pneumonia, Eye infection and Burns (Marigi, 1999). There is also a limitation to the continued use of wood fuel in the country owing to the fact that much of the country is either arid or semi-arid meaning that the area coverage of such resources is very small compared to the size of the country. Over-exploitation of this resource as result of the ever increasing population with increased demand has therefore resulted in massive environmental degradation and ultimate climatic alterations. There is therefore need to promote alternative, new and renewable sources of energy in the rural areas of the country. This approach is inevitable given the fact that the biomass based fuels are becoming increasingly environmentally unsustainable, thus affecting the development process. Solar energy is more environmentally friendly. This resource is therefore one of the better energy alternatives and that is why the focus of this thesis is more on it, especially for the benefit of the country's rural dwellers.

1.5 JUSTIFICATION OF THE STUDY

Faced with the danger of depletion of world petroleum oil supplies, and the almost certain global climate change, associated with its utilization, nations are forced to seek alternative sources to supply growing energy demands. For Kenya, several clean energy technologies will play an important role in this challenge, including wind, geothermal, biomass, hydroelectricity, and nuclear power. However, none of these technologies has the scalable capacity to meet the whole of our global energy demands. Nuclear power is capable of providing Kenya with the entire power requirement. The problem is security associated with its use, scarcity of Uranium, advanced technology involved and radioactive wastes which the country may have difficulties dealing with. There is therefore a need to turn to the sun, which provides power to the earth at a rate of 130 TW (Duffie, 2006).

Solar power for domestic applications is quite promising (Marigi, 1991). Solar cookers have the potential to substantially reduce stress on families. Families with solar cookers will be able to spend less time searching for fuel and have less exposure to toxins from smoke (Marigi, 1999). In addition, solar cookers can ameliorate the detrimental effects wood fuel collecting has on the environment.

Renewable energy has received little attention in Kenya compared to developed countries such as Germany and Denmark where wind and solar energy are fully utilized. For example, in Denmark 60% of its energy requirement is from wind energy (Asplund, 2008).

With ample sources of renewable energy such as solar, there is great potential for Kenya to be self-reliant. The Solar energy resource in Kenya is relatively under-utilized. It is therefore important to explore further its potential and search for possible areas of prime usage especially within the households. With knowledge of geographical location and characteristics, this resource can be effectively tapped and utilized. Since a majority of the Kenyan population lives in dire poverty particularly in the rural and urban slam areas, it is imperative that environmental friendly energy sources be readily available for their benefit as well as that of the environment, otherwise, the environment will continue to suffer and this will compromise the capacity of future generations to meet their basic requirements sustainably from the same environment.

Knowledge of the exploitable potential of the solar resource and identification of potential regions for development will help energy planners to incorporate the resource as alternative means of supplying energy by conducting a more accurate techno-economic analysis which will lead to realistic economic projections.

1.6 HYPOTHESIS

Nakuru lies along the equator where the sun is overhead all the year round and therefore, the region must be endowed with a high solar energy potential.

1.7 OBJECTIVES OF THE STUDY

The overall objective of this study is to assess the potential of solar energy for utilization within Nakuru municipality. This overall objective will be achieved through the following specific objectives:

- i. To examine the temporal (diurnal, seasonal and annual) characteristics of global solar radiation as an energy resource in Nakuru municipality.
- ii. To evaluate the availability of the solar energy resource in (i) with specific reference to energy requirements (cooking, lighting and water heating).
- iii. To perform a cost analysis of the available solar energy resource and compare with the total cost of the conventional biomass or fossil based fuels currently in use within the municipality.
- iv. Based on (iii), evaluate the extent of climate change mitigation through utilization of solar energy within the municipality.

1.8 AREA OF STUDY

The study was conducted within the Nakuru Municipality, which was founded in 1904 as a railway outpost 160 km from Nairobi. It is located along the east-west transport route that links the Kenyan Coast with Lake Victoria and Uganda. It is located between longitudes 35° 28' and 35° 36' East and latitudes 0° 12' and 1° 10' South. Its altitude is 1859m above the sea level and it is within the Great Rift Valley region, figure 7 (Sourced from KMD, 2011).

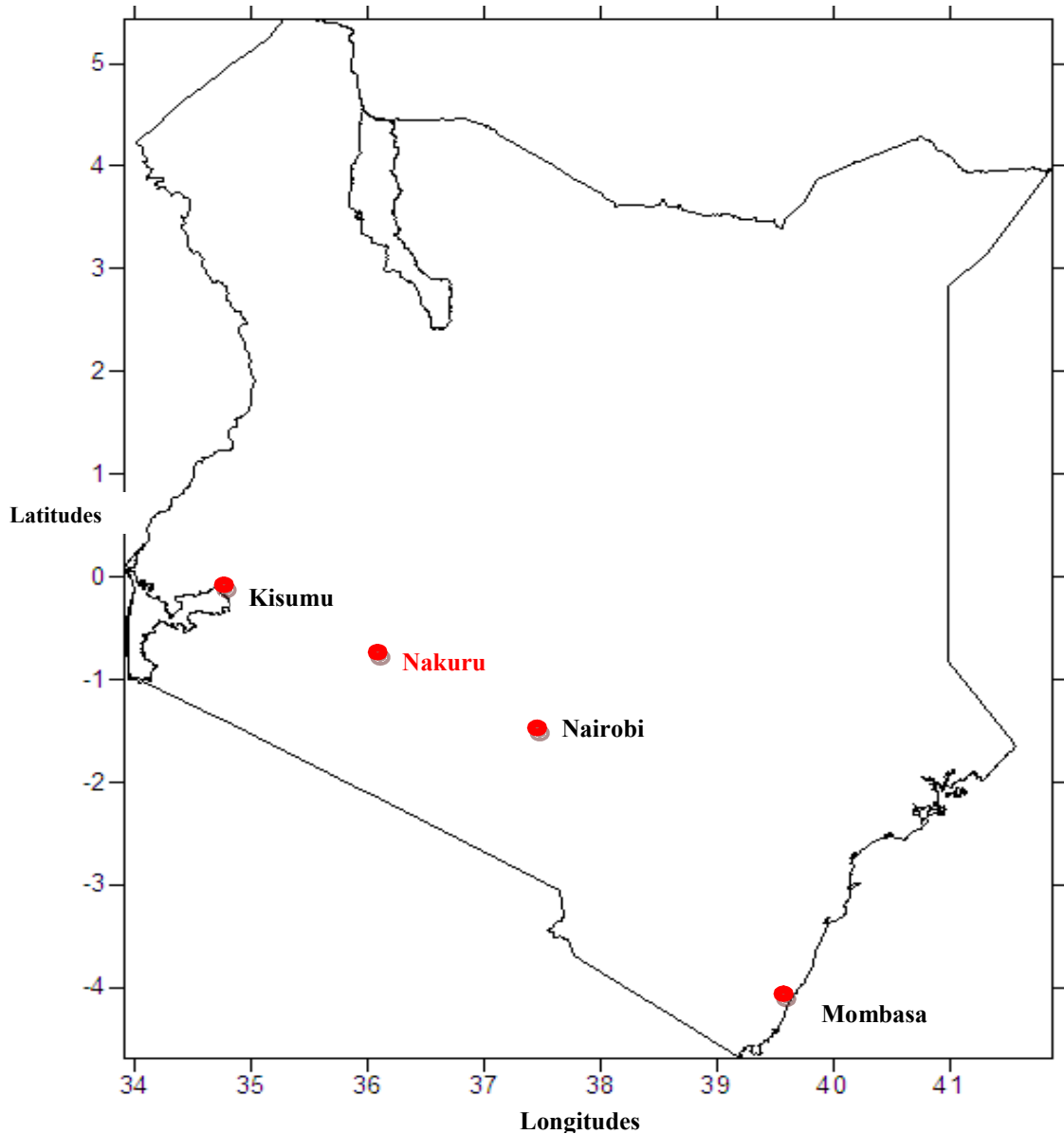


Figure 7: Location of Nakuru on the map of Kenya.

The town is on a remarkable and overwhelming setting between the Menengai Crater and Lake Nakuru - home to the famous flamingoes. Located on the floor of the Rift Valley, Nakuru founded on volcanic soils is prone to whirlwinds of dust during the dry season - giving the town its name. At present the town is the fourth largest in Kenya

after Nairobi, Mombasa and Kisumu and is the headquarters of Nakuru County. After the 1992 boundary extension, the Municipality now covers an area of 290 sq. km with the town occupying 102 sq. km while the famous Lake Nakuru Park covers the remaining 188 sq. km.

The town's population has been growing at the rate of 5.6% per annum since 1948. From a population of 17,625 in 1948, 38,181 in 1962, the population reached 163,927 in 1989 and 289,385 in 1999 as shown in table 2 (GOK, 2000; GOK, 2010). By the year 2020, the population of the Nakuru Metropolitan Area (NMA) is projected to rise to over 1,052,018 of which 953,378 are expected to be residing within the present Municipal boundaries.

Table 2: Population growth for Nakuru.

Year	1948	1962	1969	1979	1989	1999	2009
Population	17,625	38,181	47,151	92,851	163,927	289,385	443,424

(GOK 2005, 2009)

Before independence (1963), the movement of the African population into Nakuru, then a 'White Man's' town was 'restricted'. After independence, the town was opened up to all. The Africanization of the European farms in Nakuru District led to more migration into Nakuru District as well as the town. The bulk of workers in European farms moved to the town to look for employment opportunities. Many also formed Co-operative Societies/Companies, which bought European farms and subdivided them into smallholdings among themselves, thus accelerating in-migration.

The town and region are endowed with vast resources that include Lake Nakuru, which forms part of the Lake Nakuru National Park. The park is famous for the vast numbers of flamingoes, and some wild animals. It also hosts Menengai Crater, a dormant volcano. The town is an important educational center too hosting Egerton University, a large public university, and Kabarak University, a private university, the Rift Valley Institute of Science and Technology and the Kenya Industrial Training Institute (KITI) among others. Adequate and timely provision of infrastructural facilities and services including electricity, water, sewerage and drainage is essential for the efficient running of urban level activities such as industry, commerce, and housing, thereby enhancing the general welfare of urban dwellers. In Nakuru, the provision of these facilities is the responsibility of the public sector (Government and Municipality).

As seen from this short history, the town is growing at a very high rate while provision of basic facilities has not expanded at the same rate to serve the population. As an example, the main provider of electric power is the Kenya Power & Lighting Company, which supplies according to demand. The demand for power is growing rapidly and at the moment it exceeds the supply. There are also frequent power interruptions, which have very adverse effects on manufacturing industries and key services like hospitals, telecommunication and water supply. Many industries and key institutions have been forced to install standby power generators, (GoK, 2005).

CHAPTER TWO

2.0 LITERATURE REVIEW AND THEORETICAL BACKGROUND

2.1 LITERATURE REVIEW

The Kenya National Bureau of Statistics (KNBS) did a study using descriptive statistics to summarize the energy situation in Kenya over the 1969-1977 periods (Republic of Kenya, 1978). The study identified that oil is the major energy source in Kenya and it is wholly imported. The study suggested that the major factors leading to the economy's problems by that time were related to the imported oil and the high oil prices experienced in 1973.

Spatial and temporal characteristics of global solar radiation have been examined in Kenya using relatively simple techniques. Obasi and Rao (1976) presented mean monthly values of global radiation. They also examined the resource availability in relation to electrical energy potential at various conversion efficiencies of solar energy conversion systems.

Okoola (1982) presented the spatial distribution of mean solar radiation over Kenya and examined its availability in relation to electrical energy demand for water heating in Nairobi and deduced the sizes of solar energy conversion systems that would be required to meet this demand. Ogallo and Runanu (1998) examined the space time characteristics of maximum, minimum and mean daily solar radiation as the indicators

of the available solar power potential. Their results reveal that the potential is highest in western Kenya.

Marigi (1991) used hourly radiation values to examine the temporal characteristics of various solar power ratings in Nairobi to determine the potential of the resource. He applied the basic theories of frequency and cumulative frequency analysis. His results revealed that the potential is quite high especially for systems of medium and low solar power ratings. Marigi (1999) carried out a detailed space-time study of the solar energy resource over Kenya to determine its potential. He applied advanced statistical and several empirical techniques. His results reveal that: Kenya is divided into ten homogenous solar energy zones each with its own unique characteristics. Most parts of the country lie within the moderate and high solar energy potential classifications and the available solar energy is adequate for the household activities carried out in the rural areas of Kenya all the year round.

While investigating wind energy for some selected sites in Kenya, Kamau (2010), used empirical methods including the Power law, Logarithmic law and Weibull statistics, to investigate diurnal, monthly and inter-annual variability of the wind speed and direction, however they didn't examine solar energy which causes the wind systems.

Chiemeka and Chinene (2009) evaluated the global solar energy potential at Uturu, Nigeria. They obtained temperature data from 1st - 30th November, 2008 using the maximum and minimum thermometers placed in the Stevenson screen, 1.5 m above ground level. They used Hargreaves equation to evaluate the solar energy potential at

Uturu. Results of the evaluation revealed that the mean solar power potential obtained for the period over Uturu was 2.45 ± 0.29 kWh m⁻² per day.

The Potential of Solar and Wind energy resources for use in generating electricity for rural household in Central Rift Valley, Kenya, were explored by Kirui (2006). He did a comparative analysis to determine the appropriate renewable energy option for Njoro. Computations of the resource characteristics revealed that the magnitudes of the available resources are time dependent. On a seasonal basis, the December – February season has the highest potential of these resources while June – August season depicts the least potential. Mean wind speeds in this area lie between 2 m/s and 4 m/s while during the December – February season, mean wind speeds is in excess of 3 m/s. The seasonal minimum and maximum power available from the wind is 4.49 W/m² and 37.30 W/m² respectively while that from the sun is 201.88 W/m² and 375.83 W/m² respectively.

2.2 THEORETICAL BACKGROUND

2.2.1 SOLAR ENERGY

The solar constant is the generally accepted value for the flux density of shortwave radiant energy of 1367 Wm⁻² (Geuymard, 2004; Duffie and Beckman, 1991) intercepted on a plane perpendicular to the sun's rays at the "top" of the atmosphere at mean earth-sun distance. This value represents the theoretical maximum solar radiation input. Successively larger decreases from this theoretical maximum occur with latitudes more distant from the sub-solar point, times of day more distant from solar noon, and times of

year when the earth-sun distance increases. The theoretical maximum amount of radiation at the top of the atmosphere at a given point – the extraterrestrial solar radiation – is a known function of latitude, time of day, and time of year (Ye, 1996).

The radiation arriving at the earth's atmosphere is referred to as extra-terrestrial solar radiation. Knowledge of the spectral distribution of this radiation is important in such applications such as in the photovoltaic power systems. Further, the radiation that reaches the earth is a function of the extra-terrestrial radiation. The flux density of the extraterrestrial radiation is given by the solar constant or insolation, defined as the summation of the amount of solar energy arriving at the earth's outer atmosphere per unit area during one hour.

While the intensity of total solar radiation received at the top of the atmosphere at the sub solar point is 1367 Wm^{-2} , mean solar radiant intensity incident upon the top of earth's Atmosphere is a smaller value, but is totally predictable. For this averaged total, the spherical shape of the earth requires that the solar constant be calculated across a circle onto which the solar radiation intercepted by the earth is projected at a given time. This cross sectional area is equivalent to the area of a circle (). However, the earth rotates under this solar radiation and therefore distributes its intensity across the area of a sphere ($4 \pi r^2$). Therefore, mean extraterrestrial solar radiation is equal to one-fourth of the solar constant, or approximately 341 Wm^{-2} . Once the incoming solar radiation moves through the atmosphere, its intensity is reduced by attenuation (the combined effect of absorption and scattering) by atmospheric gases (Particularly ozone, water

vapor and carbon dioxide), aerosols (clouds and particulate matter) and Reflection in the atmosphere and on the surface is also responsible for reduction of the radiant flux density from the solar constant. The uneven distribution of these atmospheric constituents, as well as the myriad of surfaces with different reflective properties and the irregular elevation of the earth's surface (and the resulting unequal atmospheric thickness), ensure that the radiant flux density that ultimately reaches the ground varies greatly across space. The fact that the earth is moving relative to the sun and the atmosphere is moving relative to the earth ensures that the radiation distribution varies significantly at a point over time.

2.2.1.1 Solar radiation

Solar radiation is the radiant energy emitted by the Sun in the form of electromagnetic waves. The electromagnetic waves travel with speed of light C and are related to its frequency ν and wavelength λ by the relation $C = \nu \lambda$. About 98% of the total emitted energy lies in the spectrum range 250nm to 3000nm. About half of the radiation is in the visible short-wave part of the electromagnetic spectrum. The other half is mostly in the near-infrared part, with some in the ultraviolet part of the spectrum. Solar radiation having wavelength less than 0.286nm (called ultraviolet) is absorbed by the ozone layer in stratosphere. The ultraviolet radiation not absorbed by the atmosphere is responsible for the change of color in skin pigments figure 8 (SRHB, 2008). When the sun's rays pass through the atmosphere, some energy is scattered and some is absorbed in the atmosphere and hence attenuation of solar radiation takes place. The exact amount of

solar radiation will depend up on the altitude and sun's zenith angle at the observing point, which determines the amount of atmosphere the radiation has to penetrate (Gueymard, 1995; Iqbal, 1983).

Individual particles of light are called photons. An individual photon is considered to possess a single wavelength depending on its energy content. The range of wavelengths in the solar spectrum is directly due to collection of photons of different energy content. The distribution of photons in a wide energy spectrum has a deciding role in the performance of many solar energy utilization devices.

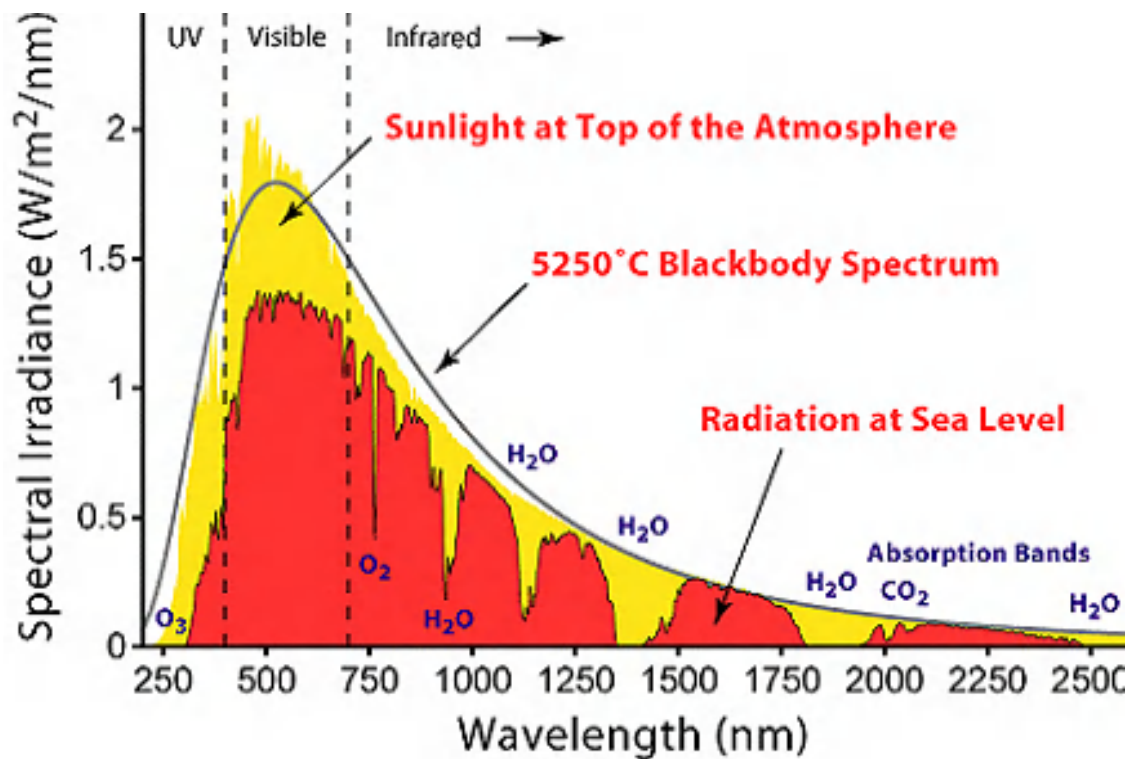


Figure 8: The solar spectrum.

2.2.1.2 Scattering

When light passes through the atmosphere, photons interact with atmosphere through *scattering*. If the light does not interact with the atmosphere, it is called *direct radiation* and is what we see if we were to look directly at the Sun. *Indirect radiation* is light that has been scattered in the atmosphere. For example, on an overcast day when shadows are not visible, there is no direct radiation reaching the ground, meaning it has all scattered. The process is also observed in the phenomenon of Rayleigh scattering where, blue (shorter wavelengths) scatter more easily than red (longer wavelengths). This is why the sky looks blue; we are seeing scattered blue light. This is also why sunsets are red. Because the Sun is close to the horizon, the Sun's rays pass through more atmosphere than normal to reach our eye. Much of the blue light has been scattered out, leaving the red light in a sunset.

2.2.1.3 Absorption

Different molecules absorb different wavelengths of radiation. For example, O₂ and O₃ absorb almost all wavelengths shorter than 300 nanometers. Water (H₂O) absorbs many wavelengths above 700 nm. When a molecule absorbs a photon, it increases the energy of the molecule. We can think of this as heating the atmosphere, but the atmosphere also cools by emitting radiation.

2.2.1.4 Emission

Emission is the opposite of absorption. This is when an object emits radiation. Objects emit radiation depending on their "black body" emission curves. Hotter objects tend to

emit more radiation, with shorter wavelengths. Colder objects emit less radiation, with longer wavelengths. For example, the Sun is approximately 5,800 K (5,530 °C), its radiation peaks near 500 nm, and is visible to the human eye. The Earth is approximately 290 K (17 °C). From *Wien's* displacement equation 2.1.

$$\lambda_{\max} = \frac{b}{T} \dots\dots\dots(2.1)$$

Where; λ_{\max} is the peak wavelength, T is the absolute temperature of the black body, and b is a constant of proportionality called *Wien's* displacement constant, equal to $2.8977685(51) \times 10^{-3} \text{ m}\cdot\text{K}$. So, its radiation peaks near 10,000 nm, and is much too long to be visible to humans. Because of its temperature, the atmosphere emits infrared radiation. For example, on clear nights the Earth's surface cools down faster than on cloudy nights. This is because clouds (H₂O) are strong absorbers and emitters of infrared radiation. This is also why it becomes colder at night at higher elevations. The atmosphere acts as a "blanket" to limit the amount of radiation the Earth loses into space. The *greenhouse effect* is directly related to this absorption and emission (or "blanket") effect. Some chemicals in the atmosphere absorb and emit infrared radiation, but do not interact with sunlight in the visible spectrum. Common examples of these chemicals are CO₂ and H₂O. If there are too much of these *greenhouse gases*, sunlight heats the Earth's surface, but the gases block the infrared radiation from exiting back to space. This imbalance causes the Earth to warm, and thus climate change.

2.3 THE SUN

The sun is the primary source of solar radiation. It's a sphere of intensely hot gaseous matter with a diameter of 1.39×10^9 m and is on average, 1.5×10^{11} m from the earth. The sun has an effective blackbody temperature of 5777 K. It's in effect, a continuous fusion reactor (Duffie and Beckman, 1991).

The sun is composed of the core that contains the burning gases at very high temperatures; so it is the centre of thermonuclear fusions that power the sun. The great majority of atoms are stripped off their electrons at temperature above 15,000,000K. Each hydrogen atom weighs 1.0078 atomic mass units (amu) and each He atom is made of 4 hydrogen atoms thus weighing 4.0312 amu. During the fusion process an excess mass in of 0.0282 amu above the He atom of 4.003 amu is converted into energy E according to Einstein's formula: $E = mc^2$ where c is the velocity of light.

The sun emits energy at an extremely large and relatively constant rate; 24 hour per day, 365 days per year. About 0.7% of the fused mass is released as energy, with mass-energy conversion rate of 4.26 million metric tons per second, 384.6 yottawatts (3.846×10^{26} W) (Duffie and Beckman, 1991). Light travels from the Sun to Earth in about 8 minutes and 19 seconds. Because of its high temperatures, all matter in the Sun is in the form of gas and plasma. This makes it possible for the Sun to rotate faster at its equator. The differential rotation of the Sun's latitudes causes its magnetic field lines to become twisted together over time, causing magnetic field loops to erupt from the Sun's surface and trigger the formation of the Sun's dramatic sunspots. This twisting action

creates the solar dynamo and an 11-year solar cycle of magnetic activity as the Sun's magnetic field reverses itself about every 11 years (Spencer, 2006). Since 1979, when satellite measurements of absolute irradiative flux became available, the numbers of sunspots have been observed to correlate with the intensity of solar radiation. Since sunspots are darker than the surrounding photosphere, it might be expected that more sunspots would lead to less solar radiation and a decreased solar constant. However, the surrounding margins of sunspots are brighter than the average, and so are hotter; overall, more sunspots increase the sun's solar constant or brightness (Spencer, 2006).

2.4 EARTH'S ATMOSPHERE

The atmosphere of Earth is a layer of gases surrounding the planet Earth that is retained by the Earth's gravity. The atmosphere protects life on Earth by absorbing ultraviolet solar radiation, warming the surface through heat retention (greenhouse effect), and reducing temperature extremes between day and night (the diurnal temperature variations).

2.4.1 ATMOSPHERIC STRATIFICATION

Figure 9 (Wikipedia, 2010) describes the structure of the atmosphere, dividing it into distinct layers, each with specific characteristics such as temperature or composition. The atmosphere has a mass of about 5×10^{18} kg, three quarters of which is within 11 km of the surface. The atmosphere becomes thinner and thinner with increasing altitude (Wikipedia, 2010). Air is the name given to atmosphere used in breathing and photosynthesis. Dry air contains roughly (by volume) 78.09% nitrogen, 20.95% oxygen,

0.93% argon, 0.039% carbon dioxide, and small amounts of other gases. Air also contains a variable amount of water vapor, on average around 1%, while air content and atmospheric pressure varies at different layers. Air suitable for the survival of terrestrial plants and terrestrial animals is currently known only to be found in Earth's troposphere and artificial atmospheres (Wikipedia, 2011).

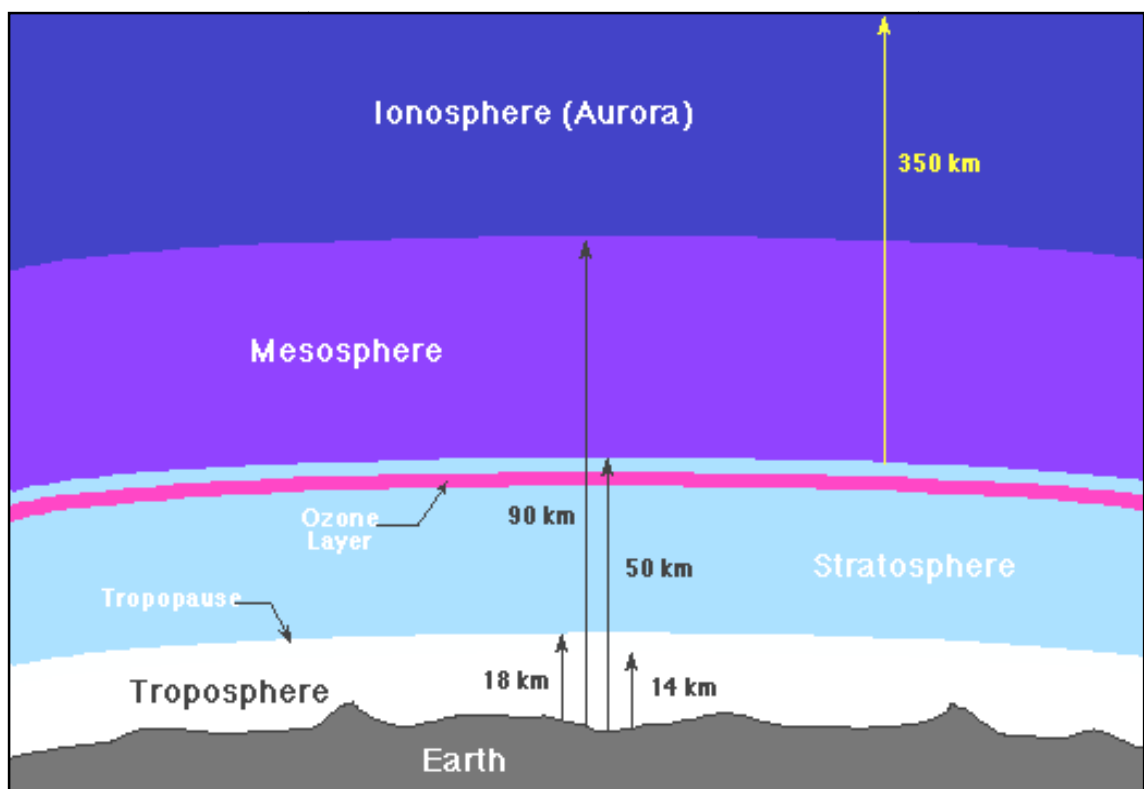


Figure 9: The Earth's Atmosphere.

2.4.1.1 Troposphere

Three quarters of the atmosphere lies within the troposphere. The troposphere begins at the surface and varies to around 17 km at the equator and 7 km at the poles. Variation is due to weather. The troposphere is mostly heated by transfer of energy from the earth's

surface, so on average the lowest part of the troposphere is warmest and temperature decreases with altitude. The tropopause is the boundary between the troposphere and stratosphere.

2.4.1.2 The stratosphere

The stratosphere extends from the tropopause to about 51 km. It is the sphere with the largest atmospheric ozone (O_3) distribution at distance range of about 40 to 50 km above the surface, called Ozone layer or Ozonosphere. Ozone is the gas that absorbs the harmful part of the Ultraviolet radiation, and therefore protects life on Earth. Within this region, temperature increase with height. This' due to increased absorption of ultraviolet radiation by the ozone layer, which restricts turbulence and mixing. While the temperature may be very low at the troposphere, the top of the stratosphere is much warmer, and may be near freezing. The stratopause, which is the boundary between the stratosphere and mesosphere, typically is at 50 to 55 km.

2.4.1.3 The mesosphere

The mesosphere extends from the stratopause to 80–85 km. It is the layer where most meteors burn up upon entering the atmosphere. Temperature decreases with height in the mesosphere. The mesopause, the temperature minimum that marks the top of the mesosphere, is the coldest place on Earth and has an average temperature around $-85\text{ }^{\circ}\text{C}$. At the mesopause, temperatures may drop to $-100\text{ }^{\circ}\text{C}$. Due to the cold temperature of the mesosphere, water vapor is frozen, forming ice clouds (or noctilucent clouds).

2.4.1.4 The Ionosphere

This is the layer of the Earth's atmosphere ranging from about 100 to 700 kilometers above the surface where oxygen and nitrogen are ionized by sunlight, producing free electrons. The radio waves from the earth are reflected here. It is divided into two regions;

a) The Exosphere

This is the top most region of a planet's atmosphere from which particles in the atmosphere can escape into space. It ranges from about 690 km to about 800 km from the surface of the Earth. It is mainly composed of hydrogen and helium. The particles are so far apart that they can travel hundreds of kilometres without colliding with one another. Since the particles rarely collide, the atmosphere no longer behaves like a fluid. These free-moving particles follow ballistic trajectories and may migrate into and out of the magnetosphere or the solar wind.

b) The thermosphere

It is a layer of the Earth's atmosphere, above the mesosphere, heated by x-rays and Ultraviolet radiation from the sun; it ranges from 80-85 km to about 640 km. This is the region of auroras.

Temperature increases with height in the thermosphere, after which it becomes constant. Unlike in the stratosphere, where the inversion is caused by absorption of radiation by ozone, in the thermosphere the inversion is as a result of the extremely low density of molecules. The temperature of this layer can rise to 1,500 °C, though the gas

molecules are so far apart that temperature in the usual sense is not well defined. The air is so obscure, that an individual molecule (of oxygen, for example) travels an average of one kilometer between collisions with other molecules (Donald, 2005). The International Space Station orbits in this layer, between 320 and 380 km. Because of the relative infrequency of molecular collisions, air above the mesopause is poorly mixed compared to air below. The top of the thermosphere is the bottom of the **exosphere**, called the exobase. Its height varies with solar activity and ranges from about 350–800 km. The **Kármán line**, located within the thermosphere at an altitude of 100 km, is commonly used to define the boundary between the Earth's atmosphere and outer space. However, the exosphere can extend from 500 up to 10,000 km above the surface, where it interacts with the planet's magnetosphere.

2.5 MODELS FOR SOLAR ENERGY ESTIMATION

Even in the regions of the earth that receive large amounts of sunshine, there are significant localized differences in the total amount and times of solar radiation reaching the earth's surface. Coast lines, rivers, large lakes, hills and mountains, and other geographic features affect the low cloud amounts and the time of the day at which they form or dissipate (WMO, 1981). It is not practical to install the large number of Pyranometers and radiometers that would be required to monitor these localized differences in cloud cover. Empirical formulae can be used to provide this essential solar radiation data. Several physical and empirical models have been developed to

calculate the solar radiation using various parameters which are as follows (Gueymard, 1995; Iqbal, 1983):

2.5.1 The Bird Clear Sky Model

The Bird Clear Sky Model, authored by Richard Bird, is a broadband algorithm which produces estimates of clear sky direct beam, hemispherical diffuse, and total hemispherical solar radiation on a horizontal surface. The model is based on comparisons with results from rigorous radiative transfer code. It is composed of simple algebraic expressions with ten user provided inputs. Model results should be expected to agree within $\pm 10\%$ with rigorous radiative transfer code. The model computes hourly average solar radiation for every hour of the year based on the ten user input parameters; however variable atmospheric parameters such as Aerosol Optical Depth, Ozone, and Water vapor are fixed for the entire year.

2.5.2 The Bird Simple Spectral Model

The Bird Simple Spectral Model computes clear sky spectral direct beam, hemispherical diffuse and hemispherical total irradiance on a prescribed receiver plane-tilted or horizontal at a single point in time. For tilted planes the user specifies the incidence angle of the direct beam or the tilt and azimuth of the plane. The wavelength spacing is irregular covering 122 wavelengths from 305 nm to 4000 nm. Aerosol optical depth, total precipitable water vapor (cm) and equivalent ozone depth (cm) must be specified by the user. No variation in atmospheric constituents or structure is available. There is no separate computation of circumsolar radiation. The direct beam spectral irradiance is

assumed to contain the circumsolar radiation within a 50° solid angle. No smoothing functions are provided.

2.5.3 DISC model

In the DISC model the user supplies hourly average measured global horizontal data. The algorithm uses empirical relationships between the global and direct clearness index to estimate the direct beam component. Computations are based on the solar geometry for the hour and clearness indices.

2.5.4 The SMARTS model

The SMARTS model authored by Dr. Christian Gueymard, computes clear sky irradiance (direct beam, circumsolar, hemispherical diffuse and total on a prescribed receiver plane-tilted or horizontal) for one set of atmospheric conditions (user specified, or selected from ten standard atmospheres); and for one to many points in time of solar geometries. The algorithms were developed to match the output from the MODTRAN complex band models within 2%. The algorithms are implemented in compiled FORTRAN code for the Macintosh and PC platforms. Source code is available. The algorithms are used in conjunction with files for atmospheric absorption of atmospheric components and spectra albedo functions. The spectral function is 0.5 nm from 280 nm to 400 nm; 1 nm from 400 nm to 1750 nm, and 10 nm from 1750 nm to 4000 nm. The user constructs a text file of between 20 and 30 lines of simple text and numbers specifying input conditions and up to 28 spectral output parameters. The user may specify field of view angles for direct beam computations, and a separate computation

for circumsolar component. Gaussian or triangular smoothing functions with user-defined band width may be specified to compare model results with measurements made with the specified pass band. The user may specify only ultraviolet (280 nm-400 nm) computations for erythemal dose, UV index, etc. Photometric (luminous flux) computations, weighted by selected photopic response curve, may also be specified. Output is spreadsheet-compatible ASCII text file and heads information with prescribed conditions [Gueymard, 1993].

2.6 TECHNOLOGIES FOR THE CONVERSION OF SOLAR ENERGY

There are a variety of technologies for the conversion of solar energy. These range from solar collectors on house roofs for space and water heating to solar power plants, with large arrays of mirrors concentrating solar energy to heat water and drive turbines to produce electricity. The type of solar energy conversion system installed in an area depends on the prevailing climate. Solar thermal electric conversion systems based on the power tower concept convert only direct solar radiation. They are therefore more suited to the dry (arid and semi-arid climate) regions, where the proportion of direct radiation is higher than in the cloudier areas. The use of solar energy for domestic space and water heating as well as lighting depends on a number of climatic factors including heat losses in the house (Makokha, 1991). Information on microclimatic conditions (shading and sheltering) as well as on the macroclimate of the area of interest is therefore necessary for the design of solar heated houses as well as selection of appropriate photovoltaic systems. (Makokha, 1991) has for example emphasized the

importance of making a balanced assessment of all factors when making an evaluation of the economic and viability of solar heating systems, incoming solar radiation and the length of time over which heating is required ought to be considered. This also applies to other solar energy conversion systems such as photovoltaics. A longer operating season in less climatically favorable regions could give an installed solar space heating system or photovoltaic system a greater economy.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 INTRODUCTION

This chapter discusses the various Instruments, materials and methods, which were employed to study the solar energy resource in Nakuru. The instruments include those installed by the KMD on the ground to monitor the solar radiation while the methods include those which were used to determine the quality of climatological data of Nakuru Meteorological station, temporal characteristics of the resources, capital together with running costs of the solar energy conversion technologies as well as, household energy consumptions with their associated costs.

Details of these methods are presented in the sections and sub-sections that follow

3.2 INSTRUMENTS FOR MEASURING SOLAR RADIATION

In order to assess the available solar energy arriving on the earth's surface, measurements of solar radiation at locations on the earth are essential. The solar radiation reaching the earth's surface consists of two components: direct and diffuse solar radiation. The former component is that part of the direct solar beam which reaches the earth surface directly from the sun without being scattered, reflected or dispersed in any form. The latter component is that part of the solar radiation which reaches the earth's surface as a result of scattering, reflection, and other dispersion of

the solar beam. The sum of the direct and diffuse components of solar radiation gives the total (global) solar radiation.

Solar radiation can be measured or derived from empirical models. Some of the models were briefly discussed in section 2.5. Measurements are done by several different types of instruments having various characteristics and degree of accuracy. A Pyrheliometer is an instrument used for measuring direct radiation flux, and a Pyranometer is used for measuring global radiation. A specially shaded Pyranometer measures diffuse radiation. Pyranometers are most frequently used to measure solar radiation (WMO, 1981; Uiso, 1998).

Data from Nakuru meteorological station is measured directly with LiCor® pyranometers. Brief descriptions of these instruments are given below.

3.2.1 Pyranometer

This instrument is widely used by weather and climate scientists. It is used to measure the amount of sunlight hitting the Earth's surface at a particular place and time, that is, it measures the solar radiation falling on a horizontal surface in watts (the amount of energy received each second) per square meter (insolation).

A typical, laboratory-grade pyranometer is essentially a thermopile (a collection of thermocouples, perhaps 50-100) mounted on a black carbon disc, which generates electricity according to how hot it gets (how much solar radiation falls on it). There's a dome made from one or two layers of ground and polished optical glass or acrylic

plastic covering the thermopile, which eliminates air movements and dirt that might affect the measurements. The curved outer surface also ensures any raindrops fall away quickly. A small, replaceable cartridge of silica gel (or other desiccant) inside the dome absorbs any dew. Since a thermopile typically sits outside in an exposed position, its case is made from toughened, rustproof, and anodized aluminum. There's also built-in spirit level to ensure that the pyranometer is flat, (WMO, 1983).

The pyranometer, figure 10, (Researchers' initiative), works on the principle that when sunlight falls on it, the thermopile sensor produces a proportional response typically in 30 seconds or less: the more sunlight, the hotter the sensor gets and the greater the electric current it generates. The thermopile is designed to be precisely linear (i.e., doubling of solar radiation produces twice as much current) and also has a directional response. It produces maximum output when the Sun is directly overhead (at midday) and zero output when the Sun is on the horizon (at dawn or dusk). This is called a cosine response (or cosine correction), because the electrical signal from the pyranometer varies with the cosine of the angle between the Sun's rays and the vertical.



Figure 10: Pyranometer

3.2.2 Campbell-Stokes Tropical Sunshine Recorder

The instrument (figure15) is used to measure sunshine duration. The instrument has a T-shaped metal base drilled to take three screws. Circular nuts on three vertical screws fixed to the top of the main base, support a sub-base which may be leveled and also rotated through a small angle in the horizontal plane. The sub-base is locked in position by means of another set of circular nuts. A sturdy column with a curved top mounted on the sub-base, carries a vertical semi-circular bar at the ends of which are screws supporting a glass sphere. A metal card holder is fixed at right-angles to the sphere support. The cardholder is a section of a sphere concentric with the glass sphere and has

three overlapping sets of grooves on its concave face which carry the three different recording cards which must be used at different times of the year. The semi-circular bar slides in grooves along the top of its mounting to adjust the card-holder for latitude. The glass sphere focuses sun's rays which burn a trace along the card with apparent motion of the sun across the sky.

With regard to exposure and adjustment, the instrument should be situated so that it can "see" the sun throughout the day on every day of the year. The sphere must be concentric with the card-holder. This adjustment, in which a special centering gauge is used, is best carried out in an instrument workshop before the instrument is dispatched to the site. If the sphere has to be removed for any reason, one support screw only should be unscrewed. Leaving the other screw undisturbed ensures that the sphere can be replaced in its original position.

In the case of records and measurements, three types of cards are used to allow for the sun's apparent movement across the Equator to the Northern and Southern Hemispheres. These cards are: Cord No. 6732 - a straight EQUINOCTIAL Card used at about the time when the sun is overhead; Cord No. 6731 - a shorter, curved WINTER Card and Cord No. 6730- a longer curved SUMMER Card. But in Kenya, we mainly use card No 6730 (W.M.O, 1983).

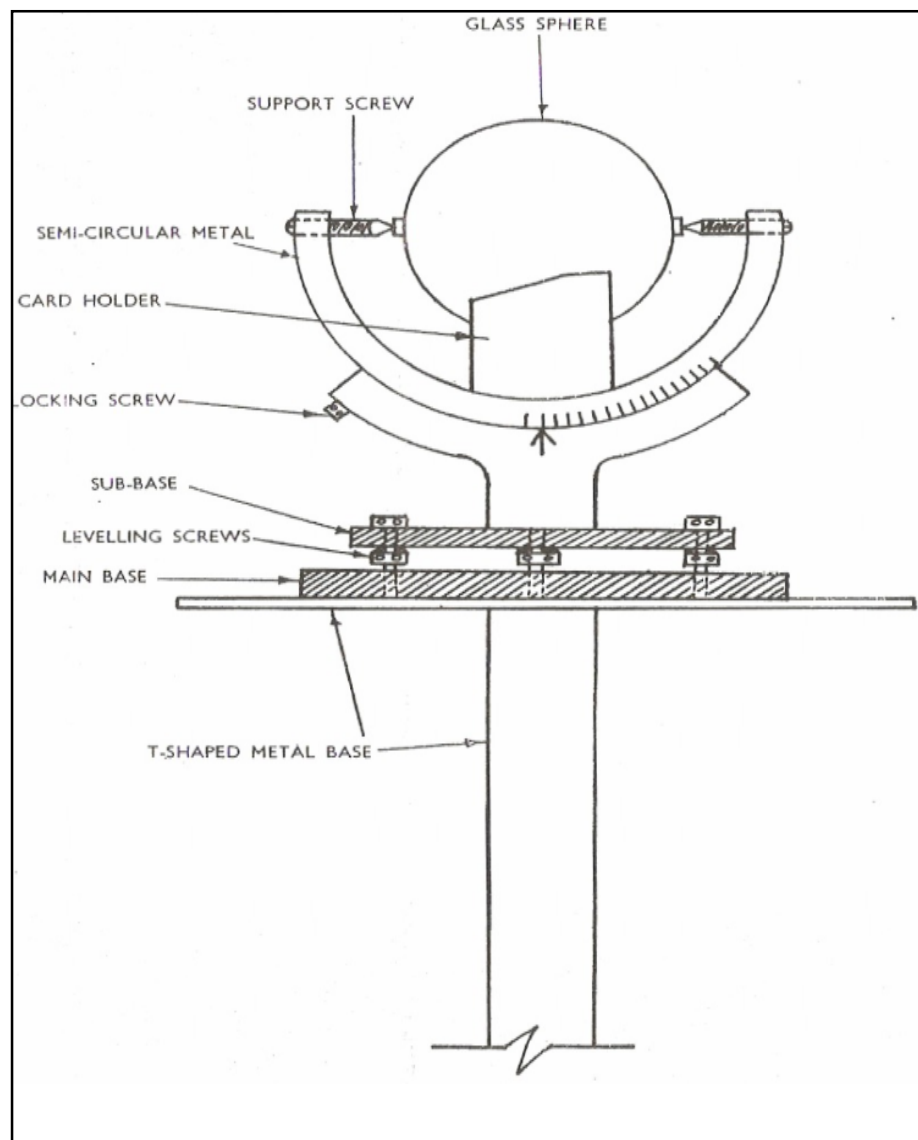


Figure 11: Campbell-stokes tropical sunshine recorder

3.3 QUALITY CONTROL METHODS

The methods include those which were used to determine the quality of climatological data of Nakuru Meteorological station and they include:

3.3.1 Quality Control Tests

Most climatological records are characterized by inconsistencies which may be caused by changes in the location and exposure of the measuring instrument, technology, instrument type and microclimate. Errors associated with data collection, transmission and processing may also introduce heterogeneity into the records. The inclusion of estimated data into the records may also introduce heterogeneity into such records. It is therefore necessary to check for the quality of climatological records before such data is used in any climatological analyses. Numerous factors could affect the consistency of the record at a given station. This include: damage and replacement of the instrument; change in the instrument location or elevation; growth of high vegetation or construction of a building; change in measurement procedure; or human, mechanical, or electrical error in taking readings.

Quality control is thus concerned with the detection of errors in the data to ensure that data sets are error free, complete and have been recorded according to international standards.

Homogeneity tests on the other hand examine whether data samples are from the same statistical distribution. Many statistical tests have been used to control the quality of climatological records. These range from the use of simple mass curves to complicated non-parametric methods. Brief accounts of the Range validation, Mass curves and one sample runs tests methods that were adopted in this study are given in the next sub-sections.

3.3.2 Range Validation

Range validation was carried out to compare the recorded values against the historical largest and lowest values at the Nakuru location in order to ensure that the records are within the physical or logical limits. This was accomplished by appropriate manipulation of the data in Microsoft excel software.

3.3.3 Mass Curve Analysis

The method used cumulative values (Y_t) of observations (X_t) which were plotted against time (t). This was meant to test for homogeneity and heterogeneity.

3.3.4 One Sample Runs Test

A run is defined as the persistence of consecutive values above or below a given threshold value; where, the threshold is the median value of a set of observations. The number of runs above or below the median value of a sample of observations can give some indications of homogeneity or heterogeneity in a time series of observations. In this study a statistic “Z” was calculated from Equation 3.1 (Marigi, 1999).

$$Z = \frac{\tau - \left(\frac{2n_1 n_2}{n_1 + n_2} + 1 \right)}{\sqrt{\frac{2n_1 n_2 (2n_1 n_2 - n_1 - n_2)}{(n_1 + n_2)^2 (n_1 + n_2 - 1)}}} \dots\dots\dots (3.1)$$

Where: τ is the number of observed runs, n_1 and n_2 are the number of runs above or below the median. For large sample sizes ($N > 40$), the Z approximates to a standard normal distribution (mean zero and unit variance). The significance of the calculated Z

is determined with reference to a standard normal table. $|Z| > 1.96$ at 5% level of significance indicates heterogeneity in the records.

3.4 THE SOLAR ENERGY RESOURCE

3.4.1 Characteristics of the Solar Energy Resource

The characteristics examined in this respect include the diurnal; seasonal and annual power expectations as well as resource reliability.

3.4.2 Diurnal and Seasonal Solar Energy and Power Computations

The values of (x) as collected from the Kenya Meteorological Department archives were all in Mega joules per square meter per day ($\text{MJ m}^{-2}\text{d}^{-1}$). These were, therefore, converted to the widely used standard units of energy (kWh) for ease of use. The following expression was applied:

$$1kWh = 3.6MJ \dots\dots\dots (3.2)$$

The mean daily solar energy (\bar{X}) available in Nakuru was determined as the ratio of the daily summations of the energy observed to the total number of days in the given month.

The total available solar energy on a unit area of horizontal surface for Nakuru in a given season was then obtained as a product of the number of days (N) in the season and the daily mean energy (\bar{X}) value for the season. The cumulative value for the four seasons represented the annual value.

3.4.3 Solar Energy Resource Reliability

The percentage of time in days in a given season in which available daily global radiation reaches or exceeds a reference threshold radiation value is a measure of its reliability. The reliability (δ_r) was quantified through equation 3.3.

$$\delta_r = \frac{100n}{N} \dots\dots\dots(3.3)$$

Where: n and N are the total number of days in which daily global radiation reaches or exceeds the reference threshold value and the total number of days in the month/season respectively. In this study, the threshold value has been taken as the minimum daily power requirement for moderate temperature to high temperature activities.

For ease of counting due to voluminous data involved, the daily global radiation dataset was converted into two dummies (**1**- for any value equal or above the threshold, **0** - for any value below the threshold). Threshold values used were 5.4kWh/m²/day and 6.8kWh/m²/day for moderate and high temperature activities respectively (Marigi, 1999). High temperature activities correspond to those carried out in industrial (manufacturing and processing) settings.

3.4.4 Temperature Trends

The annual trends of temperature in Nakuru were investigated through a simple time series plot of the observed data. This was necessary since temperature has implications in installation and operation of solar energy systems.

3.5 COST ANALYSIS

The Renewable Energy Decision Method developed by the Working Group on Development Techniques (WOT), University of Twente, Netherlands was adopted (Marigi, 1999), this method makes quick and simple estimations of costs of different renewable energy resources and provides a conventional solution. This decision method is only a useful guide to make a rough estimation of the costs so that no time is wasted on solutions that are not feasible at all. Calculations and the prices mentioned in this method are only estimates and can vary strongly due to differences in quality and local circumstances. For a final decision, prices from suppliers are absolutely necessary. A description of the method is hereby given:

3.5.1 Daily Energy Demand

The total daily household energy demand (E_d) is one of the factors which determine the size of a given energy source. This is dependent on equipment used, the energy consumption of each apparatus and how long each apparatus is used per day. If batteries are used, 40% more energy is needed. This is due to losses during charging/discharging of the batteries. Hence $E_d = \text{total in kWhd}^{-1}$ (without batteries) or $E_d = 1.4 \text{ total in kWhd}^{-1}$ (if batteries are used). In this study, the values of E_d were obtained from estimations of household fuel (wood, charcoal, kerosene) consumptions and utilization technologies within the municipality.

3.5.2 Battery Storage

The size of the battery storage depends on the number of days to cover energy demand if the energy source is not available (for instance the sun is not shining). A period of two or three days will be taken. For the number of days d of storage, the size of storage E_s and investment Inv on batteries are given by the relations:

$$E_s = d \times E_d = \text{_____}(\text{kWh})\dots\dots\dots(3.4)$$

$$Inv = 100 \times E_s = \text{_____}(\text{US\$})\dots\dots\dots(3.5)$$

3.5.3 Solar Energy

Given a certain climate with annual, seasonal, monthly or daily average amount of sunshine, a certain size of solar energy conversion system (e.g. photovoltaic) is needed to fulfill the daily energy demand. The size and costs depend on the solar insolation G ($\text{kWh m}^{-2}\text{d}^{-1}$) and the energy demand. The size of the solar energy conversion system, A , is given by the relation 2.6 (Marigi, 1999):

$$A = 12 \times \frac{E_d}{G} \dots\dots\dots (3.6)$$

Investment (in US\$) on the solar energy conversion system (inclusive of controls) varies with the sizes i.e.

$$Inv = 500 \times A \quad \text{for } A > 10 \text{ m}^2 \dots\dots\dots(3.7)$$

$$Inv = 1000 \times A \quad \text{for } 1 \leq A < 10 \text{ m}^2 \dots\dots\dots (3.8)$$

$$Inv = 2500 \times A \quad \text{for } A < 1 \text{ m}^2 \dots\dots\dots(3.9)$$

3.5.4 Investment and Running Costs

It is necessary to take into consideration the investment, the running costs and the expected lifetime. It is generally best to compute the total cost per year, consisting of investment costs (interest on the investment) and running costs (e.g. fuel and maintenance). For a lifetime N and percentage discount rate d (= Interest rate – annual inflation), the yearly investment costs are computed using equation 3.7 (Marigi, 1999).

$$\text{Inv cost} = \frac{(Ix d/100)}{\left(\left(1 - \left(1 + \frac{d}{100}\right)^{-N}\right)\right)} \dots\dots\dots (3.10)$$

For the renewable energy options like solar energy, the running costs are difficult to estimate but it is wise to reserve some percentage, for instance 3%, of the initial investment each year for maintenance and repair.

3.6 EVALUATION OF THE EXTENT OF CLIMATE CHANGE MITIGATION

3.6.1 The Run Concept.

In this evaluation, the concept of “**runs**” was employed. Based on the threshold global radiation value for moderate temperature activities such as those performed in households, the sequentially ordered radiation dataset was converted into two dummies (**1**- for any value equal or above the threshold, **0** - for any value below the threshold).

From the resultant dummy patterns, the following were determined:

- a) Mean length (in days) of a run above the threshold value, i.e. number of days of continuous solar power availability

- b) Mean length (in days) of a run below the threshold value, i.e. number of days of continuous solar power deficits
- c) The longest run (in days) above the threshold value
- d) The longest run (in days) below the threshold value

The mean length of a run above the threshold value represents the optimum duration (days) a solar powered system can be put into use. The expected longest run above the threshold represents the maximum possible duration a solar powered system may be put into use. On the other hand, mean length and longest runs below the threshold value represent respectively the optimum duration (days) as well as the expected longest duration (days) back-up systems or supplementary energy sources will have to be put into use. These parameters, as determined from this analysis, have been used to evaluate the extent of climate change mitigation based on the percentage of fuel savings and Carbon dioxide reduction. Expressions in section 3.6.2 below were used.

3.6.2 Chemical Equations for Burning Fuels

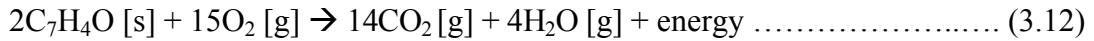
The fuels which were analysed include wood, charcoal, kerosene, LPG, and natural gas.

a) Wood

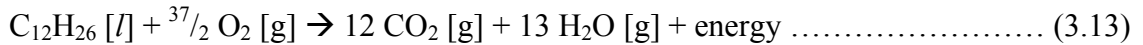
Cellulose is the single most abundant organic molecule in the biosphere. It is the major structural material of which plants are made. Wood is largely cellulose while cotton and paper are almost pure cellulose. Working on assumed complete combustion, when cellulose burns, the following reaction takes place:



b) Chemical equations for burning Charcoal

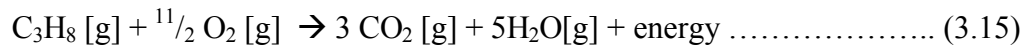
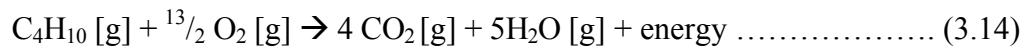


c) Chemical equations for burning Kerosene

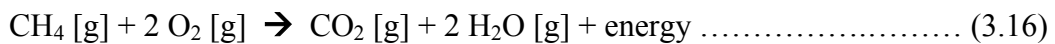


d) Chemical equations for burning Liquefied petroleum gas (LPG)

Butane (C_4H_{10}) and Propane (C_3H_8)



e) Chemical equations for burning Natural gas is primarily that of methane



A typical family's fuel consumption of Y kg per day for X days of continuous usage results in a release of kYX kg of CO₂, where k is amount of CO₂ given out per kg of the fuel.

For a period of say N days, if solar energy is used, then percentages of fuel savings and CO₂ reduction are the same and equals to 100(X/N).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter presents and discusses the results as obtained using the methodologies discussed in chapter three. The results are discussed independently under the following sub-sections.

- i) Quality control tests,
- ii) Spatial patterns of solar radiation,
- iii) Power computations,
- iv) Resource reliability,
- v) Cost analysis, and
- vi) Extent of climate change mitigation

4.2 RESULTS FROM QUALITY CONTROL TESTS

The methods which were used to examine the quality of the radiation records were described in section 3.3. A scan of the entire data revealed that the observed radiation records were consistent and within the standard logical limits. This signified that the observations were of good quality. Results from homogeneity tests which were used in the study are independently discussed in the following sub-sections. These included mass curve analysis and one sample runs-test.

4.2.1 Mass Curve Analysis

For homogeneous records, all Y_t values will cluster about a single straight line. If more than one line can be fitted to the Y_t scatter diagram then X_t values are heterogeneous. Figure 12 presents the pattern of the mass curve obtained from the cumulative values of annual average radiation records for the entire period of study. The vertical axis of these figures represents the cumulative solar radiation in MJm^{-2} . It is evident that only one straight line could be fitted. This indicates that the data samples were from the same statistical pyranometer and therefore homogeneous, hence high quality data used.

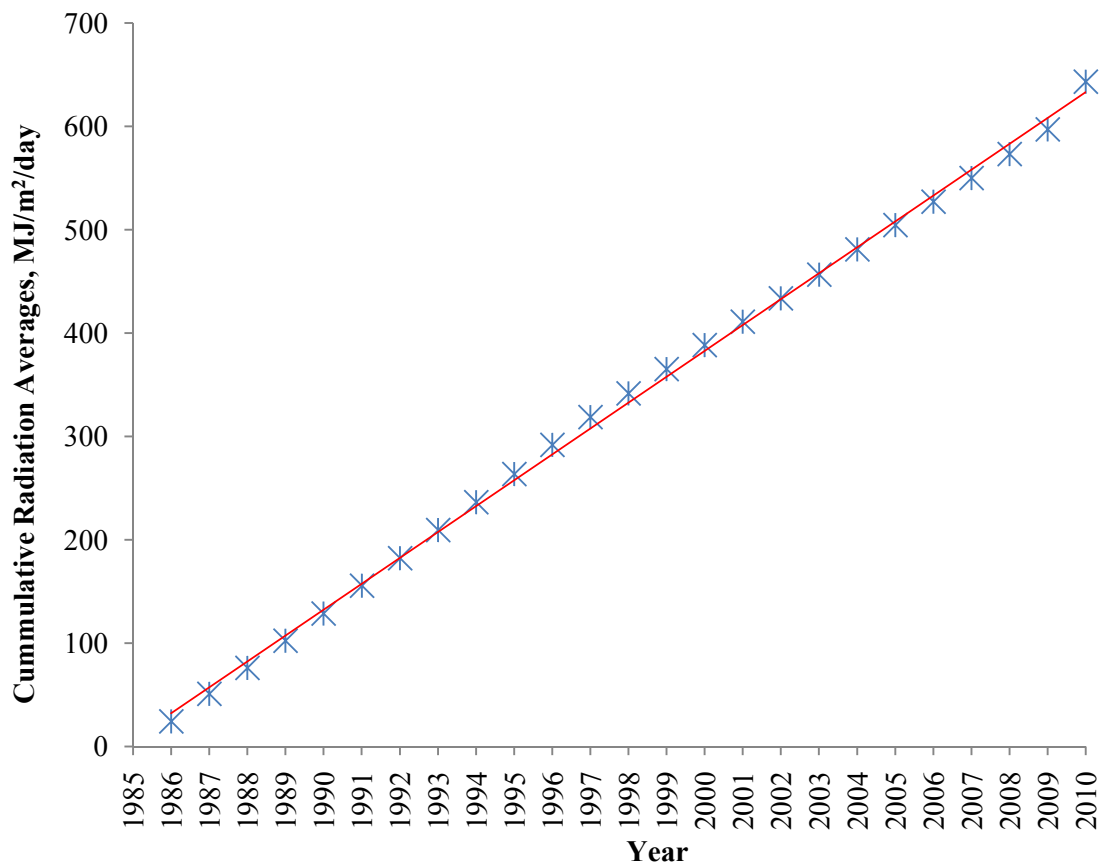


Figure 12: Mass curve for Nakuru radiation data

4.2.2 One Sample Runs-Test

A summary of the results of the run test are given in the Table 3 below.

Table 3: One sample runs-test results

Month	Jan	Feb	Mar	Apr	May	Jun
Z - Value	0.9913	0.9923	0.9912	0.9899	1.0125	0.9898
	Jul	Aug	Sep	Oct	Nov	Dec
	1.0253	0.9915	0.9899	0.9956	0.9914	0.9913

From table 3, all the Z values are less than 1.96 at 5% level of significance for all the months thus indicating that the series were all homogeneous and therefore high quality of data used.

4.3 TEMPORAL PATTERNS OF SOLAR RADIATION

4.3.1 Monthly Radiation Values

From the insolation values as measured for Nakuru municipality, 1986-2010 (Table 4). It was observed that the minimum ever recorded monthly value was 4.8kWh/m²/day and maximum value ever recorded is 9.8kWh/m²/day. A scan of the mean monthly values on the same table reveals that both values were observed in 1997. The maximum value was observed during the month of February and the lowest value occurred during the month of November. It should be noted here that December –February season is generally a dry hot season and therefore devoid of any significant cloudiness. A lot of solar radiation therefore penetrates the earth's atmosphere during this season.

Table 4: Average daily radiation values in kWh/m²

Year	Monthly Radiation Averages in kWh/m ² /day												Yr Av	Min value	Max value
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
1986	7.9	7.8	6.4	5.8	6.5	5.9	6.5	7.0	7.1	7.3	6.2	7.0	6.8	5.8	7.9
1987	7.6	8.1	7.6	7.1	6.6	6.6	7.9	7.5	7.9	7.6	6.1	7.9	7.4	6.1	8.1
1988	7.5	8.3	7.1	5.7	7.0	7.3	6.4	6.8	6.5	7.5	6.4	7.2	7.0	5.7	8.3
1989	8.1	8.5	8.1	6.5	7.0	7.6	6.8	7.3	7.5	6.8	6.2	7.1	7.3	6.2	8.5
1990	8.2	7.3	6.7	6.6	7.4	7.8	7.5	7.3	8.0	7.0	6.8	7.5	7.4	6.6	8.2
1991	8.7	8.9	7.9	7.1	6.8	7.3	6.3	7.3	8.1	7.2	6.3	7.5	7.4	6.3	8.9
1992	8.0	8.7	7.9	7.2	7.3	7.2	7.3	7.1	7.4	6.7	7.2	7.2	7.4	6.7	8.7
1993	6.6	8.2	8.5	7.2	7.2	7.0	7.1	8.2	8.2	7.5	7.3	7.6	7.6	6.6	8.5
1994	8.7	8.5	8.1	7.2	7.1	7.0	6.9	7.2	8.0	6.9	6.0	7.7	7.4	6.0	8.7
1995	9.0	8.5	7.6	7.2	7.4	7.8	6.7	8.0	7.3	6.8	7.3	7.4	7.6	6.7	9.0
1996	9.0	8.8	8.0	8.3	7.2	6.5	7.0	7.6	8.0	8.0	6.3	8.8	7.8	6.3	9.0
1997	8.8	9.8	7.8	6.7	7.9	7.6	6.9	8.1	8.6	6.4	4.8	6.3	7.5	4.8	9.8
1998	5.6	7.4	7.2	6.0	6.2	6.0	5.7	6.0	6.7	6.5	5.8	7.6	6.4	5.6	7.6
1999	7.3	7.4	6.4	6.3	6.5	6.6	6.3	6.5	6.7	6.3	5.3	6.2	6.5	5.3	7.4
2000	7.7	7.4	6.9	5.9	6.1	6.4	5.8	6.2	6.7	6.3	6.0	6.5	6.5	5.8	7.7
2001	6.1	7.4	6.3	5.5	6.3	6.2	6.2	6.5	6.4	6.2	5.4	7.0	6.3	5.4	7.4
2002	6.8	7.7	6.8	5.4	6.4	6.5	6.7	6.0	6.2	5.6	5.7	5.7	6.3	5.4	7.7
2003	7.4	7.3	6.9	5.8	5.5	6.2	6.2	5.6	6.4	5.8	5.6	6.9	6.3	5.5	7.4
2004	7.6	7.9	6.9	6.4	6.6	6.7	6.4	6.9	6.9	6.3	6.1	6.9	6.8	6.1	7.9
2005	7.3	7.7	6.7	5.8	6.5	6.6	6.3	6.6	6.1	6.1	6.0	7.2	6.6	5.8	7.7
2006	6.9	7.2	6.6	5.8	6.4	6.2	5.8	6.2	7.0	6.1	4.9	5.8	6.3	4.9	7.2
2007	7.3	6.9	6.9	6.0	6.4	5.5	5.6	6.0	6.2	6.2	6.1	6.7	6.3	5.5	7.3
2008	6.8	7.5	6.5	6.2	6.3	6.2	5.7	6.1	6.3	5.9	6.7	7.3	6.5	5.7	7.5
2009	7.0	7.1	7.3	6.5	6.3	6.9	6.6	6.7	6.4	5.6	6.6	6.3	6.6	5.6	7.3
2010	7.1	6.7	6.4	6.5	6.3								6.6	6.3	7.1
Monthly Av	7.6	7.9	7.2	6.4	6.7	6.7	6.5	6.9	7.1	6.6	6.1	7.1	6.9		
Max value	9.0	9.8	8.5	8.3	7.9	7.8	7.9	8.2	8.6	8.0	7.3	8.8			
Min value	5.6	6.7	6.3	5.4	5.5	5.5	5.6	5.6	6.1	5.6	4.8	5.7			

On the other hand, September – November season is the short rain season in the region with abundant and significant cloudiness. The penetration of solar radiation through the earth's atmosphere is therefore partially inhibited. This had been amplified by the El-

nino phenomena that prevailed during that period (Okoola *et al.*, 2008), hence the lowest radiation value which was observed during that month.

4.3.2 Global Dimming Phenomenon

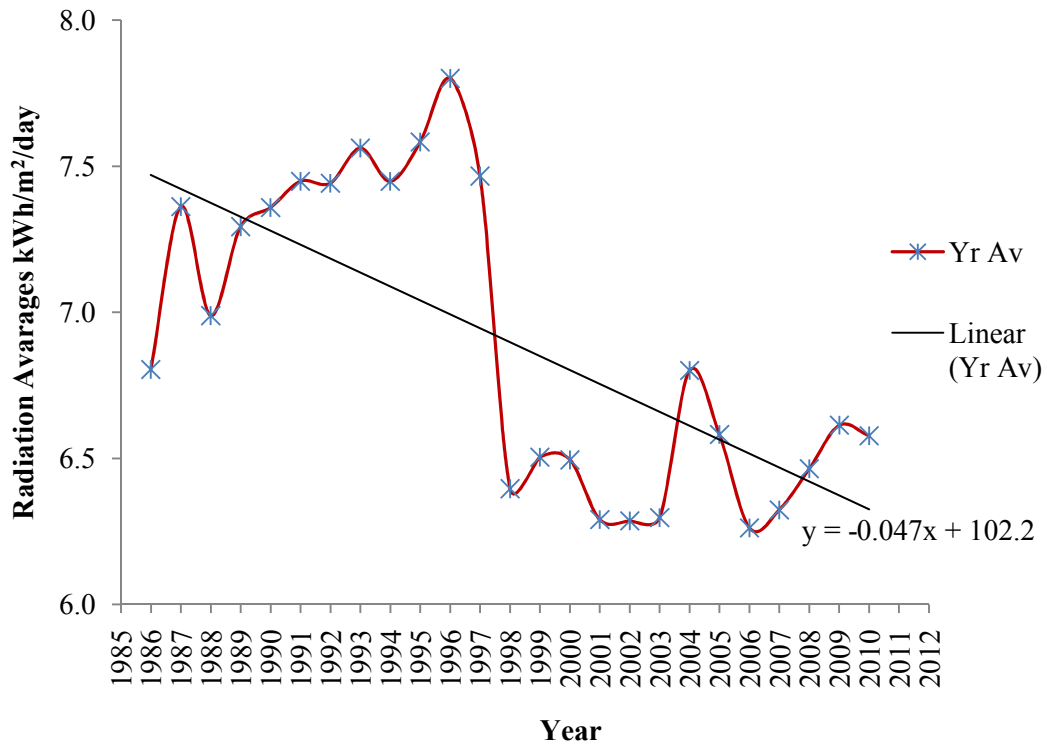


Figure 13: Average daily solar radiation pattern measured at Nakuru (1986-2010).

Figure 13 depicts the inter-annual variation of global radiation received on a horizontal surface in Nakuru. From the figure, it is evident that the amount of global radiation reaching the surface shows a gradual decreasing trend for the entire period analyzed. Similar monthly curves plotted are provided in Appendix 2. This confirms literature suggesting that the magnitude of solar radiation reaching the surface of the earth per

unit area is on downward trend, the so-called “global dimming” phenomenon (Stanhill and Cohen, 2001; Liepert, 2002).

The year 1997 was the wettest year in the Kenyan history (Okoola *et al.*, 2008). Heavy seasonal rains were also observed in some years including 1967, 1972, 1977 and 1982. It happens that the years 1997, 1982, 1972 and 1977 were El Nino years confirming the strong relationship between El Nino and rainfall associated with cloudiness that inhibits adequate penetration of sun’s radiation to the earth’s surface. However, a few heavy rainfall years, 1967 and 1961 do not coincide with El Nino events (Okoola *et al.*, 2008).

4.3.3 Radiation Trends

Table 5: Daily and monthly radiation averages in kWh/m², 1986 to May 2010

Month	Daily Average kWh/m²/day	Monthly Averages kWh/m²/month
December	7.1	212.0
January	7.6	226.9
February	7.9	236.4
March	7.2	215.6
April	6.4	193.1
May	6.7	200.5
June	6.7	202.2
July	6.5	195.9
August	6.9	206.1
September	7.1	213.6
October	6.6	198.3
November	6.1	184.1
Average and Total	6.9	2484.7

Table 5 provides a general trend of solar insolation averages all year round from which the daily, monthly and yearly potential is estimated. The daily potential estimate is 6.9

kWh/m² and the annual estimate is 2518.5 kWh/m², with varied monthly values as shown.

Figure 14 provides the raw data (1986 to May 2010) trend in MJ/m² before conversion to kWh. The upper curve provides radiation values for monthly maximums, the middle represent average value curve and the lower represent curve for minimum monthly values. Figure 15 provides trend after conversion for only the average monthly values. All the figures (14, 15 and 16) confirm that the region receives its highest insolation in the month of February and least value in the month of November. This information is important with regard to the trend and appropriate months to maximally harvest the solar energy resource.

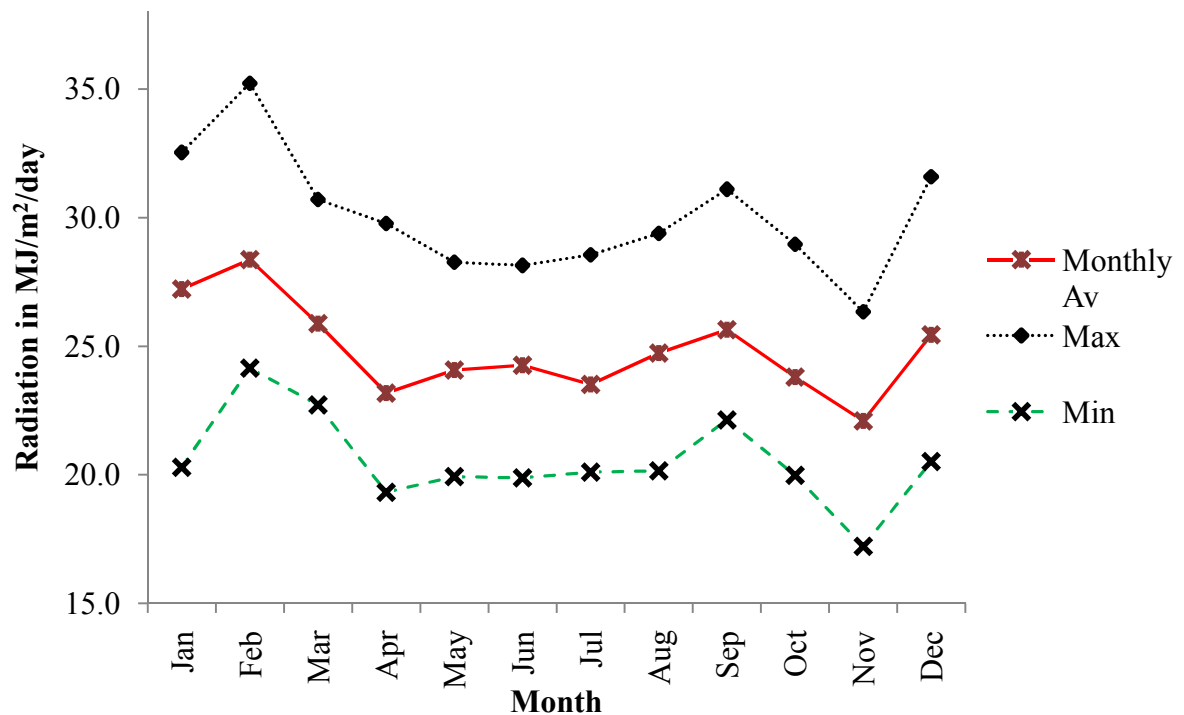


Figure 14: Radiation max, mean and min value graphs for Nakuru.

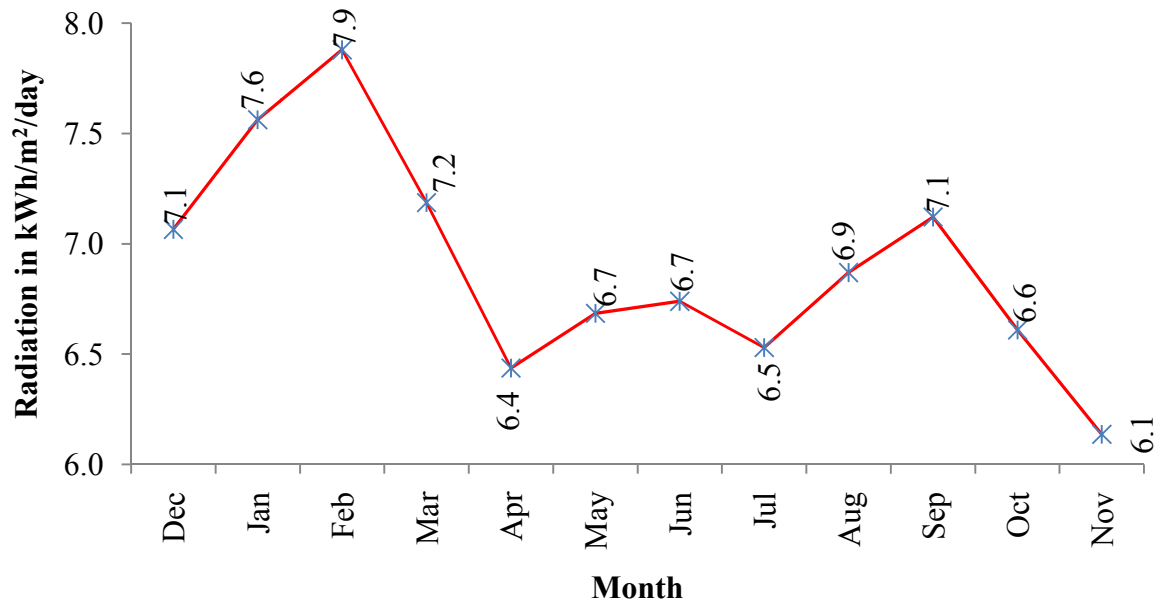


Figure 15: Graph of monthly average daily solar radiation pattern in kWh/m²

Figure 16 presents monthly solar energy trends for Nakuru.

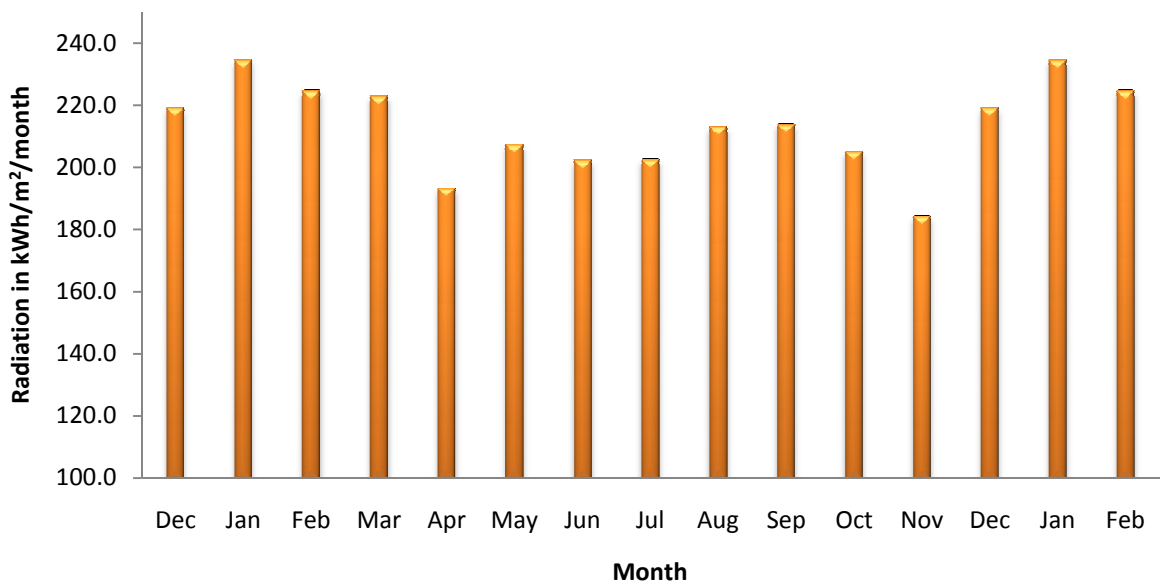


Figure 16: Average monthly insolation trend bar graph.

4.4 SEASONAL RADIATION ANALYSIS

The Kenyan climate is divided into four distinctive seasons that include: December-February, dry hot season; March-May, long rains season; June-August, dry cold season and September-November, short rains season (Okoola *et al.*, 2008).

The amounts of radiation received during these seasons are depicted in Table 6-9 and figures 17-20.

4.4.1 December - February Season.

Table 6 and figure 17 summarize the Radiation average values for the months of December, January, and February (1986 to 2010).

Table 6: Radiation average values for December – February season.

	December	January	February
Max recorded value (kWh)	8.8	9.0	9.8
Min recorded value (kWh)	5.7	5.6	6.7
Mean daily value (kWh)	7.1	7.6	7.9
Monthly mean value (kWh)	220.1	235.6	225.2

From the observations, the month of January receives the highest value of 235.6 kWh/m², followed by February with a value of 225.2 kWh/m² and lastly December with value of 220.1 kWh/m², totaling to 680.9 kWh/m² for the entire season.

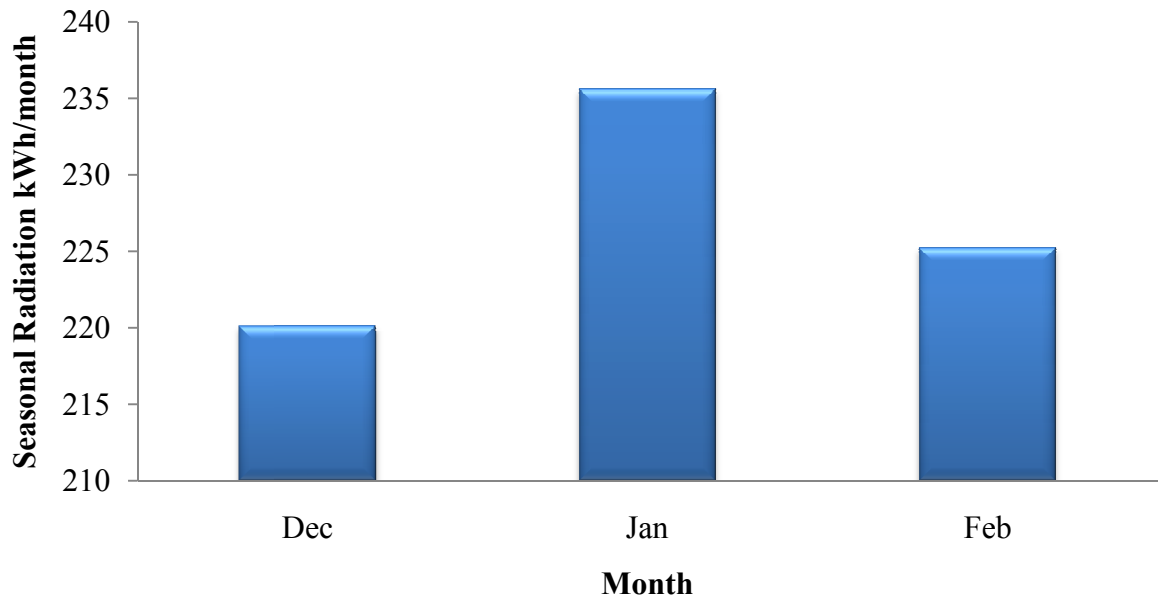


Figure 17: December - February seasonal radiation bar graph

4.4.2 March - May Season

Table 7 and figure 18 summarize Radiation values for the months of March, April and May (1986 to 2010).

Table 7: Radiation values for March – May season

	March	April	May
Maximum recorded value (kWh)	8.5	8.3	7.9
Minimum recorded value (kWh)	6.3	5.4	5.5
Mean daily value (kWh)	7.2	6.4	6.7
Monthly mean value (kWh)	222.8	193.1	207.2

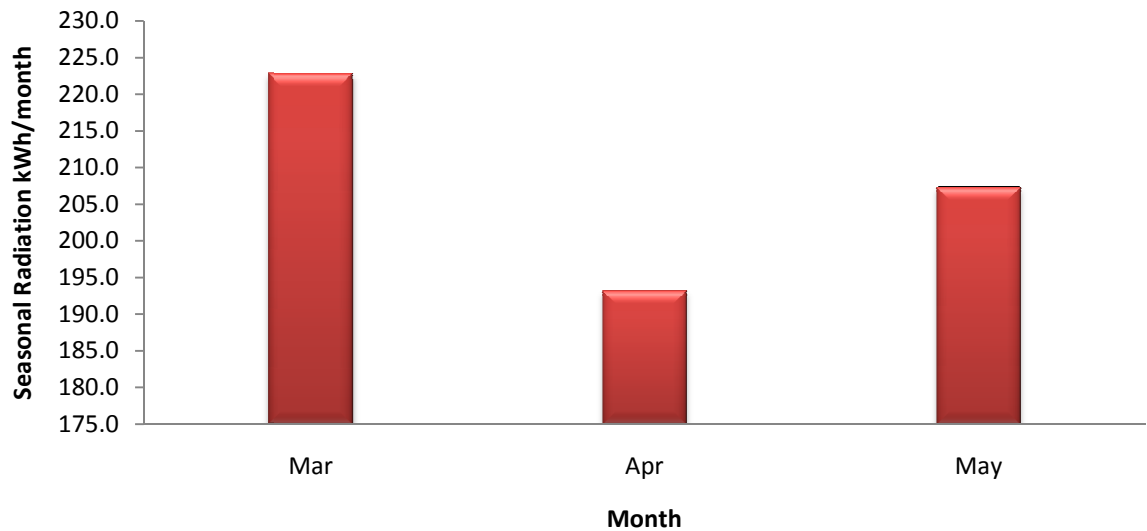


Figure 18: March – May season bar graph.

The month of March receives the highest value of 222.8 kWh/m² followed by May with average value of 207.2 kWh/m² with April receiving the least value of 193.1 kWh/m² totaling to 623.1 kWh/m² for the season.

4.4.3 June - August Season

Table 8 and figure 19 below summarize the Radiation values for the months of June, July and August (1986 to 2010).

Table 8: Radiation values for June - August season

	June	July	August
Max recorded value (kWh)	7.8	7.9	8.2
Min recorded value (kWh)	5.5	5.6	5.6
Mean daily value (kWh)	6.7	6.5	6.9
Monthly value (kWh)	202.2	202.4	213.0

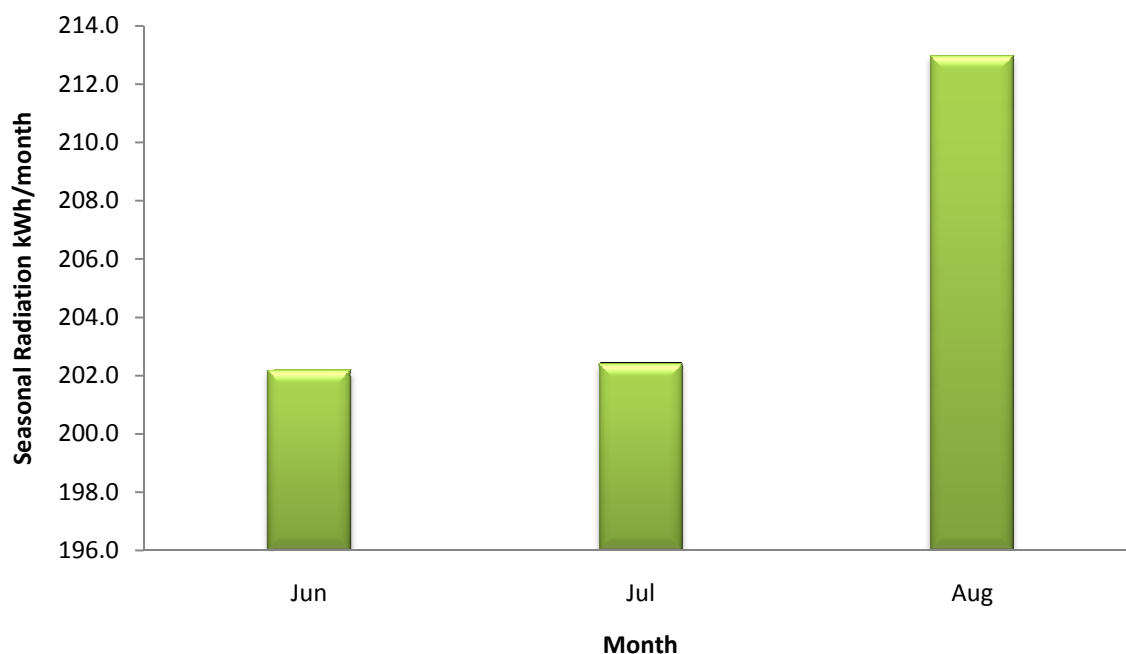


Figure 19: June - August season bar graph

The month of August receives the highest value of 213 kWh/m² followed by July and June least with 202.2 kWh/m² summing up to 617.5 kWh/m² for the season.

4.4.4 September- November Season

Table 9 and figure 20 summarize the radiation values for the months of September, October and November (1986 to 2010).

Table 9: Radiation values for September - November season

	September	October	November
Maximum recorded value (kWh)	8.6	8.0	7.3
Minimum recorded value (kWh)	6.1	5.6	4.8
Mean daily value (kWh)	7.1	6.6	6.1
Monthly value (kWh)	213.6	204.9	184.1

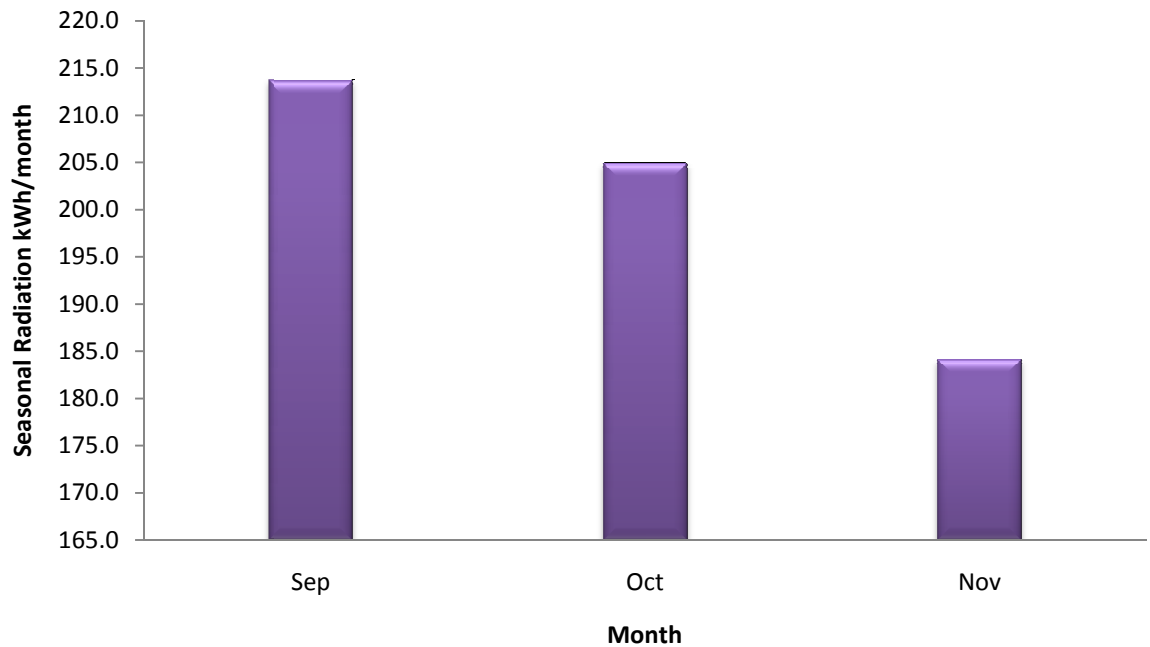


Figure 20: September- November season bar graph.

From the analysis, the month of November receives the least amount of radiation and September the highest. The season receives a total amount of 602.6 kWh/m².

4.4.5 Seasonal Energy Trends/comparisons

From figure 21, December-February season receive the highest insolation of 678 kWh/m². The seasonal values reduce gradually attaining their minimum during the September-November season.

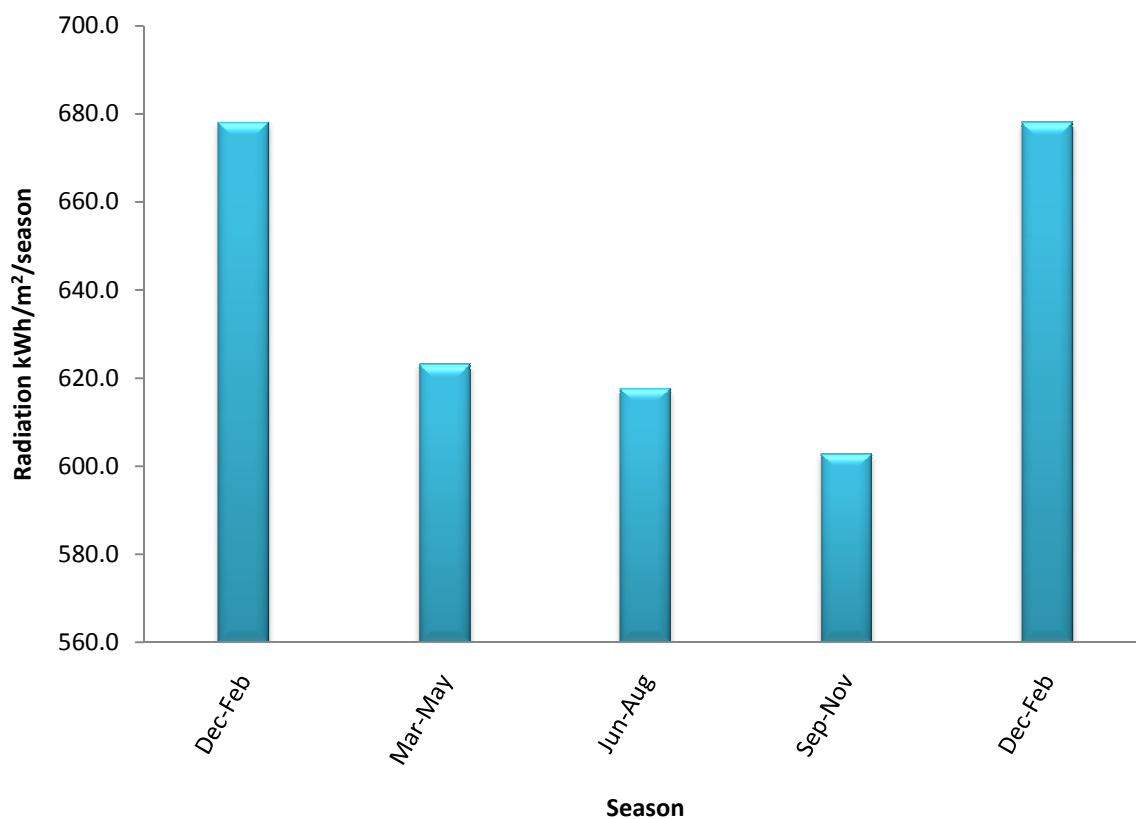


Figure 21: Seasonal energy trends/comparisons bar graph.

This can also be used to establish relationship between insolation and rainfall in a region, since after any dry spell depending on its magnitude; it is preceded by a proportional amount of rainfall.

4.5 SOLAR ENERGY RESOURCE RELIABILITY FOR NAKURU

4.5.1 Monthly Reliability Values

Table 10 provides values of the reliability as determined in this study. It is evident from the table that the highest reliability values of 95.7% and 80.2% for activities

corresponding to high and moderate temperature activities respectively. These are both observed during the month of February. The table indicates that reliability values generally range from 95.7% to 70.3% for activities corresponding to moderate temperature activities and from 80.2% to 34.6% for activities corresponding to high temperature activities. This indicates that the potential of the resource is quite promising and in particular for activities requiring moderate temperatures as those carried out in many households. The highest potential reliability is noted to exist during the month of February and the lowest potential in the month of November.

Table 10: Computed monthly solar energy reliabilities values for Nakuru

Month	Type(use)	Dummy Count Totals		Reliability (%)
		Total Days	Greater than threshold	
JANUARY	Medium	744	680	91.4
	High		544	73.1
FEBRUARY	Medium	677	648	95.7
	High		543	80.2
MARCH	Medium	744	670	90
	High		464	62.4
APRIL	Medium	720	564	78.3
	High		291	40.4
MAY	Medium	713	613	86
	High		362	50.8
JUNE	Medium	660	576	87.3
	High		330	50
JULY	Medium	682	555	81.4
	High		327	47.9
AUGUST	Medium	713	627	87.9
	High		398	55.8
SEPTEMBER	Medium	690	620	89.9
	High		427	63.3
OCTOBER	Medium	713	579	81.2
	High		333	46.7
NOVEMBER	Medium	720	506	70.3
	High		249	34.6
DECEMBER	Medium	682	584	86.6
	High		414	60.7

4.5.2 Seasonal Reliability Values

Table 12 provides a summary of the seasonal computed solar energy reliability values. It is evident from the table that December-February season has the highest reliability of 91.2% and 71.3% for temperatures corresponding to moderate and high temperature activities respectively while the September-November season has the least reliability values of 80.5% and 48.2% for temperatures corresponding to moderate and high temperature activities respectively. The annual reliability values are 85.5% and 55.5% for activities corresponding to moderate and high temperatures respectively.

These results further reveal the fact that the potential of solar energy in Nakuru is indeed promising given that reliability values are in excess of 50% for activities corresponding to both moderate and high temperatures.

Table 11: Summary of computed seasonal reliabilities values for Nakuru

Seasonal Reliability		
Season	temperature activities	Reliability %
Dec-Feb	Medium	91.2
	High	71.3
Mar-May	Medium	84.8
	High	51.2
Jun-Aug	Medium	85.5
	High	51.3
Sep-Nov	Medium	80.5
	High	48.2
Annual	Medium	85.5
	High	55.5

4.6 SURFACE TEMPERATURE TRENDS IN NAKURU

Ambient temperature has an impact on the installation and utilization of solar energy. Temperature generally determines the design characteristics of the solar energy capturing devices. In this study, therefore, the annual trends of ambient temperature in Nakuru were investigated through a simple time series plot of the observed data. Figure 22 depicts the trends in annual temperature observed. The figure reveals a general trend of temperature rising over time which confirms a general warming as result of increases in Green house gas concentrations (carbon dioxide, water vapor and other green house gases), a phenomenon referred to as “global warming”.

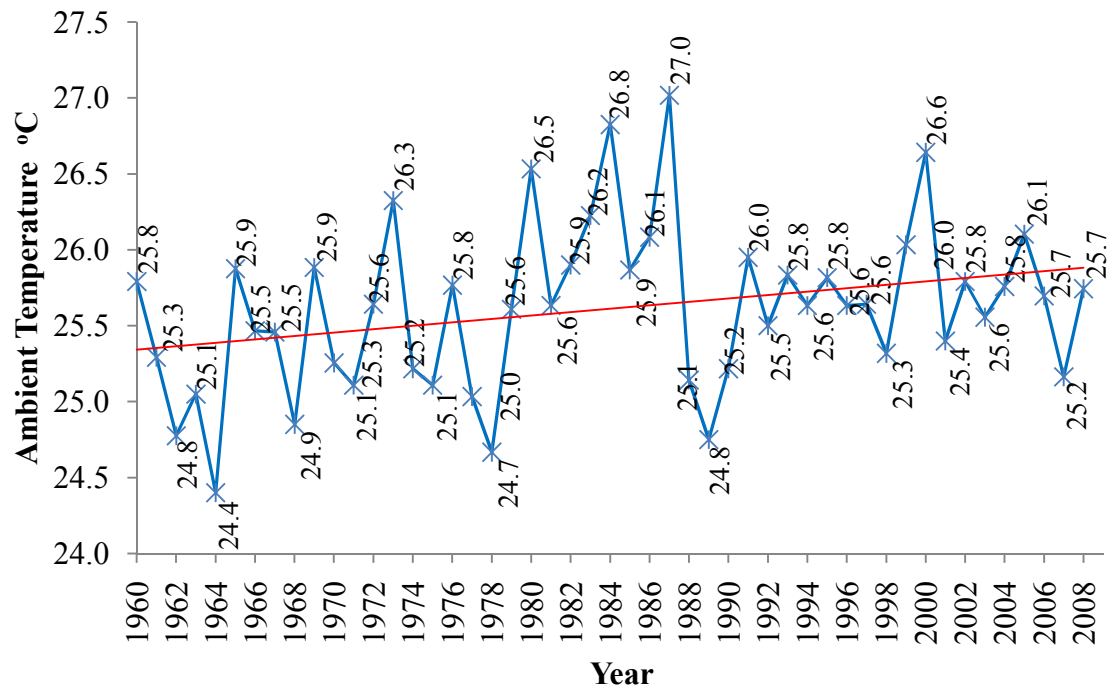


Figure 22: Observed annual temperature trends for Nakuru 1960-2008

4.7 ENERGY DEMAND.

4.7.1 Household Energy Demand.

Details of quantifying the household energy demands were presented in section 3.5 of methodology chapter. Research results are detailed in table 12. Results from the table indicate that consumption values for firewood, charcoal, kerosene, electricity and Liquefied Petroleum Gas (LPG), varied depending on location of household; whether urban or rural. The consumption patterns were also influenced by household size, occupation, and fuel price and education level. The usage of fuel types by various income categories reveals that the use of kerosene and fuel wood declines with rise in income (KIPPRA, 2010).

Table 12: Rural/Urban household energy demand.

Location	Fuel type	Quantity (kg)	Net Calorific Value by mass kWh/kg	Consumption (kWh)	Average Efficiency stove %	Effective Consumption (kWh)
Rural	Firewood	236	4.1	967.6	17	164
	Charcoal	21	8.7	182.7	28	51
	Kerosene	12.92	10.6	136.952	42	58
30days				1287.3		273
91 days				3904.8		828
92 days				3947.7		837
Urban	Electricity			107	89	95
	Charcoal	63	8.7	548.1	28	154
	LPG	13	12.9	167.7	60	101
30 days				822.8		350
91 days				2493.4		1062
92 days				2520.8		1973

4.7.2 Rural Scenario.

$$\begin{aligned}\text{Daily household demand (E}_d\text{)} &= 273/30 \\ &= \underline{\mathbf{9.1\ kWh}} \quad (\textit{Without Batteries})\end{aligned}$$

$$\begin{aligned}\text{or } &= 9.1 \times 1.4 \\ &= \underline{\mathbf{12.74\ kWh}} \quad (\textit{with batteries})\end{aligned}$$

4.7.3 Urban Scenario

$$\begin{aligned}\text{Daily household demand (E}_d\text{)} &= 350/30 \\ &= \underline{\mathbf{11.7\ kWh}} \quad (\textit{Without Batteries})\end{aligned}$$

$$\begin{aligned}\text{or } &= 11.7 \times 1.4 \\ &= 16.3 \underline{\mathbf{kWh}} \quad (\textit{with batteries})\end{aligned}$$

4.7.4 Battery Storage:

Taking period of two days (**Rural**),

Number of days of storage: $d = 2$ days

Size of storage: $E_s = d \times E_d$

$$= 2 \times 12.74 = 25.48 \text{ kWh}$$

Investment on batteries: $\text{Inv} = 100 \times E_s$

$$= \$ \underline{\mathbf{2548}}$$

Life time of batteries: $N = 5$ (years)

Taking period of two days (**Urban**),

Number of days of storage: $d = 2$ days

Size of storage: $E_s = d \times E_d$

$$= 2 \times 16.3 = 32.6 \text{ kWh}$$

Investment on batteries: $\text{Inv} = 100 \times E_s$
 $= \$ 3260$

Life time of batteries: $N = 5$ (years)

4.7.5 Solar Energy

4.7.5.1 Rural

Insolation for Nakuru (G) = $6.9 \text{ kWh m}^{-2}\text{d}^{-1}$

Size of solar panel: $A = 12 \times \frac{E_d}{G} \text{ (m}^2\text{)}$

$$= 12 \times 12.74 / 6.9 \text{ m}^2$$

$$= \mathbf{22.16 \text{ m}^2}$$
 Investment on solar system (inclusive control):

since $A > 10 \text{ m}^2$ then

$$\begin{aligned} \text{Inv} &= 500 \times A \\ &= \$ 500 \times 22.16 \\ &= \$ 11,078 \end{aligned}$$

Lifetime of solar system: $N = 25$ (years)

4.7.5.2 Urban

Insolation for Nakuru (G) = $6.9 \text{ kWh m}^{-2}\text{d}^{-1}$

Size of solar panel: $A = 12 \times \frac{E_d}{G} \dots \text{ (m}^2\text{)}$

$$= 12 \times 16.3 / 6.9 \text{ m}^2$$

$$= \mathbf{28.35 \text{ m}^2}$$

Investment on solar system (inclusive control): since $A > 10 \text{ m}^2$

$$\begin{aligned} \text{Inv} &= 500 \times A \\ &= \$ 500 \times 28.35 \\ &= \$ 14,173.91 \end{aligned}$$

Lifetime of solar system: N = 25 years)

4.7.6 Investment and Running Costs

4.7.6.1 Yearly Investment Costs

The yearly investment costs for **rural scenario**

Investment: Inv = \$ 11,078

Lifetime of investment: N = 25 Years

Discount rate: d = ... % (Interest rate – annual inflation) the current inflation rate in Kenya is 14.5% (CBK, 2011)

$$= 4.22 \% (18.72 - 14.5)$$

$$\mathbf{Inv\ cost} = \frac{(Ixd/100)}{\left(\left(1 - \left(1 + \frac{d}{100}\right)^{-N}\right)\right)} = ..US \$/year$$

$$= \underline{\underline{\$ 468}}$$

The yearly investment costs for **urban scenario**

Investment: Inv = \$ 14,173.91

Lifetime of investment: N = 25 Years

Discount rate: d = .. % (Interest rate – annual inflation)
= (18.72 – 14.5) %
= 4.22 %

$$\mathbf{Inv\ cost} = \frac{(Ixd/100)}{\left(\left(1 - \left(1 + \frac{d}{100}\right)^{-N}\right)\right)} = ...US \$/year$$

$$= \underline{\underline{\$ 599}}$$

4.7.6.2 Running Costs,

3% of the initial investment each year for maintenance and repair.

Rural = \$ 332 and Urban = \$ 425

4.8 EXTENT OF CLIMATE CHANGE MITIGATION

Details of evaluating the extent of climate change mitigation were presented in section 3.6 of methodology chapter. Results obtained are detailed in table 13.

4.8.1 Seasonal Energy Insolation

Table 13: Seasonal energy insolation analysis.

1986-2010 Average Seasonal Energy Insolation Analysis						
Season	Total Days	No of Days Below Threshold	No of Days Above Threshold	Longest Run in Days Above Threshold	Longest Run in Days Below Threshold	Solar Availability (%)
Dec- Feb	91	9	82	56	4	90.1
Mar - May	92	45	47	23	29	51.1
Jun - Aug	92	52	39	8	14	42.4
Sep -Nov	91	51	40	26	37	44

The mean length of a run above the threshold value represents the optimum duration (days) a solar powered system can be put into use. The expected longest run above the threshold represents the maximum possible duration a solar powered system may be put into use. On the other hand, mean length and longest runs below the threshold value represent respectively the optimum duration (days) as well as the expected longest duration (days) back-up systems or supplementary energy sources will have to be put into use. Threshold values used were 5.4kWh/m²/day and 6.8kWh/m²/day for moderate and high temperature activities respectively (Marigi, 1999). Moderate temperature activities correspond to those activities carried in many households while high temperature

activities correspond to those carried in industrial (manufacturing and processing) settings.

4.8.2 Percentage of Fuel Savings and Carbon Dioxide Reduction

Finally, the extent of climate change mitigation was determined by the percentage of fuel savings and Carbon dioxide reduction. This imply that one mole of cellulose reacts with six moles of oxygen to give six moles of carbon dioxide and five moles of water vapour (from Equation 3.11).

Taking the molar masses, we have the following;

$$\text{C}_6\text{H}_{10}\text{O}_5 = 72 + 10 + 80 = 162 \text{ grams}$$

$$6\text{O}_2 = 6 \times 32 = 192 \text{ grams}$$

$$6\text{CO}_2 = 72 + 192 = 264 \text{ grams}$$

$$5\text{H}_2\text{O} = 10 + 80 = 90 \text{ grams}$$

It imply that for a complete combustion, 162grams of cellulose gives 264 grams of carbon dioxide, from which by ratio 1000 grams (1kg) of cellulose will give 1.6296 kg of carbon dioxide and 0.5556 kg of steam (water vapor). Working on complete combustion of one kilogram each of charcoal, kerosene and Liquefied Petroleum Gas (from equation 3.11 to 3.16), results obtained are summarized in table 14.

Table 14: Environmental pollution due to combustion of fuels.

Fuel Type (1 kg Each)	Amount of Oxygen Needed (kg)	Carbon Dioxide Emitted (kg)	Water Vapour Emitted (kg)
Wood	1.8462	1.6296	0.5555
Charcoal	2.3077	2.9615	0.3462
Kerosene	3.4824	3.1059	1.3647
Butane	3.5862	3.0345	1.5517
Propane	4.0000	3.0000	2.0455
LPG	3.7931	3.0173	1.7986
Natural Gas	4.000	2.7500	2.2500

Varieties of LPG bought and sold include mixes that are primarily propane (C_3H_8) and butane (C_4H_{10}) and, most commonly, mixes including both propane and butane, depending on the season, that is, in winter more propane, in summer more butane. Propylene and butylenes are also present in small concentration. A powerful odorant, is added so that leaks can easily be detected.

4.8.3 Rural Family's Fuel Consumption and Environmental Pollution

A typical rural family's fuel consumption (table 12) of firewood 7.87 kg, charcoal 0.7 kg and kerosene 0.43 kg per day emits 12.8, 2.1, 1.3 kilograms of carbon dioxide and 4.37, 0.24, 0.59 kilograms of water vapour respectively. This cumulates 16.2 kg of carbon dioxide and 5.2 kg of water vapour per day. If used continuously for the whole season of say 91 days, 1474 kg of carbon dioxide and 473.2 kg of water vapour are emitted to the atmosphere as summarised in table 15.

Table 15: Carbon dioxide emissions (rural/urban household).

	Rural Set-up (kg)				Urban Set-up (kg)			
	1	30	91	92	1	30	91	92
Days	1	30	91	92	1	30	91	92
Wood	12.8	384	1164.8	1177.6	-	-	-	-
Kerosene	1.3	39	118.3	119.6	-	-	-	-
Charcoal	2.1	63	191.1	193.2	6.2	186	564.2	570.4
LPG	-	-	-	-	1.3	39	118.3	119.6
TOTAL	16.2	486	1474	1490	7.5	225	682	690

4.8.4 Percentages of Fuel Savings and CO₂ Reduction

For the same period of time, and with reference to table 13, in each season, if solar energy is used, then the amount of seasonal fuel savings and CO₂ reduction are summarised as shown in table 16 below.

Table 16: Amount of fuel saving (kWh) and carbon dioxide (kg) reduction

1986-2010 Average Seasonal Energy Insolation Analysis			Amount of seasonal fuel saving (kWh) and Environmental Carbon Dioxide (kg) reduction			
Season	Total Days	Solar Energy Availability (%)	Rural Set up		Urban Set up	
			kWh	CO ₂	kWh	CO ₂
Dec- Feb	91	90.1	3518.2	1328.0	2246.5	615.0
Mar - May	92	51.1	2017.3	762.0	1288.1	353.0
Jun - Aug	92	42.4	1673.8	632.0	1068.8	293.0
Sep -Nov	91	44.0	1718.1	649.0	1097.1	300.0
Total annually		56.9	8927.4	3371.0	5700.5	1561.0

4.9 WATER HEATING

4.9.1 Electrical Water Heating

The energy necessary to heat water is determined by the specific heat of water (Nelcon, 2002):

$$c_{\text{water}} = 1 \text{ calorie/gm } ^\circ\text{C} = 4,186 \text{ J/kg}^\circ\text{C}$$

Taking a residential water heater of Capacity 100 liters and typical heating range to be taken from (15.6 °C to 60 °C), the energy required to heat the water can be determined from the specific heat relationship:

$$Q = cm\Delta T \dots\dots\dots(4.1)$$

The energy required to heat one tank of water over the specified range is then

$$(4186 \text{ J/kg}^\circ\text{C})(100 \text{ kg})(60 \text{ }^\circ\text{C} - 15.6 \text{ }^\circ\text{C}) = 18,585,840 \text{ Joules}$$

Assuming this water is enough to meet a daily household family demand of five people, and since a kilowatt-hour is 3.6 million Joules, this energy amounts to about 5.16 kWh of electricity per day. Taking an electric energy cost of kshs 11.38/kWh (table 18 below), it would cost about kshs 59 to warm one tank of water with an electric hot water heater assuming all the electric energy went into heating the water, translating to about kshs 1,770 per month, kshs 21,535 per year and kshs 538,375 in 25 years life time. Table 17 (KIPPRA, 2010) shows the electricity tariffs in Kenya, according to the National Energy Survey 2009.

Table 17: Electricity tariffs in Kenya

Sector	Kshs/kWh
Households	11.38
Agriculture	12.16
Manufacturing including mining and quarrying	13.01
Electricity and water	11.95

4.9.2 Solar Water Heating

Pilot survey on the Costs of solar water heaters within Nairobi shops were conducted within the month of June, 2011 and findings summarized in table 18. Installing a solar water heater that can meet demand of a standard household of five persons will cost kshs 60,000. Saving on electricity to install solar water heater will have a payback period of $(60,000/21,525) = 2.79$, approximately three years.

Table 18: Current market solar water heater capacity and prices.

Solar Water Heaters			
Company	Capacity(litres)	Cost(Kshs)	Family size
Asachi(India)	100	60,000	4 to 6
“	200	140,000	6 to 10
“	300	210,000	10 to 18
“	500	350,000	18 to 30

Source: Researcher's initiative Survey, 2011.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

This chapter provides conclusions and recommendations which were derived from this study.

5.1 CONCLUSIONS

Results of the study have revealed that Nakuru is a moderate to high solar energy potential region, with an average daily insolation of 6.9kWh/m^2 . However, the amount of available solar energy is season dependent with December-February season receiving the highest amount of 678 kWh/m^2 and September-November season receiving the least amount of 602.6kWh/m^2 .

Computed reliability values show reliability values in excess of 50% (79.3%-95.7% for moderate temperature activities and 34.6% - 80.2% for high temperature activities) all the year round confirming the promising potential of the resource.

The sizes and costs (capital and running) as computed for the solar energy interceptors that would be required indicate that they are modest and within reach of majority of inhabitants provided that the initial investment cost is subsidized. Ultimately, the investment is worth it in the long run given the envisaged energy security, environmental preservation and potential climate change mitigation.

Substantial conventional energy use reduction as well as carbon dioxide reduction is envisaged if solar energy replaces the current conventional energy sources in the area,

meaning that there will be cost and time savings. The time saved in fuel collection can be used in other productive activities to uplift the living standards of Nakuru inhabitants.

In conclusion therefore, results of this study indicate that the potential of solar energy utilization in Nakuru is indeed promising for both moderate and high temperature activities. This is due to the high insolation values as well as reliability values which are in excess of 50% all the year round. The resource however exhibits some diurnal and seasonal variability that would require use of supplementary power sources when a continuous power supply is needed.

5.2 RECOMMENDATIONS

1. Policies should be put in place to harness this freely available, abundant, renewable and clean resource for the benefit of the inhabitants of Nakuru municipality.
2. Detailed diurnal and seasonal characteristics of wind speeds in the region should be investigated since these have a bearing in the dust deposition on the solar systems as well as the strengths of the mounting structures.
3. A study of the wind power regime to consider a solar/wind hybrid system should be done.
4. Detailed diurnal and seasonal characteristics of both maximum and minimum temperatures in the region should be investigated since these have a bearing in the design of the solar energy systems and hence their overall performance.

REFERENCES

Asplund W. R. (2008). *Profiting From Clean Energy*. John Willey and Sons Publications, Hoboken, New Jersey.

Bird, R.E. (1984). A simple solar spectral model for direct-normal and diffuse horizontal irradiation. *Solar Energy*, 32(4):461-471.

Bothwell B, (2004). *Potential for solar water heating in Zimbabwe*. M.Sc. Thesis, Utrecht University, The Netherlands.

CBK, July 1, 2011: *The Central Bank of Kenya Weekly Bulletin*.

Chukwuemeka, A., Nnabuchi, M.N. (2009): Solar radiation in Port Harcourt. *Pacific Journal of science and Technology*, 10:681-685.

Chiemeka, I. U., Chineke, T. C. (2009). Evaluating the global solar energy potential at Uturu, Nigeria. *International Journal of physical sciences*, 4(3):115-119.

Donald C. A. (2005). *Essentials of Meteorology*. Thomson Brooks/Cole Publications.

Duffie J. A., Beckman W. A. (2006). *Solar Engineering of Thermal Processes*, 3rd edition. Wiley, New York, 2006.

Duffie, J.A., Beckman, W.A. (1991). *Solar Engineering of Thermal Processes*, John Wiley and Sons, New York.

GOK (Government of Kenya), (2005). Nakuru district, District Strategic Plan 2005 - 2010.

GOK (2010). Kenyan Humanitarian Update, Vol. 63. 12 August - 17 September 2010.

GOK (2009). Population and Housing Census Highlights, 2009, Government Printer.

Gueymard, C.A. (1993). Mathematical integrable parametrization of clear- sky beam and global irradiances and its use in daily irradiation applications , *Solar Energy* 50(5); 385- 97.

Guemard C.A (1995). Simple Model of the Atmospheric Radiative Transfer of Sunshine (SMARTS): Algorithms and Performance Assessment.

Gueymard, C.A. (2004). The sun's total spectral irradiance for solar energy applications and solar radiation models. *Solar Energy* 76(4): 423-453.

Hartmut, B., Hermann, M., Christopher, S., Franz, T. (2001). Assessment of solar electricity potentials in North Africa based on satellite data and a geographic information system. Retrieved on September 6th, 2010, from: http://spaceresearch.nasa.gov/sts-07/107_solcon3.pdf.

Iqubal M. (1983). An Introduction to Solar Radiation. Academic press, Canada.

Kamau J. N., (2010). *Determination of the wind power parameters for the assessment of the wind energy potential for some selected sites in Kenya.* Ph.D Thesis. Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya.

Kamfor, (2002). Study on Kenya's energy demand, supply and policy strategy for households, small-scale industries, and service establishments. Final Report. Ministry of Energy.

Kirui, H. W. (2006). *Assessment of Solar and Wind Energy Potential in the Central Rift Valley of Kenya.* M.Sc Thesis. Egerton University, Kenya.

Kimuyu, P.K. (1988), Demand for Commercial Energy in Kenya: A Structural Investigation, Ph.D thesis. University of Nairobi, Nairobi.

KIPPRA, (2010). Comprehensive Study and Analysis on Energy Consumption Patterns in Kenya. *Final Report Submitted By The Infrastructure and Economic Services Division*, Kenya Institute for Public Policy Research and Analysis 2nd Floor, Bishops Garden Towers, Bishops Road, Nairobi, Kenya.

Lewis, N.S., Crabtree G. (2005). Basic Research Needs for Solar Energy Utilization. *Report on the Basic Energy Sciences Workshop on Solar Energy Utilization, Office of Science, US Department of Energy, Washington, DC.*

Liepert, B.G. (2002). Observed reductions of surface solar radiation at sites in the United States and worldwide from 1961 to 1990. *Geophysical Research Letters* 29 (10): 61-1 – 61-4.

Makokha, J. (1991). *Domestic woodstoves in Kenya*. In: Proceedings of regional training course on Biomass energy development, June 2–28, Nairobi, Kenya.

Marigi, S. N. (1991). *Rating of solar Energy Systems in Nairobi*. M.Phil Thesis, School of Environmental Studies, Moi University, Kenya.

Marigi, S. N. (1999). *An Assessment of Solar Energy Resource in Kenya*. Ph.D. Thesis, Moi University, Kenya.

Kemp, M. U. (2007). Spatial and Temporal Distribution of Solar Radiation in Louisiana. M.Sc. Thesis, Louisiana State University, USA.

Ndeda H. J. (2008). Solar Radiative Variability Forcing of Climate Change on Seasonal to Decadal Scales in Kenya. Ph.D Thesis, Jomo Kenyatta University of Agriculture and Technology, Kenya.

Nelcon M. (2002). Principles of Physics. Edinburgh Gate, Harlow, Essex CM20 2JE, England.

Neville, R. C. (1995). *Solar Energy Conversion*. Elsevier Science B. V. Publishers, Netherlands.

Natowitz, J.B., Ngo, C. (2009). *Our Energy Future*. John Willey and Sons Publications, Hoboken, New Jersey.

Obasi, G.O .P., Rao, N.P. (1976). *A detailed study of solar radiation and potential distribution in Kenya*. In: The proceedings of UNESCO symposium, 30th August to 3rd September 1976, Geneva, Switzerland.

Ogallo. L.J., Runanu, K. (1998). *Space time characteristics of the maximum and minimum solar power expectation in Kenya*. In: First National conference on meteorological applications, Nairobi, Kenya.

Okoola, R.E. (1982). Solar power potential in Kenya. *An IMTR Research publication report. No. 1/82*.

Okoola R. E.,Camberlin P., Ininda J.M. (2008). Wet periods along the East Africa Coast and the extreme wet spell event of October 1997. *Journal of Kenya Meteorological Society*, Volume 2(1), page 67-83.

Onuonga, S.M. (2008). An Econometric Analysis of Energy Utilization in the Kenyan Manufacturing Sector, Ph.D Thesis, Kenyatta University, Kenya.

Osiolo, H. (2009), Enhancing household fuel choice and substitution in Kenya, Kippra Discussion Paper no 102.

Republic of Kenya (1978), Statistics of Energy and Power, 1969-1977, Central Bureau of Statistics, Ministry of Economic Planning and Community Affairs. Nairobi: Government Printer.

Republic of Kenya (2010). Leading Economic Indicators. Central Bureau of Statistics, Ministry of Economic Planning and Community Affairs. Nairobi: Government Printer.

Republic of Kenya, (2009). Energy Regulatory Commission Magazine, 08/09 Annual report and financial statement.

Republic of Kenya (2001). Study on Kenya's Energy Demand, supply and Policy. Strategy for Households, Small-scale Industries and Service, Establishments. Nairobi: Government Printer.

Republic of Kenya (2008). Economic Survey, Nairobi: Government Printer.

Salehi-Isfahani, D. (1996). Government Subsidies and Demand for Petroleum.

Spencer, (2006). The Discovery of Global Warming. American Institute of Physics. Retrieved on 8th July, 2010 from: <http://www.aip.org/history/climate/index.html>.

Stanhill, G., Cohen, S. (2001). Global dimming: A review of the evidence for a widespread and significant reduction in global radiation with discussion of its probable causes and possible agricultural consequences. *Agricultural and Forest Meteorology* 107(4): 255-278.

SRHB (Solar Radiation Hand Book), (2008). A joint Project of Solar Energy Centre, MNRE Indian Metrological Department.

WMO (world meteorological organization), (1981). *Meteorological aspects of the utilization of solar radiation as an energy source.* In: WMO Technical Note no. 172, Geneva.

Uiso, C.B.S. (1998). Solar Radiation. Academic Press, Tanzania.

UNEP (2006). Integrated Assessment of the Energy Policy with Focus on the Transport and Household Energy Sectors, United Nations Environment Programme (UNEP), Nairobi.

wikipedia (2010). Atmospheric Stratification. Retrieved on 22/12/2010, <http://csep10.phys.utk.edu/astr161/lect/earth/atmosphere.gif>.

wikipedia (2011). Atmosphere of Earth. Retrieved on 9/5/2011, <http://en.wikipedia.org/wiki/Atmosphere>.

WMO (World meteorological organization), (1981). Meteorological aspects of the utilization of solar radiation as an energy source.

WMO (world meteorological organization), (1983). Guide to Meteorological instruments and methods of observation. In: WMO Technical Note No. 8, Geneva.

Ye, L. (1996). *An Evaluation of Solar Radiation Variability in Louisiana.* M.Sc. Thesis, Louisiana State University, USA.

APPENDICES

APPENDIX 1:

Table 19: International SI unit prefixes

Symbol	Name	Exponential	Multiplier
Y	yotta	10^{24}	1,000,000,000,000,000,000,000,000
Z	zetta	10^{21}	1,000,000,000,000,000,000,000
E	exa	10^{18}	1,000,000,000,000,000,000
P	peta	10^{15}	1,000,000,000,000,000
T	tera	10^{12}	1,000,000,000,000
G	giga	10^9	1,000,000,000
M	mega	10^6	1,000,000
K	kilo	10^3	1,000
		10^0	1
m	milli	10^{-3}	0.001
μ	micro	10^{-6}	0.000001
n	nano	10^{-9}	0.000000001
p	pico	10^{-12}	0.000000000001
f	femto	10^{-15}	0.000000000000001
a	atto	10^{-18}	0.000000000000000001
z	zepto	10^{-21}	0.000000000000000000001
y	yokto	10^{-24}	0.000000000000000000000001

APPENDIX 2:

Monthly Radiation Trend Graphs 1986 to 2010 Averages for the Months of;

a) January

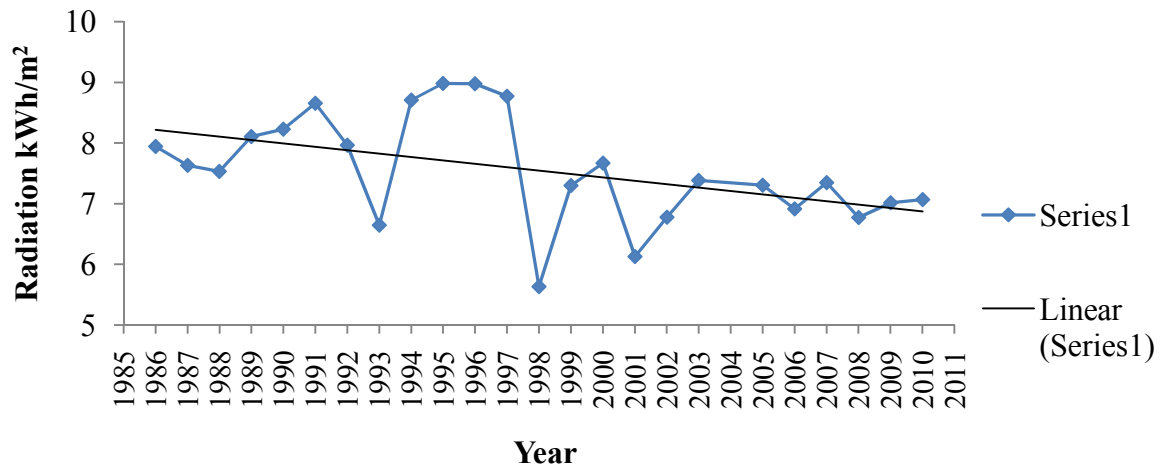


Figure 23: Radiation trend graph for January 1986-2010

b) February

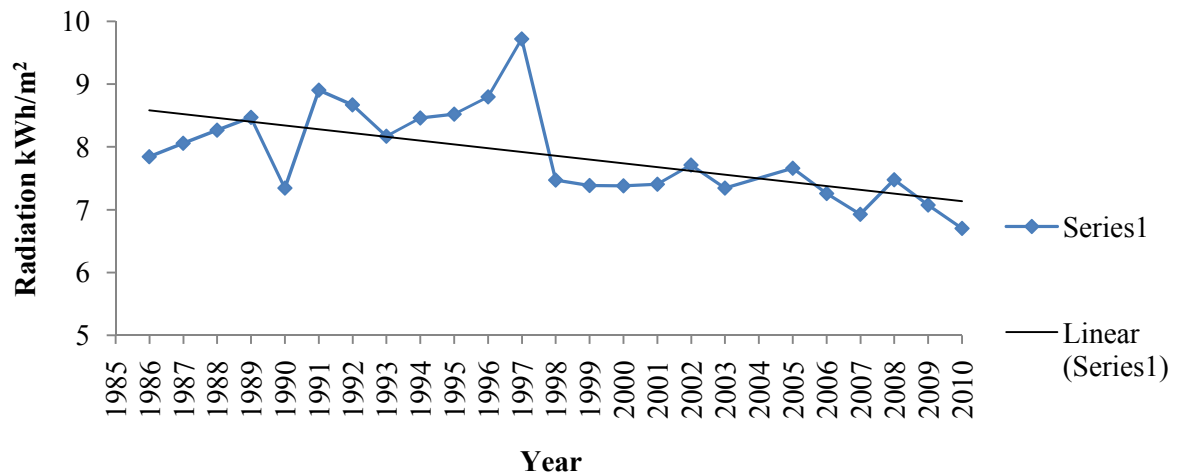


Figure 24: Radiation trend graph for February 1986-2010

c) March

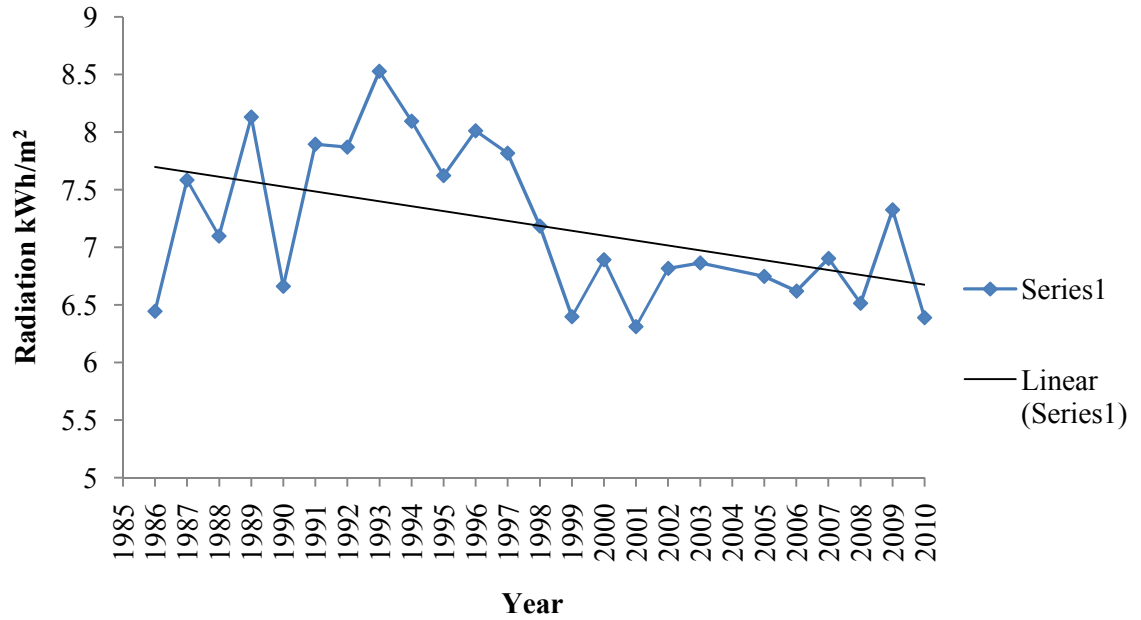


Figure 25: Radiation trend graph for March 1986-2010

d) April

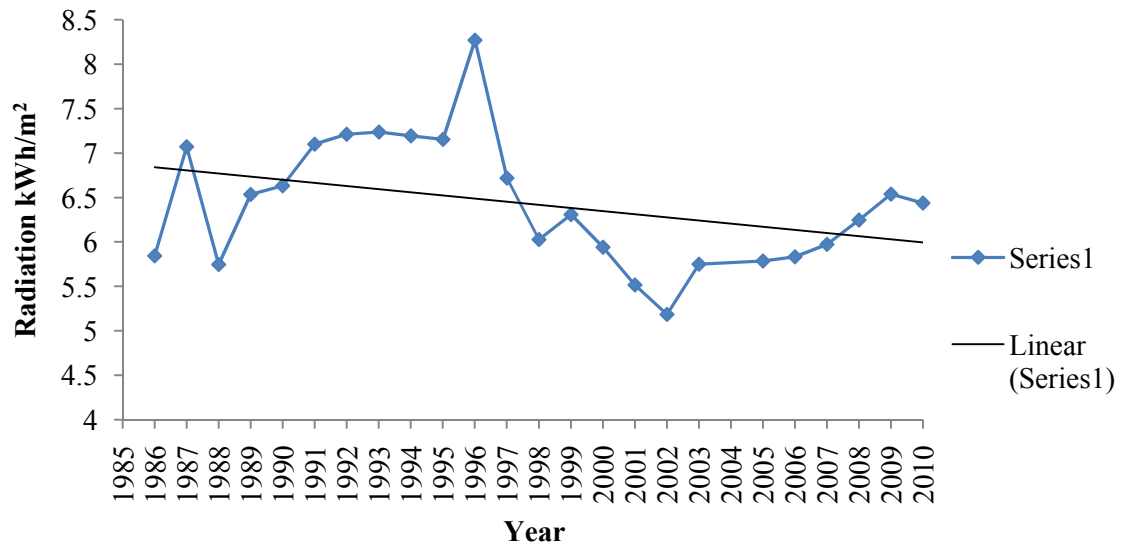


Figure 26: Radiation trend graph for April 1986-2010

e) May

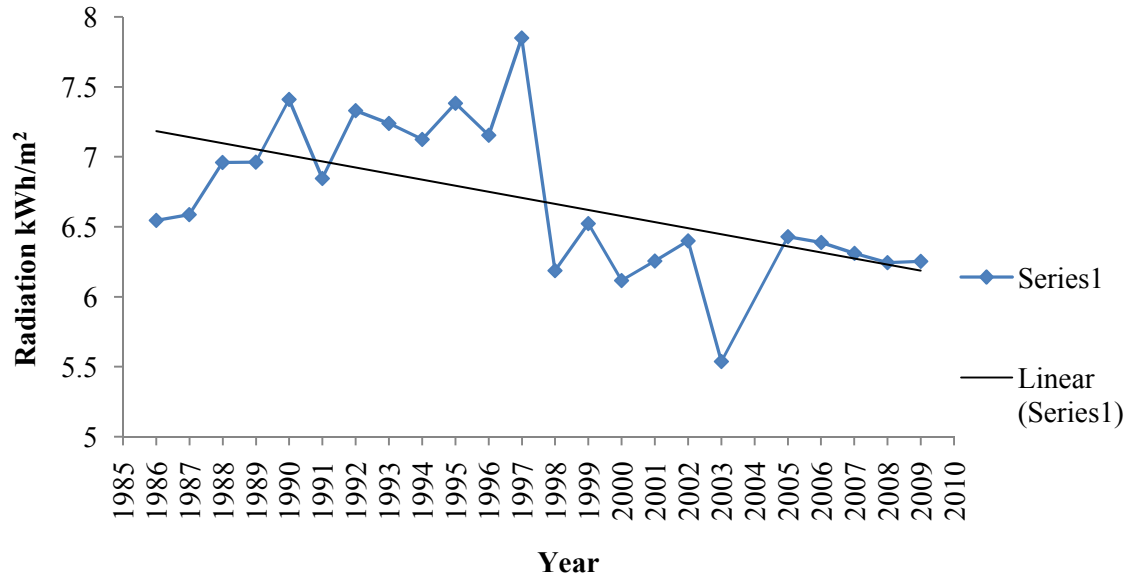


Figure 27: Radiation trend graph for May 1986-2010

f) June

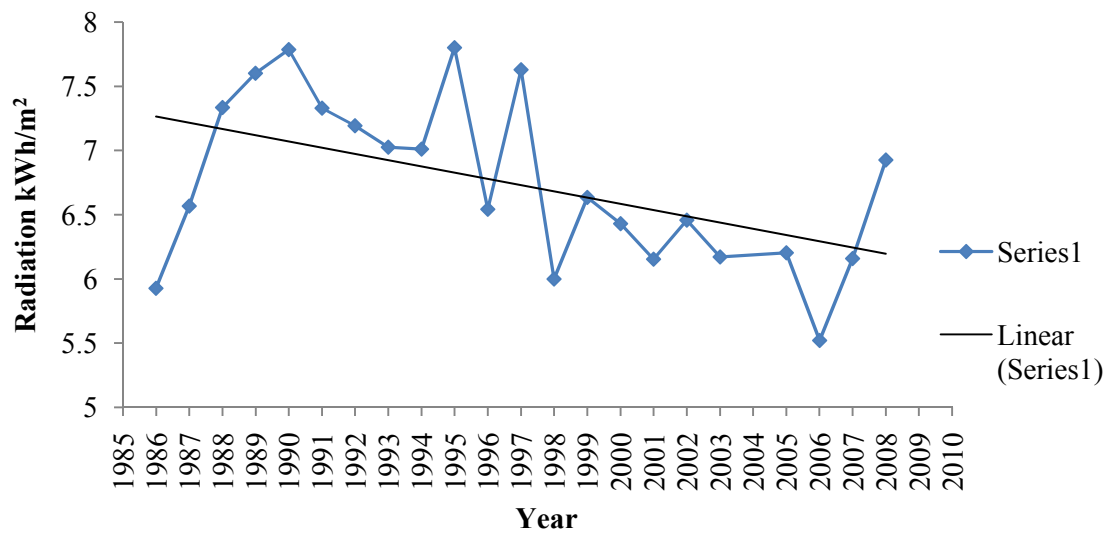


Figure 28: Radiation trend graph for June 1986-2010

g) July

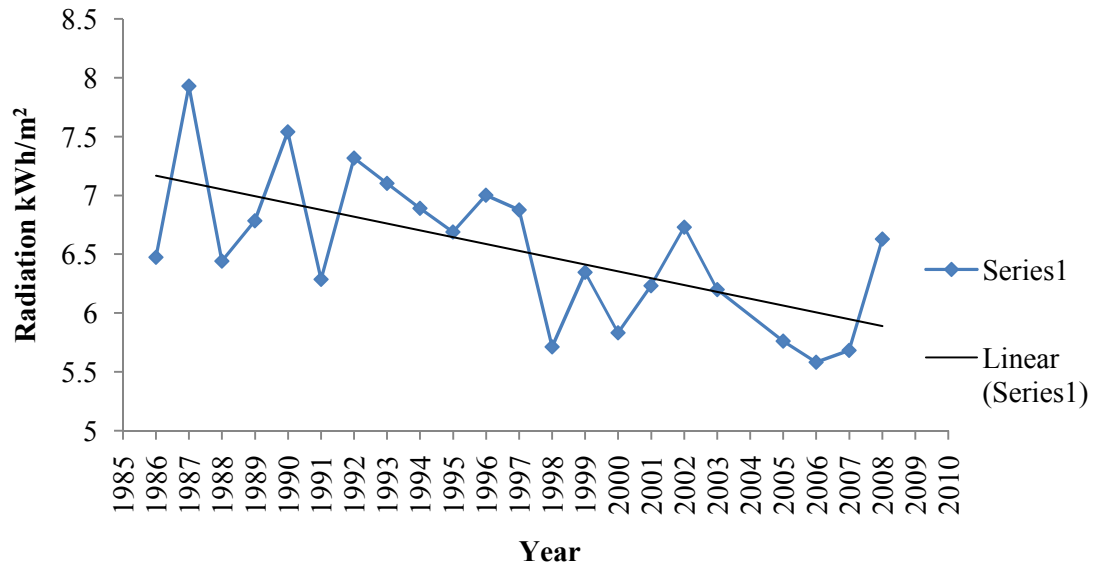


Figure 29: Radiation trend graph for July 1986-2010

h) August

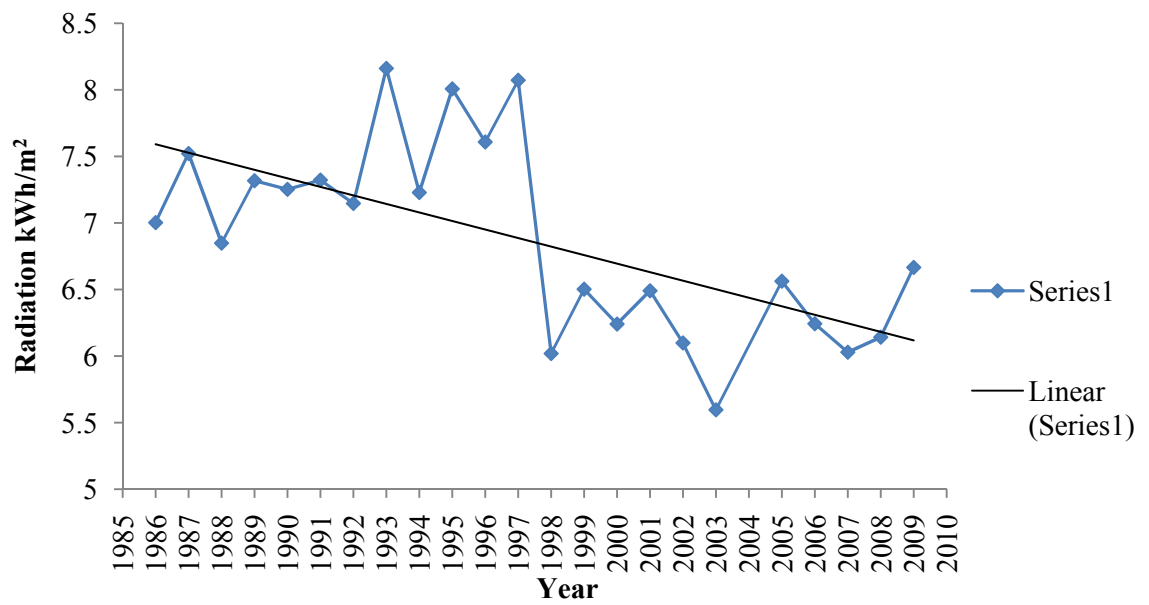


Figure 30: Radiation trend graph for August 1986-2010

i) September

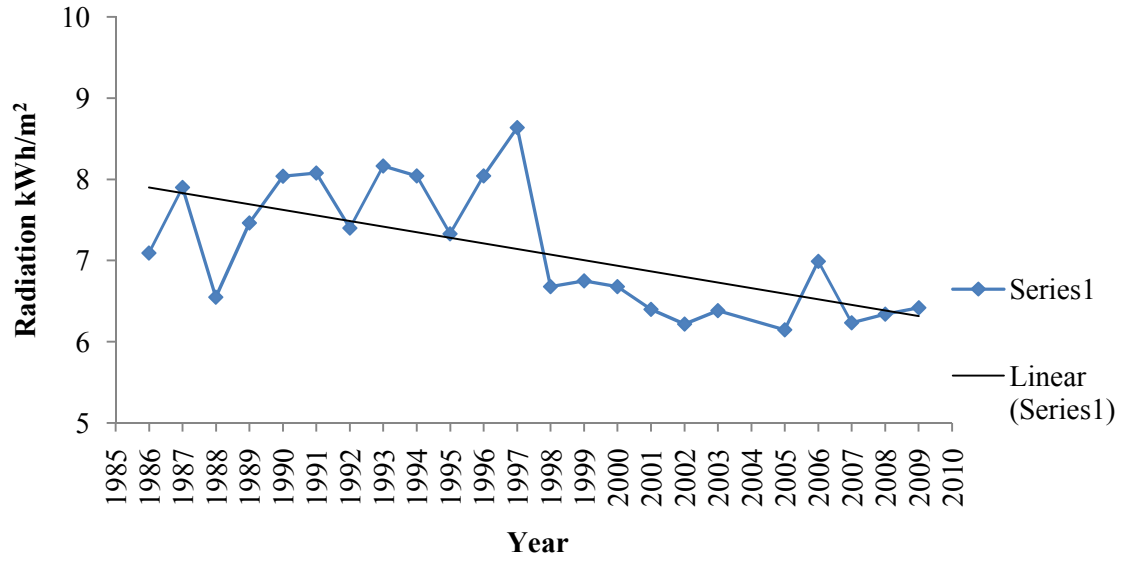


Figure 31: Radiation trend graph for September 1986-2010

j) October

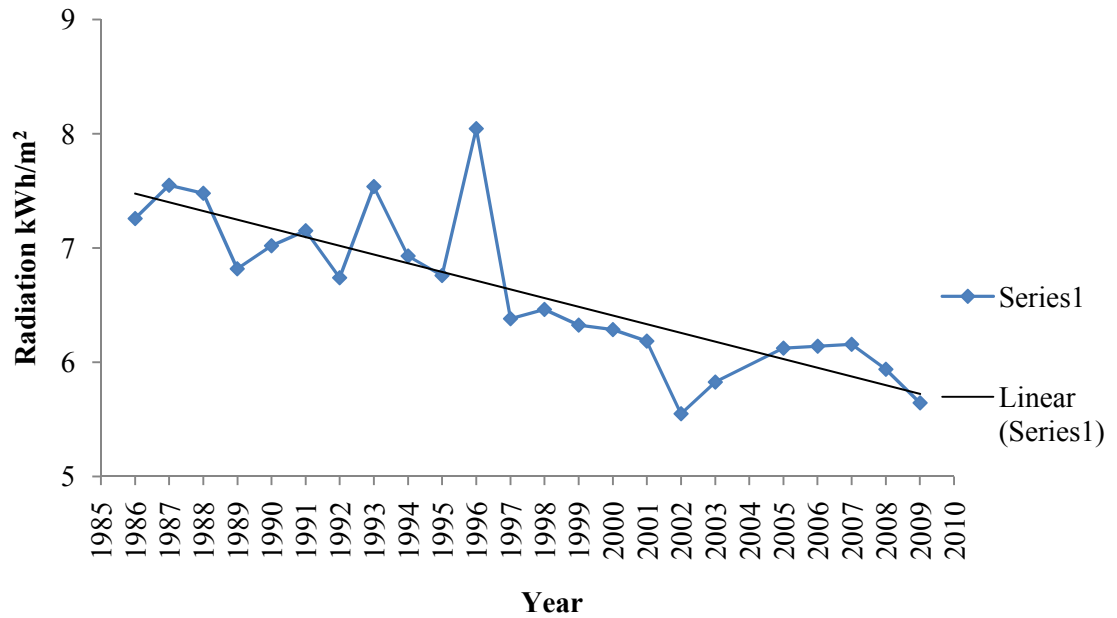


Figure 32: Radiation trend graph for October 1986-2010

k) November

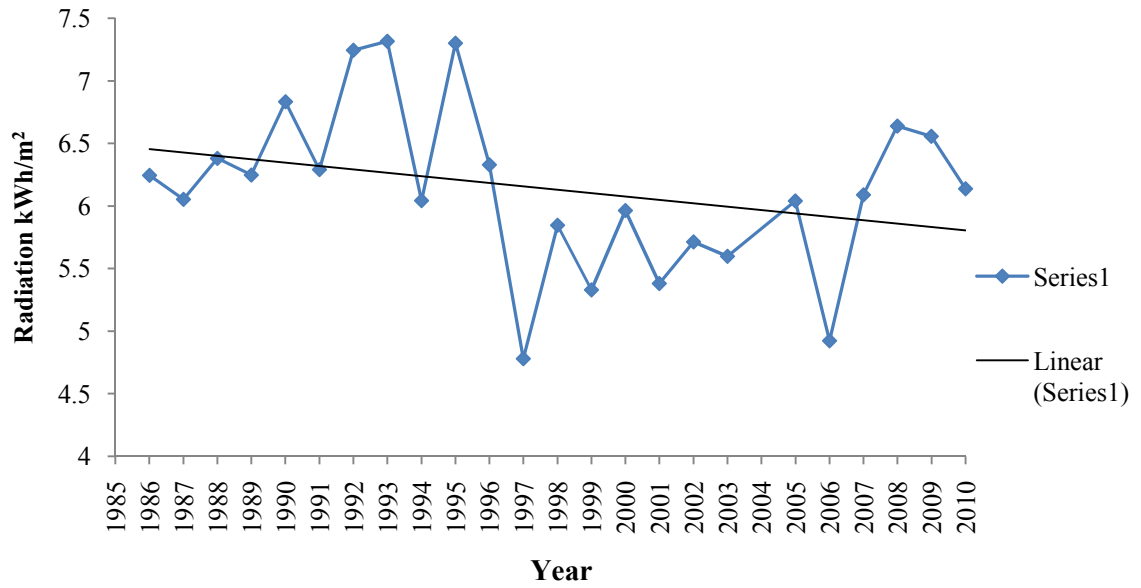


Figure 33: Radiation trend graph for November 1986-2010

l) December

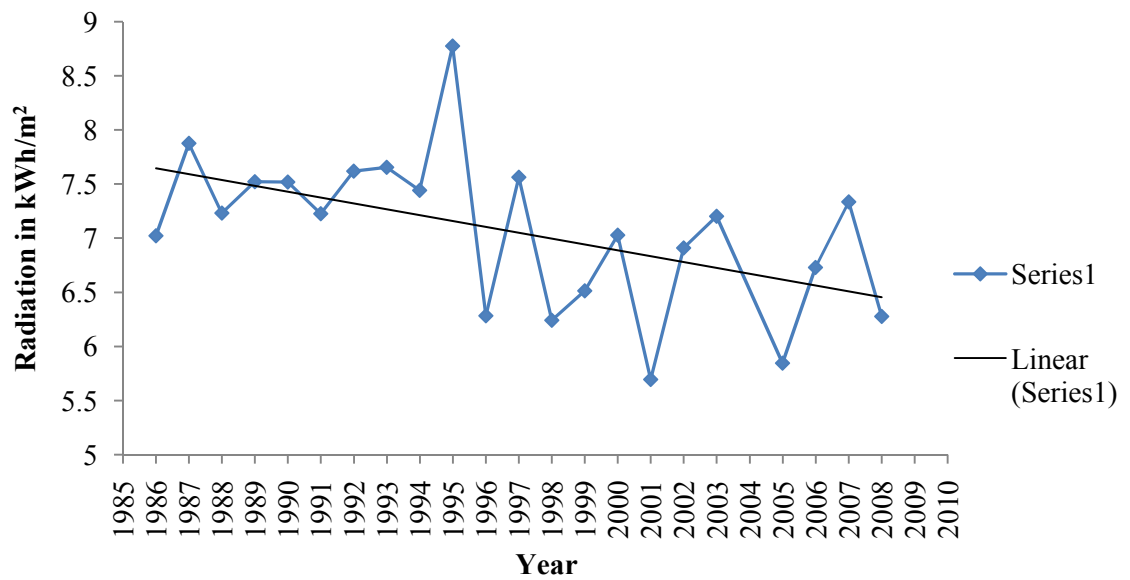


Figure 34: Radiation trend graph for December 1986-2010