UNIVERSITY OF CAPE COAST

ESTIMATION OF GLOBAL SOLAR RADIATION IN SELECTED SYNOPTIC STATIONS IN GHANA

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JULY, 2014

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BY

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THESIS SUBMITTED TO THE DEPARTMENT OF PHYSICS OF THE SCHOOL OF PHYSICAL SCIENCES, FACULTY OF SCIENCE, UNIVERSITY OF CAPE COAST, IN PARTIAL FULFILMENT OF THE AWARD OF A MASTER OF PHILOSOPHY DEGREE IN PHYSICS.

JULY, 2014

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own work and that no part of it has been presented for another degree in this University or elsewhere.

Candidate's Name: Barrett Samuel Teye Wussah

Signature …………………… Date: …………………

Supervisors' Declaration

We hereby declare that the preparation and presentation of this thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Name: Dr. I. K. Anderson

Signature ……………………….. Date: ……………………

Co-supervisor's Name: Dr. Alfred Owusu

Signature …………………….. Date: ……………….

ABSTRACT

The global solar radiation potential of eight Synoptic Meteorological Stations in Ghana was reported in this study. Five stations were selected from the Northern belt, mostly made up of Sudan Savanna and Guinea Savanna regions of Ghana and the other three stations were selected from the Middle belt, mainly Deciduous Forest and Coastal Savanna regions of Ghana. Angstrom-Prescott Sunshine Hour Model was employed to estimate the global solar radiation for these stations. The daily sunshine hour data and other geographical parameters were obtained from the Ghana Meteorological Agency in Accra for the period of 2000 to 2010. Monthly and yearly means of daily global solar radiation values were determined for each of the selected Synoptic Stations. The computation and the analysis were done using MatLab codes together with Microsoft excel. Standard error was determined to check the consistency of the global solar radiation values obtained. Also, the performance of the model was evaluated by using a standardized test statistics (z-statistics).

The yearly mean of monthly global solar radiation values for the entire period for the Selected Synoptic Stations ranged from 19.94$MJm^{-2}day^{-1}$ to 21.95$MJm^{-2}day^{-1}$ using Angstrom– Prescott Sunshine Hour model. In general, maximum values of yearly mean of monthly global solar radiation for the Study Synoptic Stations were observed between March and April, while minimum values were observed in August and December. From analysis of the result, it was observed that the availability of global solar radiation throughout the period in the selected stations is very consistent and steady in pattern. Therefore, the possibility of prospects of solar energy utilisation at these locations is very bright.

ACKNOWLEDGEMENTS

I wish to express my utmost appreciation to my supervisor Dr I.K Anderson for his priceless contribution and guidance in bringing this study to a successful end.

I would also like to extend my sincere gratitude to all lecturers of the Department of physics for their motivation and encouragement.

I am indebted to all members of my family for their prayers and supports throughout the period of my studies.

DEDICATION

This thesis is dedicated to my brothers and sister and to Mr. Seth Acquah and his wife Philomena Ayambila.

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CHAPTER ONE

INTRODUCTION

Background to the Study

Solar radiation at the earth's surface is the main source of energy that drives physical, chemical and biological processes. Solar radiation therefore plays a key role in soil, vegetation and atmospheric processes resulting in the estimation of evapotranspiration rates. Evapotranspiration rate values are important in surface water balance and energy balance calculations. Knowledge of solar radiation estimates is a key factor in guiding architectural design and solar energy systems. Furthermore, solar radiation data is important in the study of applied sciences such as hydrology, meteorology, and soil physics.

The awareness of limited availability of energy resources and their associated environmental problems is making it imperative that we shift emphasis to the renewable energy resources such as solar radiation and other applications that depend on the availability of solar radiation.

The shift is imperative since renewable energy technology is capable of alleviating the already over stretched ecosystem and supplying the energy necessary for rapid development. For example in the rural areas, the applications of solar radiation such as solar panels and solar heating systems could promote the establishment of cottage industries.

Information on global solar radiation received at any site is not only useful to the locality where the radiation data is collected but also for a wider community. For example, a study of the world distribution of global solar radiation requires radiation data in various countries. Also, for the purpose of worldwide marketing, designers and manufacturers of solar energy equipment need to know the mean global solar radiation available in different and specific regions (World meteorological organization [WMO], 1981).

While solar energy data are recognized as important, their acquisition is not easy. Measuring of solar radiation sensor is not readily available and may be expensive. Therefore, there have been several studies which estimate global solar radiation through the use of meteorological and physical parameters such as water vapor content, aerosol optical depth and ozone depth (Iqubal, 1983).

The amount of global solar radiation reaching the earth's surface varies from one place to another owing to the attenuation properties of the atmosphere and the diverse geographical characteristics of the earth's surface. Hence detailed study of solar radiation under local climate conditions is essential.

For locations where measured values of global solar radiation are not available, the common practice is to estimate global solar radiation from commonly measured meteorological parameters like surface pressure, relative humidity, relative sunshine duration, minimum and maximum temperature, and precipitation using empirical and physical models (WMO, 1981). For example, studies carried out on global solar radiation measurements in some parts of Ghana suggest that there is a potential for solar energy to be used on commercial scale. However, the immediate short term to the long term solutions to address the problems of inadequate infrastructure in the area of solar energy data acquisitions would be the application of empirical models that rely on the correlation between the parameters obtained from measured meteorological data (Quansah, et.al, 2011).

The model results may then be used for locations of similar meteorological and geographical characteristics.

Statement of the Problem

The world's population will continue to grow for several decades to come. Energy demand is likely to increase even faster, and the proportion of energy supplied by electricity will also grow at the same rate (William & Marry, 2004).The main sources of energy (fossil fuels: coal, petroleum and gas) that we use are believed to be running out. Moreover, these sources of energy can cause harm to our environment. Carbon monoxide (CO) is an example of a short lived trace gas created from incomplete combustion of fossil fuels and burning of biomass. This gas is converted later to Carbon dioxide (CO_2) which is one of the main greenhouse gases and also responsible for a global temperature rise. This environmental challenge can be mitigated by looking for alternative clean energy resources along with adaptation strategy against those environmental consequences that cannot be reversed. One of the clean and renewable alternative resources is solar energy (Atique &Veziroglu, 1987).

Ghana over the years has been faced with shortage of electricity due to low water levels in the Volta Lake for hydroelectricity generation. The worst power crises in Ghana were during 1984, 1994, 1998, 2001 and 2007 (Arku, 2011). Currently, Ghana has achieved access to electricity mainly through grid extensions which cover regional and district capitals, major commercial and economically viable communities. However, there are still over ten million people in two million households, scattered in small, remote off grid communities that could not be served economically by grid extension (Akuffo, 2004).

Although there is reliable sunshine throughout the year in Ghana, not much of the power of the sun is converted into electricity as alternative source of energy. In order to convert the power of the sun into viable electrical energy, one needs to know the intensity of the solar radiation from one place to another and from month to month, but this is not well known in quantitative terms.

To make this data available would require erecting a sufficiently dense network of pyranometric stations that comes with substantial resource investment far beyond the benefits generally obtained. It is for these reasons that modeling of monthly average of daily global solar radiation is essential.

Purpose of the Study

The purpose of this study is to provide an extensive knowledge of global solar radiation at eight weather stations in Ghana using empirical model based on sunshine hour duration.

Significance of the Study

The study may provide data on estimated global solar radiation for a given period in some selected areas in Ghana using empirical model based on sunshine duration. From this point of view the study could be considered as a reference for any solar energy utilization technology, which is a possible solution to the energy problems of especially the remote areas of the country.

It may also provide a basis for assessing the feasibility of establishing solar energy systems at those specific locations selected and other places with similar climate.

Additionally, this research could provide reliable information that will be useful for agriculturalist in agricultural applications particularly for monitoring the effect of solar radiation on plants growth, forecasting of evaporation from dams and irrigation. Furthermore, the study might provide knowledge of solar radiation which will help scientists to predict rates of future global warming on a grander scale.

Organization of the Study

This thesis is organized into five chapters. The introductory chapter deals with the background issues of the study, statement of the problem, the purpose of the study and the significance of the study. Chapter two presents review of literatures which are important for this study. Chapter three describes the materials and method used for the study. The fourth chapter contains the model prediction results (tables and graphs) and the discussion of the results. Finally, chapter five gives the summary, conclusion and recommendation of the study.

CHAPTER TWO

LITERATURE REVIEW

Concepts in Solar Radiation

The Solar Spectrum

Solar radiation is the electromagnetic radiation emitted by the sun. Solar radiation consists of electromagnetic waves spanning from cosmic rays to radio waves. Almost all known physical and biological cycles in the earth system are driven by solar radiation reaching the earth. The distribution of electromagnetic radiation emitted by the sun as a function of wavelength incident on the top of the atmosphere is called the solar spectrum or the electromagnetic spectrum. The solar spectrum consists of a continuous emission with some superimposed line structures. The region of solar radiation spectrum that is of principal importance in so far as the earth and the atmosphere are concerned is in the thermal radiation range. The thermal radiation range comprises the ultraviolet in wavelength between 400nm and 10nm, the visible in wavelength between 750nm and 400nm and the infra-red in wavelength between 1mm and 750nm. Other components of the electromagnetic spectrum are gamma rays, x-rays, microwaves and radio waves. Figure 1 illustrates solar spectrum in order of wavelength.

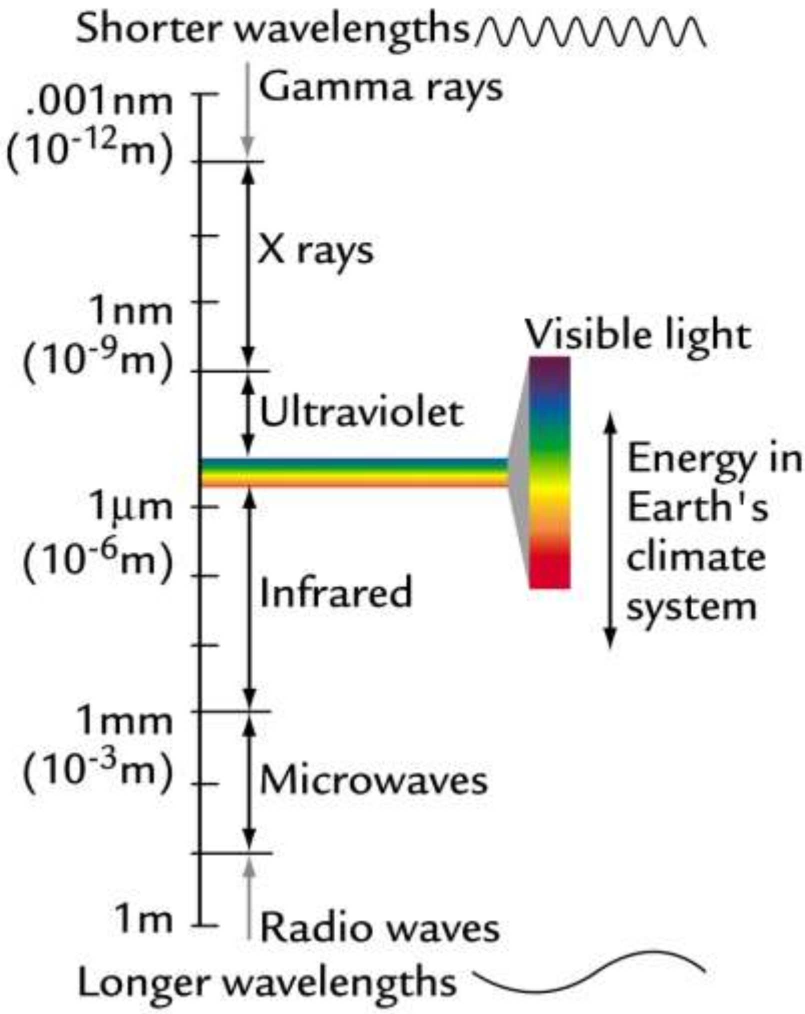


Figure 1: Solar spectrum ranging from gamma rays to radio waves in wavelengths (http:www.geo.utexas.edu/courses/387h/ScheduleGPCdetail.htm, 2005).

The Sun's total radiation output is approximately equivalent to that of a blackbody at 5776K.The solar radiation in the visible and infrared spectrum fits closely with the blackbody emission at this temperature. A black is a hypothetical body that absorbs all the radiation falling on it. The solar irradiance incident on a given plane on the earth's surface is determined by the sun-earth astronomy (physical or radioactive properties of the sun, sun-earth distance), the solar geometry (latitude, declination, solar time, azimuth and tilt angle of receiving surface) and the extinction and emission processes in the atmosphere.

Solid Angle

The analysis of radiation field (a field that represents the energy lost from the radiator to space) requires the consideration of the amount of radiant energy confined to an element of solid angle. A solid angle (Ω) is defined as the ratio of the area (σ) of a spherical surface intercepted at the core to the square of radius *r* as indicated in Figure 2. The solid angle is an essential parameter which is used to determine extraterrestrial radiation on a horizontal surface at a location on the earth. The extraterrestrial radiation is amount of solar radiation that a location on the earth would receive if there were no intervening atmosphere. The solid angle (Ω) is expressed as $\Omega = {}^{\sigma}/{}_{r^2}$.

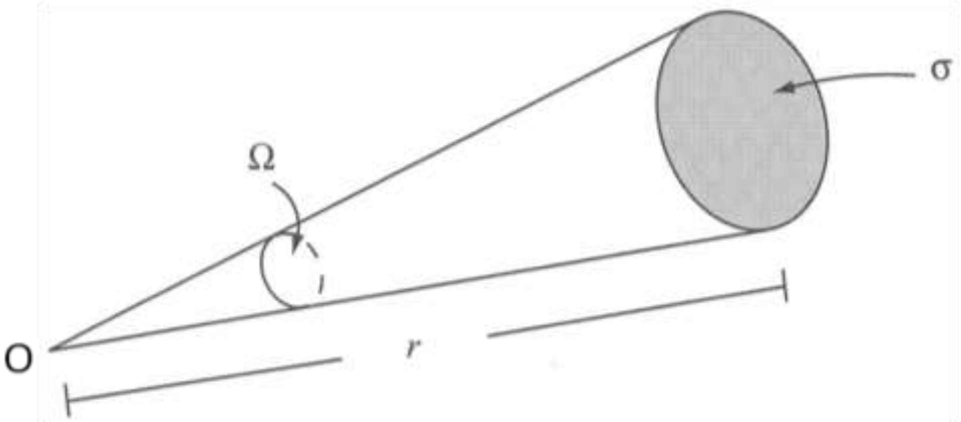


Figure 2: Illustration of the definition of a solid angle (Liou, 2002).

A differential elemental solid angle is obtained by constructing a sphere whose central point is denoted as *O*. Assuming a line through point *O* moving in space and intersecting an arbitrary surface located at a distance *r* from point *O*, then as shown in Figure 3, the differential area in polar coordinates is given by

$$d\sigma \ = (rd\theta)(r\sin\theta d\emptyset).$$

giving $$d\sigma = r^2 sin\theta d\theta d\emptyset \qquad (2.10)$$

Hence, the differential solid angle is

$$d\Omega \ = \ {d\sigma}/{r^2} = sin\theta d\theta d\emptyset \qquad (2.11)$$

where θ and $\emptyset$ denote the solar zenith and the azimuthal angles respectively in polar coordinates.

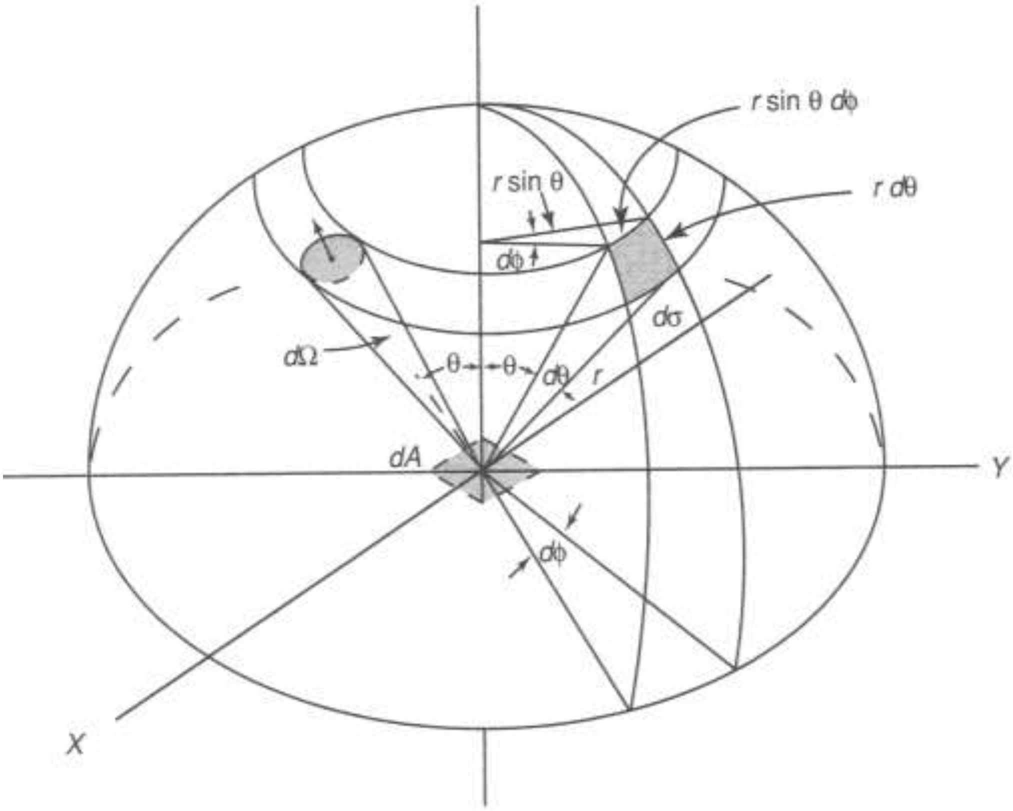


Figure 3: Illustration of a differential solid angle and its representation in polar coordinates (Liou, 2002).

The Solar Constant

The solar constant S, is a quantity denoting the amount of total solar energy covering the entire solar spectrum, reaching the top of the atmosphere.

Solar constant is defined as the amount of solar radiation received outside the Earth's atmosphere on a surface normal to the incident radiation per unit time and per unit area at the Earth's mean distance from the sun.

Suppose the sun is a blackbody of effective emission temperature of $5770K$, then using Stefan–Boltzmann law, the flux density or irradiance (the amount of solar energy per unit time across the a surface of unit area normal to the solar beam at the mean distance between the sun and the earth) is given by

$$F^{*} = \sigma T^{4} \qquad (2.12)$$

where σ the Stefan–Boltzmann constant is equal to $5.67 \times 10^{-8} Wm^{-2}T^{-4}$ and T the effective emission temperature of the sun is $5770K$.

Substituting σ and T into equation (2.12), we have

$$F^{*} = 5.67 \times 10^{-8} \times 5770^{4}$$

giving $$F^{*} = 6.28 \times 10^{7} Wm^{-2}$$ (John & Peter, 2006)

Thus the sun emits energy at the rate of about $6.28\times 10^{7} Wm^{-2}$. On the basis of the energy conservation principle and if there were no intervening medium present, the energy emitted from the sun must remain the same at some distance away. Thus,

$$F^{*} 4\pi {a_s}^{2} = S 4\pi {r_o}^{2} \qquad (2.13)$$

where F^{*} denotes the flux density or irradiance, a_s radius of the sun, and r_o the mean distance between the sun and the earth. The solar emittance is radiant energy per unit time, per unit area perpendicular to a given direction from an emitting surface. From equation (2.12), the solar constant S can be expressed as

$$S = F^*({}^{a_s}/_{r_o})^2 \quad (2.14)$$

Substituting for the Earth–sun distance, $r_o = 1.5 \times 10^{11} m$ and the radius of the sun $a_s = 7.0 \times 10^8 m$, we have

$$S = 6.28 \times 10^7 (7.0 \times 10^8 / 1.5 \times 10^{11})^2$$

giving $S = 1367.6 Wm^{-2}$

The solar constant has been studied extensively since the beginning of this century. The measurements made earlier were ground-based observations. The value of the solar constant from more recent high-altitude measurements vary from 1338Wm^{-2} to 1368Wm^{-2}.The ground-based measurements are reported to be constantly higher than the high-altitude measurements (Thekaekara,1973).

The National Aeronautics and Space Administration (NASA) in the year 1971 proposed the value of the solar constant to be 1353Wm^{-2} based on weighted average of several values. The estimated error in this value was found to be $\pm$21Wm^{-2} or 15%.

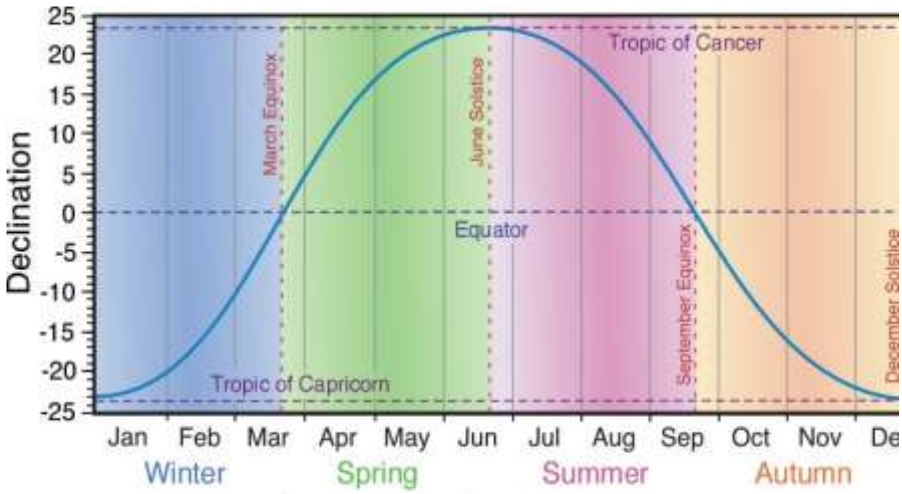
Furthermore, an International Pyreheliometer Comparisons were carried out in 1970 and 1975 under the auspices of the World Meteorological Organization (WMO) to establish a Solar Constant Reference Scale (SCRS), from a synthesis of many different measurements. A value of 1373Wm^{-2} was recommended after re-examination of the twelve previous measurements, taken from aircrafts, high altitudes balloons, satellites and rockets (Frohlich, 1977).

Since 1975, several measurements regarding determination of accurate value of solar constant have been made. Consequently the WMO has adopted a new scale called the World Radiometric Reference Scale (WRRS) as a common base for all meteorological measurements. Frohlich, Brussa and Wehlic (1981) recommended a revised value of the solar constant as 1367Wm^{-2} after re-examining eight values of solar constant measurements from 1969 to 1980, using the new reference scale discussed above. As a result of the refined measurements, the commission for instruments and methods of observation agreed to adopt the World Radiometric Reference Scale constant for all meteorological purposes (WMO, 1981).

Further analysis of satellite data by Liou (2002) suggests a solar constant of 1366Wm^{-2} with a measurement uncertainty $\pm$ 3Wm^{-2} .
A Satellite observation suggests that the solar cycle variation of the solar constant is in order of about 0.1%, which might be too small to directly cause more than barely detectable changes in tropospheric climate (Qiang, 2003).

Solar Declination

Solar Declination δ is the angular distance of the sun north or south of the earth's equator. The earth's equator is tilted 23.45 degrees with respect to the plane of the earth's orbit around the sun. So at various times during the year as the earth orbits the sun, the solar declination varies from 23.45 degrees north to 23.45 degrees south. The position of the earth’s axis relative to the sun causes seasonal changes in solar radiation. Around December 21, the northern hemisphere of the earth is tilted 23.45 degrees away from the sun. This is the winter solstice for the northern hemisphere and the summer solstice for the southern hemisphere. On the other hand, around June 21, the southern hemisphere is tilted 23.45 degrees away from the sun, which is the summer solstice for the northern hemisphere and winter solstice for the southern hemisphere. The solar declination has a value of $+23.45$ degrees at summer solstice and -23.45 degrees at winter solstice. While in between the winter and summer, the declination swings through zero at vernal and autumnal equinoxes. March 21 and September 21 are the fall and spring equinoxes when the sun is passing directly over the equator. The tropics of Cancer and Capricorn mark the maximum declination of the sun in each hemisphere. The variation in the value of solar declination within a year is shown in Figure 4.



Seasons

Figure 4: Variation of solar declination within a year (Myneni, 2005).

According to Jain (1986), the declination of the sun in degrees can be determined by using the following equation,

$$\delta = 23.45\sin[\frac{360}{365}(n + 284)] \qquad (2.15)$$

where n is the number of days of the year counting from first January to the day of observation.

Solar radiation on the Earth's Surface

Solar radiation has to pass through the atmosphere before reaching the earth's surface. The amount of radiation falling on the earth's surface depends on several factors such as Earth-Sun distance, tilt of the Earth's axis, attenuation of the Earth's atmosphere, and surface albedo.

The distance between the sun and the earth is not constant since the earth's path around the sun is an ellipse. Less energy is received when the earth is far from the sun and more energy is received when the earth is close to the sun. The average distance between the sun and the earth is about $1.5 \times 10^{11} m$.

The earth's axis is tilted at 23.5degrees with respect to its orbit around the sun. This tilted position together with the earth's daily rotation accounts for the distribution of solar radiation over the earth's surface, the change in the length of day and night and the change of seasons. The direct solar beam does not always strike a horizontal surface on the earth at normal incidence because of the way the earth moves around the sun.The sun becomes truly overhead twice a year; during the March and the September equinoxes. During these times, maximum solar radiation is received at both hemispheres of the earth (Uiso, 1998).

The earth is surrounded by an atmosphere which contains various gaseous constituents, suspended dust and other minute solid and liquid particles. The attenuation processes involving such atmospheric matter are absorption, refraction, reflection, diffraction and scattering.

Attenuation of solar radiation occurs simultaneously by three distinct physical processes, namely: selective absorption by atmospheric constituents such as water vapor, molecular oxygen, ozone and carbon dioxide; Rayleigh scattering by particles of size smaller than or equal to 0.1λ, where λ is the wavelength of radiation being scattered and Lorenz-Mie scattering by particles of size greater than or between 5λ and 25λ. For an atmosphere with particles of size between 0.1λ and 5λ, attenuation also takes place by diffraction. As the size of particles become larger than 25λ, the process of reflection, refraction and diffraction become dominant in attenuation, and the laws of geometrical optics apply. Rain drops and clouds belong to this category of particles. Clouds reflect much of the radiation falling on them, while rain drops refract much of the radiation falling on them.

One major consequence of Rayleigh scattering is that the scattering is divided evenly between the forward and backward hemispheres. The back scattering removes almost all the unabsorbed ultra-violet (UV) radiation from the incoming solar radiation and hence reduces greatly the dangerous effects of UV radiation on the earth surface. Because the Rayleigh scattering coefficient varies with λ^{-4} shorter wavelengths are scattered more than the longer wavelengths. For the case of Lorenz-Mie scattering, depletion in solar radiation occurs by true scattering, as well as by absorption by particles. The scattered radiation is directed mainly in the forward hemisphere (John & Peter, 2006).

Absorption in the UV region is mainly due to ozone, while water vapor absorbs strongly in the infrared (IR) region. Generally little absorption takes place in the visible region. In both the UV and IR absorption, the energy can be re-emitted at different wavelengths. Figure 5 shows the absorption spectrum of the major atmospheric gases.

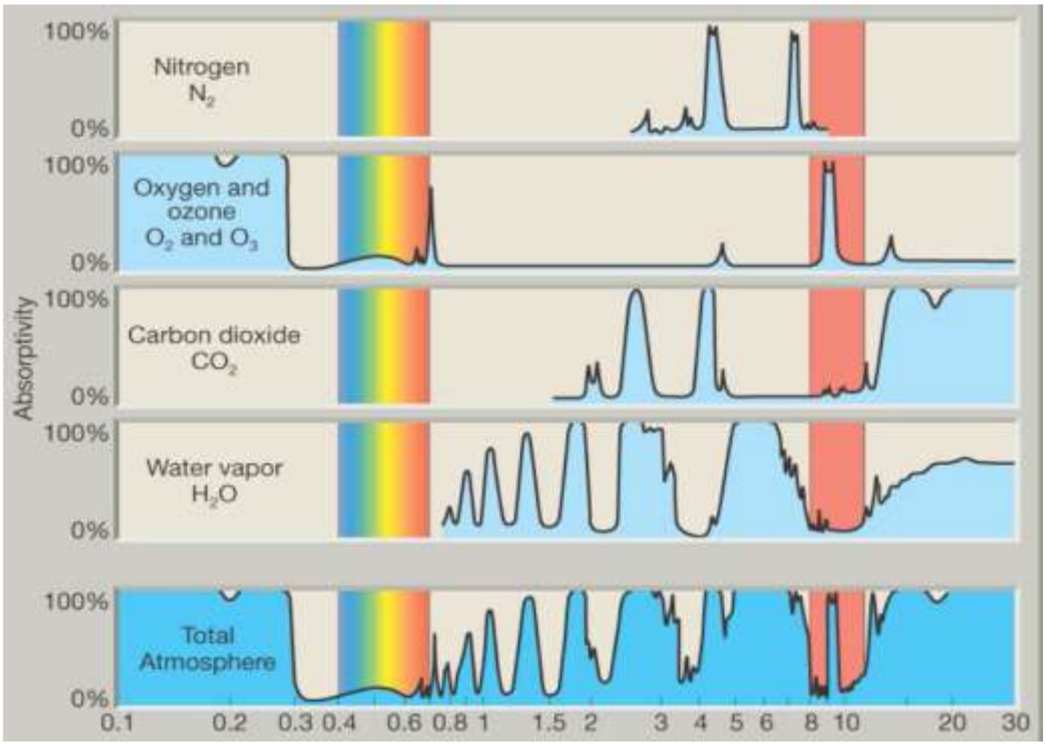


Figure 5: Absorption spectrum of major atmospheric gases (Liou, 2002).

Aerosol absorption results in higher attenuation of solar beam than scattering. In principle the absorption process can be expressed as:

$$I = I_o exp(-az)$$

where α is the absorption coefficient and z is the length of the path traversed. Absorption occurs all along the path of travel.

The amount of absorption (or scattering) of the solar beam as it traverses the earth's atmosphere depends on the atmospheric constituents, and on the solar altitude. The solar altitude determines the length of the path of the beam that has to travel before reaching the earth's surface. If the sun is along the Zenith (that is vertically above), it is overhead and the path length is shortest. On the other hand if the sun is in a direction making an angle θ with the zenith direction, the path length is longer. The path length of the solar beam in any direction is expressed as a ratio of the shortest path in the zenith direction; a quantity termed the "air-mass", m and defined as:

$$m = \frac{actual\ path\ length\ traversed\ in\ the\ direction\ of\ \theta}{path\ length\ in\ the\ zenith\ direction}$$

where by definition, $m = 0$ outside the atmosphere.

In a cloudy atmosphere considerable depletion of the solar beam takes place. A major part of the solar radiation is reflected back to space, and other part is absorbed, while the rest of the radiation is transmitted downwards to the earth as diffuse radiation. Transmission through a cloud is mainly by multiple scattering on water droplets within the cloud. The amounts involved in these processes depend on the type and distribution of clouds. The attenuation coefficient of a cloud depends on the size-frequency distribution of droplets and on the liquid content of the cloud. The attenuation coefficient A_c may be given by,

$$A_c = N \int \mathrm{r}^2 \ f(\lambda/r)dr$$

where N is the number concentration of droplets, r is the radius of a droplet (assumed spherical), λ is the wavelength of the radiation and $f(\lambda/r)$ is a function which depends on λ and r.

Reflection of solar radiation also takes place from clouds and from the earth's surface. The fraction of the solar radiant energy reflected this way together with scattering back to space by atmospheric gases and aerosols and dust particles is called the albedo of the earth-atmosphere system.

Measurement of solar radiation

In order to assess the available solar energy arriving on the earth's surface, measurement of solar radiation at locations on the earth is 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 by several different types of instruments having various characteristics and degree of accuracy. The standard instrument for measuring global solar irradiance is the pyranometer. Direct solar radiation is measured on a surface that is kept normal to the sun's disc by a pyrheliometer at normal incidence. Direct radiation measurement instruments are aimed directly at the sun, so that the detector surface is at right angles with the incoming radiation. Diffuse solar radiation is measured with a pyranometer that is continually shaded from the direct solar irradiance (WMO, 1981).

Even in the regions of the earth that receive large amount 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 therefore not practical to install the large number of pyranometers and radiometers that would be required to monitor these localized differences in cloud cover. Fortunately, empirical formulae can be used to provide this essential solar radiation data.

Solar Radiation Measurement in Ghana

The Ghana Meteorological Service Department is responsible for collecting data on solar radiation and other meteorological parameters across the entire country. According to Forson et.al. (2003), the Ghana Meteorological Service Department measured solar radiation across the country using Bellani-distillation pyranometers. This was done until 1988 when the instruments broke downand so they changed over to measuring duration of bright sunshine using Campbell-Stokes sunshine recorders. Independently, the solar energy applications laboratory of Kwame Nkrumah University of Science and Technology (KNUST) had been measuring global and diffuse solar radiation using Kipp and Zoen radiometers connected to a data logger at few stations in Kumasi (Forson et.al., 2003). For example, Quansah et.al. (2013) used measured values of global solar radiation at Owabi (6.750^{o}N, 1.716^{o}W) in the Asante region of Ghana to evaluate the performance of Angstrom-Prescott sunshine hour and Hargreaves and Samani temperature models.

Prior to 1988, global solar radiation was measured at 16 meteorological stations, whilst 24 stations recorded sunshine hours in the country. Currently, solar radiation is not measured by the Ghana Meteorological Agency due to high cost of installation and maintenance of pyranometers. Meanwhile, sunshine duration, precipitation and temperature (maximum and minimum) are constantly measured (Ghana Meteorological Agency [GMA], 2011).

Therefore in order to obtain solar radiation data in Ghana, utilization of empirical models is the best available option.

Estimation of global solar radiation

Apart from measurement by using pyranometers, global solar radiation can also be estimated from calibrated empirical models. These empirical models are obtained by collating measured global solar radiation with various meteorological variables together with calculated solar extraterrestrial radiation. This is due to the fact that the amount of global solar radiation reaching the earth's surface depends upon the local meteorological conditions.

Theory of Solar Extraterrestrial Radiation

The solar extraterrestrial radiation is the amount of global horizontal radiation that a location on the earth would receive if there were no intervening atmosphere. Two factors which cause variation in extraterrestrial radiation are variation in emitted radiation by the sun and the earth-sun distance. The solar insolation intensity, I_o (the flux of solar radiation per unit of horizontal area for a given locality) on a plane perpendicular to the sun rays on the edge of the atmosphere by correcting for the earth's elliptical orbit is given by

$$I_o = I_{sc}E_o \tag{2.16}$$

E_o is the eccentricity correction factor of the earth's orbit which is given by the expression below

$$E_o = 1 + 0.033\cos\left(360\frac{n}{365}\right) \tag{2.17}$$

I_{sc} is the solar constant.

Substituting equation (2.16) into equation (2.15) gives,

$$I_o = I_{sc}\left[1 + 0.033\cos\left(360\frac{\mathrm{n}}{365}\right)\right] \tag{2.18}$$

On a plane horizontal to the earth's surface, the extraterrestrial radiation at the latitude of the site is given by,

$$I = I_o cos\theta_o \qquad (2.19)$$

where θ_o is the solar zenith angle (the the angle between the incident radiation and the normal to the horizontal surface). From spherical trigonometry, the cosine of the zenith angle θ_o of the sun as shown in Fig.6 is

$$cos\theta_o \ = cos\delta cos\varphi cosh + sin\delta sin\varphi \qquad (2.20)$$

where ∂ is the declination of the sun, h is the sunset hour angle and φ is the latitude of the site. For easy distinction between symbols used in this research, the hour angle h has been replaced by ω and the latitude φ by $\emptyset$.

Hence, equation (2.20) can be rewritten as

$$cos\theta_o \ = cos\delta cos\emptyset cos\omega + sin\delta sin\emptyset \qquad (2.21)$$

Substituting equations (2.18) and (2.21) into equation (2.19), gives

$$I = I_{sc}[1+0.033cos[360\frac{n}{365})](cos\delta cos\emptyset cos\omega + sin\delta \sin\emptyset) \qquad (2.22)$$

To find the extraterrestrial irradiance falling on a plane horizontal to the earth's surface throughout the whole day, equation (2.22) was integrated with respect to time between sunrise ($\omega = -\omega_s$) and sunset ($\omega = \omega_s$).

Thus,

$$H_o = \int_{sunrise}^{sunset} I(t)dt$$

The resulting equation becomes,

$$H_o = \frac{24\times3600}{\pi} I_{sc}[1+ 0.033cos\ (360\frac{n}{365})]\ (cos\delta cos\emptyset sin\omega_s + \frac{2\pi}{360}\omega_s sin\delta sin\emptyset)$$

(2.23a)

The unit of H_o in this case is Jm^{-2}. Similarly, H_o can be expressed in Whm^{-2} $as\ H_o = \frac{24}{\pi} I_o[1+0.034cos(360\frac{n}{365})]\ (cos\delta cos\emptyset sin\omega_s + \frac{2\pi}{360}\omega_s\ sin\delta sin\emptyset)$.

(2.23b)

where $\omega_s = cos^{-1}(-\ tan\emptyset tan\delta)$ and n is the number of days of the year (Liou, 2002).

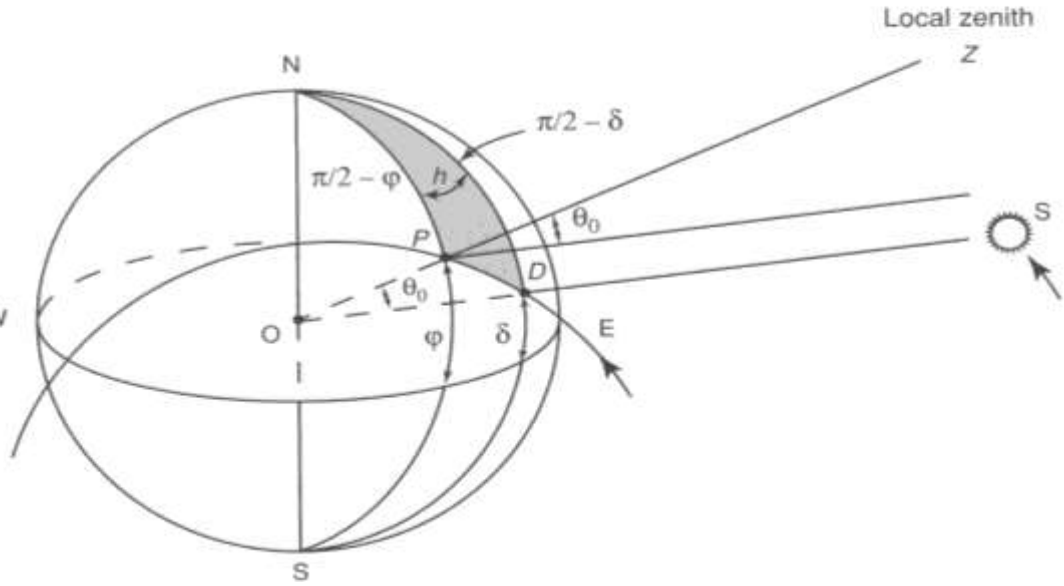


Figure 6: Relationship of the solar zenith angle $\boldsymbol{\theta_o}$, to the latitude $\boldsymbol{\varphi}$, the solar declination $\boldsymbol{\delta}$ and the hour angle, $\boldsymbol{h}$ (Liou, 2002).

Empirical models for estimating global solar radiation

When solar radiation data is unavailable, it is possible to get reasonably accurate solar radiation estimates using proposed radiation models. In literature, there are several empirical methods used to evaluate the global solar radiation.

Models Based on Temperature.

Air temperature based estimation models use maximum and minimum air temperature to estimate atmospheric transmissivity. Atmospheric transmittivity is the ratio of the amount of solar radiation that would be available on the earth if there were no atmosphere to the amount of solar radiation that is actually available on the earth. These models assume that maximum air temperature will decrease with reduced transmissivity, whilst minimum air temperature will increase due to the cloud emissivity. Clear skies will increase maximum temperature due to higher short wave radiation, and minimum temperature will increase due to higher transmissivity (Amorox, 2010).

Hargreaves and Samani (1982) were the first to suggest that global solar radiation could be evaluated from the difference between daily maximum and daily minimum temperature. The equation form introduced by Hargreaves and Samani is given as

$$H = H_o[\, A(\, T_{max} - T_{min})^{0.5}]. \tag{2.24}$$

where A is empirical coefficient, T_{max} and T_{min} are maximum and minimum temperatures respectively; H_o is the solar extraterrestrial radiation. Hargreaves later recommended A to be 0.16 for interior regions of the world and A to be 0.17 for coastal regions after analyzing solar radiation data all over the world. The model proposed by Hargreaves and Samani had been calibrated by Almorox (2010) at Aranjuez in Spain and obtained a coefficient of determination of 0.87. According to statistical analysis, a model is more efficient if the coefficient of determination is closer to 1. By this condition, Almorox concluded that the model could be used to estimate the global solar radiation with relatively high accuracy when the solar radiation and sunshine hours are unavailable, but when only temperature data are available. This is done and when the model coefficients cannot be determined directly from available data.

According to Bristow and Campbell (1984), the magnitude of the difference between daily maximum and minimum air temperatures depends on the Bowen ratio (the ratio of sensible heat to latent heat). Sensible heat depends on daily incoming solar radiation and is responsible for maximum air temperature (T_{max}). At night, sensible heat is lost into space as long wave radiation together with radiative fluxes. This results in decrease in air temperature until the daily minimum temperature (T_{min}) is reached. Based on this, Bristow and Campbell proposed a model which describes daily solar radiation as an exponential asymptotic function of global temperature range as shown below,

$$H = H_o a\,[1 - exp(-b\Delta T^c)\,]. \tag{2.25}$$

a, b and c are empirical constants, H is the global solar radiation, H_o is solar extraterrestrial radiation and $\Delta T = T_{\max\,(i)} - (\,T_{\min(i)} + T_{\min(i+1)})/2$; where i is number of data pairs.

Values most frequently reported for the coefficients a, b and c are 0.7 for a, the range 0.004 to 0.010 for b and 2.4 for c. The model had been used by Guillermo (2010) to estimate annual global solar radiation for fifteen whether stations in Peru located between latitude 0.15^o S and 18.36^{o}S, and between longitudes 68.725^{o}W and 81.36^{o}W. The errors in the values obtained for the fifteen stations range between 1 to 4% for places along the coast and 1 to 9% for the highland areas. Guillermo observed that among all the available temperature models, Bristow-Campbell model is most applicable to Peru.

Allen (1997) suggested the use of a self-calibration model to estimate mean monthly global radiation. Following the work of Hargreaves and Samani (1982), Allen proposed that the mean monthly global radiation R_G can be estimated as a function of mean monthly maximum temperature(T_M) and minimum temperature(T_m) as:

$$R_G/R_A = K_r\,(T_M - T_m)^{1/2} \tag{2.26}$$

where the coefficient K_r is expressed as a ratio of atmospheric pressure of the site P, and P_o at sea level given by,

$K_r = K_{ra}\ (P/P_o\ )^{1/2}$ and $P/\ P_0 =\ exp(-0.0001184h)$,where h is the altitude of the place.

Further, Allen used minimum and maximum temperature data all over the world and suggested $K_{ra} = 0.17$ for interior regions of the world and $K_{ra} = 0.2$ for coastal regions of the world.

Okundamiya and Nzeako (2005) investigated a model for estimating global solar radiation on horizontal surface for selected cities in six Geopolitical zones in Nigeria. The model was based on linear regression theory and computed using monthly mean daily data set for minimum and maximum ambient temperatures. The model is expressed as,

$$H = H_o\ (m_o + m_1 R_T + m_2 T_{max}) \qquad (2.27)$$

R_T is T_{min}/T_{max} (the ambient temperature ratio), H is monthly mean daily global solar radiation, H_o is monthly mean daily extraterrestrial radiation, m_o, m_1, and m_2 are empirical constants, T_{max} maximum daily temperature and T_{min} is minimum daily temperature. The values of the regression constants obtained for the locations are as follows,

Location	Latitude /^{o}N	Longitude / ^{o}E	m_o	m_1	m_2
Abuja	9.08	7.503	−1.2560	0.3815	0.00544.
Beni	6.64	5.630	0.2284	−1.0109	0.03981.
Katsina	13.00	7.600	0.5033	−0.2487	0.00932
Lagos	64.50	3.400	2.6500	3.0010	0.01932.
Nsuka	6.86	7.390	0.2445	−0.8525	0.03240
Yola	10.38	12.807	0.2445	− 0.8525	0.03240

Okundamiya & Nzeako (2005).

Okundamiya and Nzeako analyzed the results and observed that the model vary between over and under estimation of the measured global solar radiation. But there was a good agreement between the estimated and the observed values of the solar radiation as the coefficient of determination ranges between 0.809 and 0.952. However, to further improve on the accuracy of the estimated results, they suggested that additional meteorological parameters should be included in the model.

Chiemeka (2008), estimated global solar radiation at Uturu in Nigeria on latitude 05.33^o and longitude 06.03^o using global radiation estimation model proposed by Hargreaves (1982).The model is expressed as;

$$R_s = 0.6 R_a {T_d}^{1/2} \quad (2.27)$$

where $T_d = T_{max} - T_{min}$. T_{max} is maximum air temperature and T_{min} is minimum air temperature. Also, R_a is solar extraterrestrial radiation and R_s is global solar radiation. The mean global solar radiation obtained for the period is 1.89 $\pm$ 0.82 kWh per day. Chiemeka observed that a comparison of the mean global solar radiation result obtained at Uturu and that obtained by Chineke (2007) at Umudike (5.48^{o}N, 7.55E) and Chineke (2002) at Owerri (5.47^o N, 7.03^{o}E) showed that the solar radiation obtained at Uturu is low. This difference may be attributed to the fact that Uturu is bounded on the West and South by a hilly escarpment.

Models Based on Temperature and other Variables.

The estimation of global solar radiation was also done using temperature which incorporated other variables. The temperature based models were therefore improved by adding other variables such as precipitation, relative humidity; clearness index and saturation vapor pressure (Almorox, 2010). However, other models which do not include temperature have also been proposed (McCaskill, 1990).

Louis et.al.,(2004), developed multi linear regression models to estimate monthly averaged daily global solar radiation using different sets of meteorological parameters for a sixteen year period (1986 to 1999) for Onne in Nigeria. Up to ten variable correlation equations had been developed but the following equation was found to give better results in comparison with measured global solar radiation values

$$H = -7.489 + 0.316H_o + 0.236T - 7.000\theta + 6.758 + 10^{-2} + Rh + 17.35(n/N) + 4.444\times10^{-2} - \delta^2 - 0.77ST + 674.342EV \qquad (2.28)$$

The variables in the above model are defined below with H as monthly average daily global solar radiation on a horizontal surface, H_o as monthly average daily solar extraterrestrial radiation on a horizontal surface, T as monthly average daily temperature, θ as monthly average ratio of minimum to maximum daily temperatures and Rh as monthly average daily relative humidity. The ratio n/N is monthly percentage possible sunshine, δ is solar declination, ST is monthly average daily soil temperature, and EV is monthly average evaporation. The percentage error obtained upon analysis of the results using this model is within the range of $-$ 3.85% to 3.91%. According to Louis, et.al. (2004), the error is within the range of values accepted and so the multilinear regression equation could be employed for the purpose of estimating global solar radiation of locations that have the same climatic conditions, latitude and altitude as Onne which is within the forest climatic zone of southern Nigeria.

Almorox (2010) proposed the following model for estimating global solar radiation at Aranjuez in Spain which is on latitude 40.10°N and longitude 3.74°W. This model by Almorox requires saturation vapour pressures at maximum and minimum temperatures respectively. It also requires transformed rainfall data and daily minimum relative humidity. Almorox's model is given by

$$H = aH_o \{1 - exp\,[-b\,(e_s\,(T_{min})/e_s(T_{max})\,]\,\}^{-2.6518} \times (cR_T - dRh_{min}). \quad (2.29)$$

where H_o is the solar extraterrestrial radiation, e_s is saturation vapour pressure, T_{max} and T_{min} are maximum and minimum air temperatures respectively, Rh_{min} is minimum relative humidity, R_T is transformed rainfall data and a, b, c and d are empirical coefficients. A regression analysis of the result with observed solar radiation data gives values of the empirical coefficients as $a = 0.7345, = b - 0.2549$, $c = 0.1233$, $d = 0.00428$. The coefficient of determination obtained for the model was 0.92. According to Almorox (2010), a model is more effective if the coefficient of determination is close to 1.Therefore, the value of the coefficient of determination indicates that the model is effective and that it can be used at other locations of the world. However, the values of the empirical coefficients are site specific.

Ali et.al, (2010) developed the following multi linear correlation model and used it to estimate global solar radiation on horizontal surface in three different cities in Iraq. The researchers used a long term records of monthly mean of daily maximum temperatures, sunshine duration and relative humidity in their model which is given by the expression below

$$G/G_o = a + b\,(S/S_o) + cT_{max} + dRh. \quad (2.30)$$

where a, b, c and d are regression constants which could be negative or positive, G is monthly mean of daily global solar radiation, G_o monthly mean of daily global extraterrestrial radiation, S is number of hours of bright sunshine, S_o is day length, T_{max} is maximum temperature and Rh relative humidity.

The cities are Baghdad (latitude 33.22^{o}N; longitude 44.23^{o}E), Mosul (latitude 36.32^{o}N; longitude 43.15^{o}E) and Rutba (latitude 33.03^{o}N, longitude 40.28^{o}E) .The model for each city is as follows:

In Baghdad, the model was

$$G/G_o = 10.78 + 0.071(S/S_o) + 0.0026\,T_{max} - 0.00078Rh \qquad (2.31a)$$

and that of Rutba was

$$G/G_o = 15.07 + 0.104(S/S_o) - 0.00139\,T_{max} - 0.0011Rh. \qquad (2.31b)$$

The model for Mosul was

$$G/G_o = 8.86 + 0.301(S/S_o) + 0.0035\,T_{max} - 0.00157Rh. \qquad (2.31c)$$

Ali M, et. al., recorded the error of estimation between 0.035 and 0.063.The error margin shows that the designed models can reasonably predict the global solar radiation received on horizontal surfaces, and the expected solar radiation behavior at the selected sites.

Bocco M., Enrique W. and Arias M. (2010) developed linear regression models to estimate global solar radiation and compared their efficiency in application to a region of the province of Sata in Argentina (latitude, 24S.9^{o}N, 65.48^{o}W). Relative sunshine duration, maximum and minimum temperature, rainfall, and binary rainfall data for the period 1996 to 2002 were used. Three different equations were developed from their regression analysis, and are given by

$$R_1 = -6.22 + 0.03\,\mathrm{T_{max}} + 0.04T_{min} - 0.04R + 0.15RSD + 0.5ARS$$

(2.32a)

$$R_2 = -5.97 + 0.02\,\mathrm{T}_{\max} + 0.05\,\mathrm{T}_{\min} - 1.18\,BinR + 0.15RSD + 0.51ASR \quad (2.32b)$$

and $$R_3 = -8.28 + 0.7\,T_{max} + 0.47\,T_{min} - 0.08R + 0.4ASR. \quad (2.32c)$$

R_1, R_2 and R_3 represent the estimated global solar radiation values of the respective models, T_{max} and T_{min} − are maximum and minimum temperatures respectively, *R* is rainfall, *BinR* is binary rainfall, *RSD* is Relative sunshine duration and *ASR* is astronomical solar radiation. Measured global solar radiation of the site was used to determine the coefficient of determination for each model. The values of the coefficient of determination using the above three equations are 0.88, 0.88, and 0.64 respectively. Based on these results Bocco,et.al. (2010) concluded that R_1 and R_2 regression models are the best for estimating global solar radiation at the chosen sites as their coefficient of determination values are close to 1.

Emmanuel et.al (2013) developed multiple linear regression equations to evaluate various models for the estimation of monthly mean of daily global solar radiation on a horizontal surface from sunshine hours, relative humidity, ambient temperature and soil temperature to select the best model for Wa Polytechnic Weather Station. One hundred and twenty seven (127) correlation equations of different combinations were obtained and seventeen models having the best statistical errors were compared using statistical analysis. Based on the results, Emmanuel el.al (2013) recommended the following linear equation for the estimation of global solar radiation on a horizontal surface for Wa Polytechnic Weather Station and other locations with similar climate, latitude and altitude.

$$\bar{H} = -1.350 + 0.007RH + 44.800\,{}^{\bar{n}}\!/\!_{\bar{N}} + 2.00 sin\delta \qquad (2.34)$$

where $\bar{H}$ is monthly mean daily global radiation, RH is relative humidity, $\bar{n}$ monthly mean of daily hours of bright sunshine, $\bar{N}$ monthly mean of maximum possible daily hours of bright sunshine and δ declination angle.

Emmanuel et.al (2014), evaluated the performance of both sunshine and temperature dependent models for the estimation of global solar radiation over Ghana and other tropical regions and carried out a comparison assessment of the models using measured global solar radiation values at Owabi (6.75^o, 1.72^o) in the Ashanti region of Ghana.

The sunshine hour model used was the Angstom – Prescott Sunshine Hour Model given as ${}^{G_p}\!/\!_{G_o} = a + b\ ({}^{n}\!/\!_{N})$.

where G_p is the predicted monthly mean of daily global solar radiation on a horizontal surface, G_o is the monthly mean extraterrestrial solar radiation on horizontal surface, n is the number of hours of bright sunshine, N is the number of hours of possible sunshine (day length) and a and b are empirical constants. The temperature models used were Hargreaves and Samani and Chandel et.al. Temperature Models given respectively as $R = a(\Delta T^{0.5}) + b$ and $R = aln(\Delta T) + b$

where R is the clearness index (${}^{G_p}\!/\!_{G_o}$), ΔT is the difference of maximum and minimum temperatures ($T_{max} - T_{min}$) and a and b are empirical constants.

From the results, the following equations were proposed for Kumasi and other location with similar climate.

$$G_p/G_o = 0.22 + 0.43\ (n/N) \qquad (2.35a)$$

$$R = 0.311(\Delta T) - 0.293 \qquad (2.35b)$$

According to Emmanuel et.al (2014), the results showed that the models could predict the variability of the measured monthly mean of daily global solar radiation for the entire period of the study very well as they give coefficient of determination between 0.88 and 0.96%. And this could be attributed to the fact that the models require meteorological input data (sunshine hours and air temperatures) that also respond to the variability in atmospheric conditions such as rainfall, cloud cover, and the seasonal changes that affect the amount of solar radiation reaching the Earth’s surface.

Models Based on Sunshine Hours Only.

A simple model used to estimate monthly mean of daily global solar radiation on a horizontal surface based on just sunshine hours is the modified form of the Angstrom- type equation. Angstrom (1924) was the earliest to develop a linear regression model for estimating global solar radiation for the Royal meteorological society utilizing sunshine duration and clear sky radiation. The model is expressed as;

$$H\ /H_c\ = a' + b'(S/S_o) \qquad (2.34)$$

where H is monthly mean of daily global solar radiation, H_c is monthly mean daily clear sky radiation, a' and $b'$are empirical constants, S is number of hours of bright sunshine and S_o is the length of day (number of hours of possible sunshine). Angstrom suggested values of 0.2 and 0.5 for a' and b' respectively which is believed to be applicable all over the world.

Prescott (1940) modified Angstrom formula by replacing the H_c with the H_o extraterrestrial solar radiation) due to difficulty in obtaining clear sky radiation. As a result a' and b' have also been replaced with a and b. The model then becomes

$$H/H_o = a + b \ (S/S_o) \tag{2.35}$$

where a and b are empirical coefficients. These coefficients have some physical explanation with the meaning that $a + b$ value represents the maximum value of atmospheric transmission coefficient τ, and a represents the minimum value.

Ahmad and Ulfat (2004) developed a new set of constants using the Angstrom-Prescott type correlation model of first and second order to estimate monthly average global solar radiation employing sunshine hours data over Karachi in Pakistan on latitude 24.9^o N and longitude 67.13^{o}E. The first and second order equations developed are presented respectively below

$$H/H_o = 0.324+0.405(S/S_o) \tag{2.36a}$$

$$H/H_o = 0.348 +0.320(S/S_o) + 0.070(S/S_o)^2 \tag{2.36b}$$

H is monthly mean global solar radiation, H_o is monthly mean extraterrestrial radiation, S is number of hours of possible sunshine and S_o is the day length. According to Ahmad and Ulfat, the percentage error estimated for all the months are below 5.0%. The coefficient of determination of the linear model is 0.984 and that of the quadratic model is 0.949. This shows that both models could be used effectively to estimate the global solar radiation at the given location. On the other hand, the results of the coefficient of determination reveal that the linear model (equation 2.36a) shows the best agreement with the measured global solar radiation.

El-Sebaii and Trabea (2005) analyzed the global solar radiation and sunshine duration data recorded at five cities in Egypt. The cities are Matruh (latitude $31^{o}.35$ N; longitude 27.05^{o}E), AL-Arish (latitude 31.12^{o}N; longitude 33.75^{o}E), Rafah (latitude 31.22^{o}N; longitude 34.20^{o} E), Tanta (latitude 30.78^{o} N; longitude 31.00^{o}E) and Aswan (latitude 23.97^{o} N; longitude 32.78^{o}E). In this study, the main objective was to investigate the effectiveness of the Angstrom-Prescott linear regression model alongside other Angstrom-Prescott type quadratic models proposed by other researchers. Performances of the models were checked by comparing the estimated and measured values of the global solar radiation. El-Sebaii and Trabea indicated that comparisons between measured and estimated global solar radiation showed that the second and third order Angstrom-Prescott type of correlations did not improve the accuracy of estimation of global solar radiation. Therefore, they recommended the following linear correlation models for estimating the global solar radiation at those five locations. The models recommended for Al-Arish, Rafah, Matruh, Tanta and Aswan respectively are given as follow,

$$\bar{H}/\bar{H}_o = 0.295 + 0.423(\bar{S}/\bar{S}_o) \tag{2.37a}$$

$$\bar{H}/\bar{H}_o = 0.367 + 0.342(\bar{S}/\bar{S}_o) \tag{2.37b}$$

$$\bar{H}/\bar{H}_o = 0.508 + 0.186(\bar{S}/\bar{S}_o) \tag{2.37c}$$

$$\bar{H}/\bar{H}_o = 0.247 + 0.489(\bar{S}/\bar{S}_o) \tag{2.37d}$$

$$\bar{H}/\bar{H}_o = 0.334 + 0.389(\bar{S}/\bar{S}_o) \tag{2.37e}$$

Further analysis by El-Sebaii and Trabea showed a good agreement between measured and calculated global solar radiations for all locations using the modified Angstrom-Prescott linear regression equation. This is because the percentage error for estimating the global solar radiation for Tanta and Matruh for a single month was less than ±12% and for the other three locations; Al-Arish, Rafah and Aswan, it was less than ± 9%.

Mohammed (2007) determined global solar radiation on a horizontal surface for the district of Comilla in Bangladesh on latitude 23.43^{o}N, longitude 91.18^{o}E for a period of 28 years. The model for the global solar radiation was developed from Angstrom-Prescott regression equation and is given by

$$H/H_o = 0.2315{+}0.5473(S/S_o) \qquad (2.38)$$

where H is the global solar radiation, H_o is extraterrestrial radiation, S is number of hours of bright sunshine and S_o is length of day in hours.

The coefficient of determination of the model obtained by Mohammed using measured solar radiation data was 0.9854. This value indicates that the model is effective for estimating the global solar radiation of the site. According to Mohammed, the model can be used to estimate the global solar radiation at other locations when the empirical constants are accurately determined.

Khalil and Fatty (2008) calibrated Angstrom-Prescott model for six cities in Egypt: Marsa- Matrush (latitude 310.55^{o}N; longitude 270^o.58^{o}E), Abu-Simble (latitude 220.57^{o}N; longitude 270.58^{o}E), Cairo (latitude 300.08$^{o;}$ longitude 320.28^{o}E), Aswan (latitude 230.97^{o}N; longitude 320.78^{o}E), Al-Kharga (latitude 250.45^{o}N; longitude 300.57^{o}E) and Halaib-Shalatin (latitude230.50^{o}N; longitude 340.50^{o}E).The equations used for each of the cities in order in which they were presented above are as follows

$$H = H_o\ [0.351+0.406\ (S/S_o)] \quad (2.39a)$$

$$H = H_o\ [0.611+0.107(S/S_o)] \quad (2.39b)$$

$$H = H_o\ [0.461+0.259(S/S_o)] \quad (2.39c)$$

$$H = H_o\ [0.596 + 0.0174(S/S_o)] \quad (2.39d)$$

$$H = H_o\ [0.291+0.0.223(S/S_o)] \quad (2.39e)$$

$$H = H_o\ [0.490+0.223(S/S_o)] \quad (2.39f\ )$$

where, S is sunshine duration in hours and S_o is length of day in hours, H is global solar radiation and H_o is solar extraterrestrial radiation. The empirical coefficients a and b of Angstrom type was calculated for the selected sites as presented in the equations above. The values of the empirical coefficients were found to vary from 0.219 – 0.611 and 0.107–0.576, respectively. The estimated values of the global solar radiation were compared with the measured values. Khalil and Fatty observed that although a and b values differ from one site to another, the summation $a+b$ is almost the same for the selected sites. The difference between the estimated and measured values of the global solar radiation at the various sites varies from 4% to 12%.

Ahmed, Ahmad and Akhtar (2009) were the first to estimate global and diffuse solar radiation at Hyderabad in Pakistan on latitude 25.35^{o}N and longitude 68.27^{o}E using Angstrom-Prescott model (equation 2.35) given as

$$H\ /H_o = a + b\ (S/S_o) \quad (2.40)$$

where H is the monthly mean of daily global solar radiation falling on a horizontal surface at a particular location, H_o is the monthly mean of daily global solar extraterrestrial radiation and S is the monthly mean daily number of hour of sunshine. Also, S_o is the monthly mean value of day length at a particular location and a, b are empirical coefficients which can be determined using climatological data.

Because measured solar radiation records were not available at Hyderabad, the empirical coefficients a and b were obtained from the formula proposed by Tiwari & Sangeeta (1977) and confirmed by Frere (1980).The formula is given as

$$a = -0.110 + 0.235 \cos\phi + 0.323(S/S_o) \tag{2.41a}$$

$$b = 1.449 - 0.553 \cos\phi - 0.694(S/S_o) \tag{2.41b}$$

where ϕ is the latitude of the place.

The diffuse solar radiation was deduced from the following formula,

$$H_d/H = 1.00 - 1.13KT. \tag{2.42}$$

where KT is the clearness index.

According to Ahmed, Ahmad and Akhtar (2009), since experimental data for global and diffuse solar radiation was not available in Hyderabad, the estimation of global and diffuse solar radiation has to be done employing sunshine hours of the location. Linear and quadratic regression could be developed, if measured data for the location under study were available. However, the results obtained served the purpose for Hyderabad city effectively.

Medugu and Yakubu (2011) estimated global solar radiation at Yola in Nigeria on latitude 9.20^{o}N and longitude 12.48^{o}E, using daily sunshine hour data for a period of four years (from 2004 to 2007).The Angstrom-Prescott model (equation 2.35) was used to estimate the global solar radiation.

$$H/H_o = a + b\,(S/S_o)$$

According to Medugu and Yakubu (2011), measured global solar radiation records were not available at Yola, and so the empirical coefficients were calculated using equations 2.41a and 2.41b as

$$a = -0.110 + 0.235 \cos\phi + 0.323(S/S_o)$$

$$b = 1.449 - 0.553 \cos\phi - 0.694(S/S_o)$$

In general, higher value of solar radiation is obtained in the dry season than the wet season. The value of global solar radiation for Yola town over the period of measurement was estimated to be 21.54 ± 0.46 MJm^{-2} $days^{-1}$ using Angstrom-Prescott model.

Based on the results, Medugu and Yakubu concluded that the method is more accurate among others for estimating global solar radiation especially at places where measured solar radiation records are not available. This is due to the fact that the expression for the empirical constants, *a* and *b* are functions of the latitude of the place and the clearness index as expressed in the Angstrom-Prescott model.

The review reveals that a number of empirical models are applicable for estimating global solar radiation at different locations around the world. However, most of these models have empirical constants which need to be determined using measured global solar radiation data. In areas where measured global solar radiation data is not available, one of the available options is to adopt a model whose empirical constants can be determined using available climatological and geographical parameters. In this way, the specific climatological and geographical conditions of the site are taken into consideration. One of such a model is the Angstrom – Prescott sunshine based model.

CHAPTER THREE

METHODOLOGY

Introduction

Availability of solar radiation data is basic information that will enable a better utilisation of solar energy economically. Knowledge of global solar radiation data at a site is essential for the proper design and assessment of solar energy conversion systems. However, owing to the high cost of solar radiation measuring devices and apparent shortage of expert care, there are few locations in developing countries where long-term solar radiation measurements are available. Currently, Ghana has no solar radiation measuring center, where measurements of daily and monthly values of global solar radiation are carried out (Ghana Meteorological Service Department [GMSD], 2011).

The monthly mean of the daily global solar radiation on a horizontal surface will be analysed based on values obtained from the empirical model used and values obtained by other researchers for Ghana using other established models. In addition, the seasonal variations of global solar radiation will be discussed. As a result of these analyses, a general feature of the global solar radiation resource potential of the selected locations will be predicted.

Study Area

In this study, the estimation of global solar radiation was carried out at eight Synoptic (Weather) Stations in Ghana. Five stations were selected from the Northern belt, mostly made up of Sudan Savanna and Guinea Savanna regions of Ghana and three stations were selected from the Middle belt, mainly Deciduous Forest and Coastal Savanna regions of Ghana. The choice of the stations was based on the availability of data and the need for a fair representation across the Northern and middle belts of Ghana. These areas have greater number of rural settlements with mainly farming as their major occupation. Figure 7 shows the location of the Synoptic Stations used for this study.

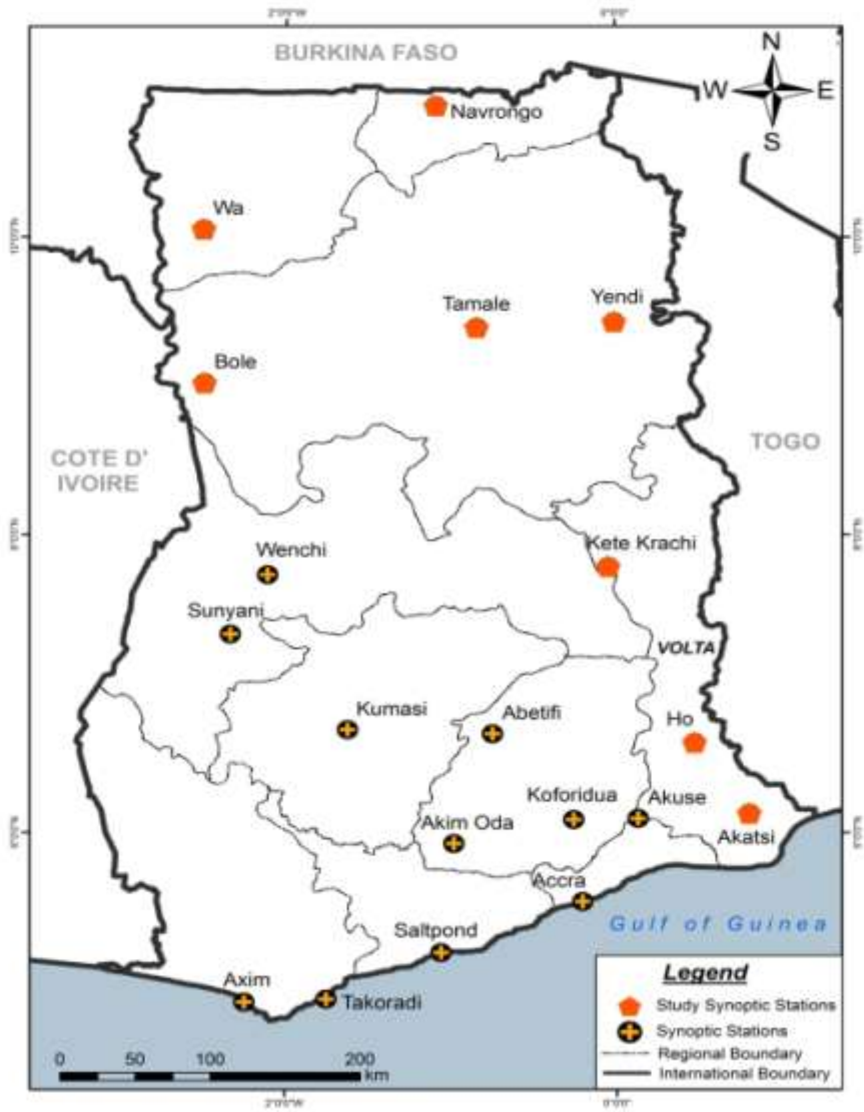


Figure 7: Location map of Selected Synoptic stations.

The geographical and climatic conditions of each of the selected Synoptic Stations are described;

Akatsi is located in the South-Eastern part of the Volta Region on latitude 6.12^{o} N and longitude 0.80^{o}E.The total population of Akatsi is about 93 477 people (GSS, 2012). The district has a total land area of about 906,455km^2 with a low lying coastal plain and flatland in the south and rolling plain to the north. The topography of the district is generally gentle and undulating land averaging 53.6m above sea level. About 60% of the total land area lies below 30.48m contour line and rising to over 60.96m in the northern part. The town falls within the coastal savannah equatorial climate regime characterized by high temperatures between 21^{o}C and 34.5^{o}C and high relative humidity of about 85%. The vegetation is made up of coastal savannah in the south and savannah woodland in the north.

A physical potential of the district is the vast savannah grassland which is ideal for irrigated mechanized farming and livestock rearing. There is moderate regime of rainfall of 1,084mm with annually wet and dry seasons of about equal lengths. The district experiences a bi-modal rainfall pattern which is suitable for crop production. Agriculture is the main economic activities of the people of Akatsi. Crop production is at the subsistence level with more intensity in the southern sector than the northern parts. Crops mainly grown include maize, cassava, sweet potato, cowpea, pepper, tomato, garden eggs, okra, groundnut and tobacco.

Bole district is located at the extreme western part of the Northern Region of Ghana and lies on latitude 9.03^{o}N and longitude 0.39^{o}W. The district is approximately 301m above sea level and covers an area of about 4800 km^2 of the

Northern Region. Bole has an estimated population of about 75,151(GSS, 2012). The vegetation of the district consists of savannah woodland, with trees such as sheanut, dawadawa, teak, kapok and mango which are all economic trees. There are also tall grasses and shrubs and thorny species. In few places, flood plain, pond, clay and flat vegetation are found. The natural vegetation in most parts of the district especially around the settlements has disappeared. What is seen today has resulted from the interference by man and animals through cultivation, grazing and exploitation for firewood. The district experiences extremes of temperature. The daily and annual range of temperature is wide. The coldest nights in the year are experienced in the months of December, January and February. During these months the air becomes dry and the atmosphere becomes hazy, making visibility impaired due to the fine airborne dust in the air. The day temperature at this period ranges between 28°C and 40°C but under cloudless skies the night can be very cold with temperatures under 28°C. This is the period of the harmattan. Sudden rise in temperature is experienced in the months of March, April and May when temperature exceeds 30°C.

The rains begin around May and end in October. The rainfall is seasonal and is characterized by a single maximum. The mean annual rainfall is about 1,100mm.Heaviest rainfall and the greatest numbers of rainy days are generally recorded in June, July and August.

The soils are generally very fertile for agriculture. Agriculture in the district covers food crops (maize, millet, sorghum, rice, groundnuts, cowpea, Bambara bean, yam, and cassava), cash crops (cashew, Shea, mango, and dawadawa), livestock (cattle, sheep, goats, pigs, guinea fowl, local and exotic fowls), fisheries and bee keeping with emphasis on mechanization, value addition and organized marketing.

Ho is the capital of Ho municipal district and the Volta region of Ghana. It lies between mount Adaklu and mount Galenukui (Togo Atakora range). It has a settlement population of 96, 213 people (GSS, 2012). The municipality lies on latitude 6.60^{o}N and Longitude 0.47^{o}E and covers an area of about 2 660km^2. The north and north-western parts are mountainous, comprising part of the Togo Ranges. The topography in the area imposes steep slopes and rapid run-offs during the rainy seasons. The average altitude of the municipality is about 157.6m.

The vegetation of Ho falls into two main types of Vegetation zones: these are the moist Semi-deciduous forest, which mostly covers the hills and savannah woodland which covers the rest of the municipality. Generally, mean monthly temperature in the Municipality ranges between 22^{o}C and 32^{o}C while annual mean temperature ranges between 16.5^{o} C and 37.80^{o} C. In effect, temperatures are generally high throughout the year which is good for plants and food crop farming. During the dry season however, daily temperatures are so high that, except for irrigation and river valleys, food crop cultivation cannot take place. The mountainous settlements like Amedzofe, Biakpa, Vane and Ashanti Kpoeta have very low temperatures during some parts of the year and are often referred to as the "local winter" of the Volta Region.

The rainfall pattern is characterized by two rainy seasons referred to as the major and the minor seasons. The major season is from March to June while the minor season is from August to November. The rest five months of the year is referred to as dry season. Mean annual rainfall figures are between

20.1mm and 192mm. The highest rainfall occurs in June and has mean value of 192mm while the lowest rainfall is in December recording a value of 20.1m.

The soils in the Municipality are suitable for farming and construction. The forest soil supports perennial crops such as Cocoa, Oil Palm, Coffee, Avocado, Plantain and Banana while the Savanna Soil supports annuals like maize, cassava, yams, groundnuts, legumes and variety of vegetables (Gyan-Baffour 2003).

Kete Krachi covers the Krachi West, Krachi East and Nkwanta districts of the Volta Region. It lies on latitude 7.81^{o}N and longitude 0.37^{o}W and is about 122m above sea level. The three districts cover an area of 8, 699 km^2. Krachi East had a population of 75,058, Krachi West 81,954, and Nkwanta 153,279 (GSS, 2012). The area is characterized by a tropical climate with dry and humid weather conditions. The area can be classified into two main relief zones: the mountainous southern portion lying along the eastern border with the Republic of Togo and the undulating northern part, with altitudes between 100m to 200m above sea level. The area has an array of vegetation ranging from the semi-deciduous forest zone on the eastern and southern parts, and the savanna woodland sandwiched between the northern grassland savanna and the semi-deciduous forest zones.

The mean annual maximum temperatures range between 24^{o}C and 39^o C, while mean annual minimum temperatures range between 11^{o}C and 26^{o}C.The highest temperatures are recorded between January and April while the lowest temperatures are recorded in December.

Rainfall regime in the district is double maxima type, the first from April to July and the Second from September to October. The mean annual maximum temperatures range between 24^oC and 39^oC, while mean annual minimum temperatures range between 11^oC and 26^oC. January to April constitutes the hottest months while December has the lowest temperatures.

Annual rainfall amounts ranges between 922mm and1874mm. Dry season occurs from November to March. Agriculture is the mainstay of the economy of the area because majority of the people are into subsistence agriculture. Major food crops include cassava, yam, maize, groundnut, sorghum, rice and cowpea. Cash crops cultivated include cocoa, oil palm, and cashew. Also, fishing is a major activity on the Volta Lake and the Oti River.

Navrongo is the capital town of the Kassena-Nankana District which is in the Upper East region of Ghana with a population of about 27,306 people (Ghana Statistical Service, [GSS], 2012). Navrongo is located on latitude 10.90^{o}N of the equator and longitude of 1.10^{o}W of the zero meridians and covers an area of 1,675km^2 sharing a boarder with Burkina Faso in the north. It measures roughly 50km long and 55km wide and has an altitude of 201.3m above sea level. The land is relatively flat and passing through it from Burkina Faso is the White Volta River, which feeds Lake Volta in the eastern part of Ghana. The town is located in the Guinea Savannah belt of Ghana and its climate is typically hot and dry, with the vegetation consisting mostly of semi-arid grassland interspersed with short trees. Monthly temperatures range from 20^o C to 40^o C. There are two main climatic seasons; the wet and dry seasons. The wet season extends from April to October, with the heaviest rainfall mainly occurring between June and October. The dry season is subdivided into the

Harmattan and the dry hot seasons. The Harmattan season starts from November to mid-February and the dry hot season starts from mid-February to April. Agriculture, hunting and forestry are the main economic activities in the region. Subsistence level agriculture is the main stay occupation of the area, as well as the rearing of domestic animals. The main crops grown are millet, guinea-corn, maize, groundnut, beans, sorghum and dry season tomatoes and onions.

Tamale is the capital of the Northern Region of Ghana. Tamale is the third most populous settlements in Ghana, with a population of 537,986 people (GSS, 2012).

Tamale is located at the Centre of the Northern Region on latitude 9.42^{o} N and longitude 0.85^{o}E.The town is approximately 183.3m above sea level with total land area of 750km^{2}. The topography is generally rolling with some shallow valleys which serve as stream courses. There are also some isolated hills but these do not inhibit physical development. The dry season is usually from November to early April and it is influenced by the dry North-Easterly (Harmattan) winds. The mean day temperatures range from 28^{o}C in December and mid-April to 43^{o}C in March and early April while mean night temperatures range from 18^{o}C in December to 25^{o}C in February and March. The climactic conditions have to a greater extent influenced the vegetation of the area. The metropolis lies within the Guinea Savanna belt of Northern Ghana and experiences one rainy season from April to September or October with a peak in July and August. The rainy season is influenced by the moist South Westerly winds. The mean annual rainfall is 1100 mm within 95 days of rainfall in the form of tropical showers. Consequently, staple crop farming is highly restricted by the short rainy season. The land is mostly low lying except in the north-eastern corner with the Gambaga escarpment and along the western corridor. The region is drained by the Black and white Volta and their tributaries.

Apart from the preserved natural colonies of vegetation at fetish groves, forest reserves and community woodlots, the whole Metropolis exhibits tall grass interspersed with drought resistant trees such as neem, sheanut, dawadawa and mahogany. Farming continues to be the major economic activity undertaken by about 60% of the total labor force. Major crops cultivated are yam, cassava, legumes (beans, groundnuts, Neri, cowpea and soybeans) and cereals (millet, sorghum, maize and rice).Vegetables are such as tomatoes, okro, spinach and pepper are cultivated but on small acreage.

Wa is the capital of Wa Municipal District in the Upper West Region of Ghana with a population of about 102,446 people (GSS, 2012).The Municipality lies on latitude 10.67^{o} and longitude 2.50^{o} W and has an area of about 234.74 km^2 which is about 6.4% of the land area of the Upper West Region. The Municipality lies in the Savanna high plains, which generally is undulating with an altitude of 306m above sea level. The climate of Wa is made up of long dry season and short rainy season. The dry season is normally from November to April while the remaining months experience the rainy season with its peak in August and September. The dry season records high temperatures ranging between $40 - 45^{o}$C in the months of March and April. Total annual rainfall in the area ranges from 910 to 2000 mm with an average humidity of 95 mm. The vegetation cover of the area is guinea savanna woodland, which is made up of grasses and tree species. Human activities such as firewood harvesting, charcoal burning, farming, and quarrying and construction are all combined to modify the natural environment. Despite its urban status, Wa is in many ways still an agricultural community and many people make a good portion of their living in small scale farming. The main crops grown are corn, millet, yams, okro and groundnuts. Upland rice is also farmed in a few areas.

Yendi is the capital of Yendi Municipal District in the northeastern quadrant of Ghana. The town is 195.2m above sea level and has a population of about 52,008 people (GSS, 2012).

The Municipality is located in the eastern corridor of the Northern Region of the Republic of Ghana between latitude 9.45^{o} N and longitude 0.19^{o} W. The municipal ranks sixth (6th) in the Region in terms of surface area with a land-mass of about 5350km^2.The degraded savannah type of vegetation is found around settlements and heavily cultivated areas. There is a rampant and extensive bush burning which is having a marked effect on the Vegetation and consequently the climate. Temperature ranges between 21°C to 36°C.

The mean annual rainfall for the Municipal is 1,125mm which occurs between January and December. The vegetation is of the tree savannah type in areas not affected by settlements and farming activities. High temperatures make the environment uncomfortable for both biotic and a biotic organisms to function effectively. Economic trees in the Municipal include ubiquitous Shea trees, Dawadawa, Mango and Cashew. Crops such as yam, maize, millet, rice, peanut and beans are grown in this area.

Rationale for choosing study area

The economic activity within the northern belt of the country is basically a rain-fed agriculture with about 90% peasant based (Ministry of Food and Agriculture [M_oFA], 2012). The economic activities mainly include food crop farming and livestock rearing followed by sheanut oil extraction and local beer (pito) production. The rainfall pattern in these areas is unimodal. A unimodal rainfall is characterized by long period of dry season. In this rainfall zone, unreliable rainfall usually leads to poor yields of crops. Furthermore, in the long dry season no agricultural activities are likely to take place. As a result, poverty may be predominant in these areas. These areas therefore require energy technologies such as solar photovoltaic technology that will pump water for irrigation during the dry season so that the rain-fed agricultural economy of these communities can be transformed into more diverse agricultural patterns, as a diverse agricultural economy can enhance wealth creation.

In the middle belt which experiences a bimodal rainfall regime, food crop farming is the main occupation followed by livestock rearing and fishing in the rural areas. It is established that poverty is concentrated amongst food crop farmers, who are encountered within the three Northern regions and relatedly amongst households for whom production of food crops is a major livelihood activity (Ghana Statistical Service [GSS], 2001). Energy is seen to play a pivotal role in human development by providing services that enhance social development including health and sanitation, education, and potable water as well as food processing and preservation. The economic and social developments of people in areas which lack modern sources of energy is likely hang in the balance. Thus a range of modern energy technologies that can generate income and benefits at relatively low cost including small micro-enterprises can be of use to alleviate poverty and improve the lives of the people. Solar energy technology stands out as one of the most important renewable and sustainable energy technology. These could include solar energy systems that can process agricultural produce thereby increasing the value of food production. The solar energy systems can also be used for pumping of water for irrigation and for livestock during the dry season, provide clean potable water through bore- hole engineering thereby reducing water borne diseases. In addition, the solar System will provide basic household lighting, Solar Hospital System for vaccine refrigeration and lighting and Solar School System for classroom lighting and television for Presidential Special Initiative on distance education. Others could include Solar Streetlight System for lighting general meeting points, such as markets, lorry stations, water supply points and important busy paths roads requiring visibility at night and Solar System for communication. Establishment of solar energy systems at any site requires detailed information about the availability of solar radiation variables on the surface of the earth at that site.

Data

In this study, the daily sunshine hour data and other geographical parameters were obtained from the archives of Ghana Meteorological Agency (GMet) in Accra for the period of 2000 to 2010. The sunshine hour data is the key input parameter for the model adopted in this study.

The Ghana Meteorological Agency (GMet) is responsible for installing, collecting and archiving of meteorological and climatological data. Currently, the GMet administers and runs about 22 meteorological stations on synoptic scales nationwide. The duration of bright sunshine is measured at these stations using Campbell – Stokes sunshine recorders. The sunshine hour data will enable solar radiation to be evaluated using appropriate model suitable for the area.

The model adopted in this study is the Angstrom-Prescott sunshine hour data model. This model requires the raw values of the sunshine hour duration measured directly. The Angstrom-Prescott model has been widely applied to estimate global solar radiation. A well calibrated Angstrom -Prescott model is usually more accurate than a temperature based model and a cloud based model (Iziomon & Mayer, 2001).

The computation and the analysis were done using Mat Lab programming software together with Microsoft excel.This is because mat lab is scientific programming tool which combines a powerful numeric engine and technical programming environment with interactive exploration and visualization tools. Using mat lab, one can explore and model data, build customized analysis and share discoveries as reports, published codes or applications. The language, tools, and built-in mathematics functions enable one to explore multiple approaches and reach a solution faster. The program used for the computation is presented in appendix II. The geographical locations of the weather stations used in this study are presented in Table 1.

Table 1: Selected weather stations and their geographical locations.

Location	Latitude /˚N	Longitude /˚S	Altitude /m
Akatsi	6.12	0.80	53.6
Bole	9.03	0.39	301
Ho	6.60	0.47	57.6
Kete Krachi	7.82	0.37	122
Navrongo	10.90	1.10	201.3
Tamale	9.42	0.85	183.3
Wa	10.07	2.50	306.0
Yendi	9.45	0.019	195.2

The choice of the period was based on the need to obtain long term solar radiation resource data and on the availability of current data. The long term average values capture most of the climate variability, thereby making evaluated values more reliable.

Methodology

Several empirical models have been developed to estimate global solar radiation using various meteorological parameters (Igubal, 1983). The parameters used as inputs in the calculations include sunshine duration, maximum and minimum temperatures, mean temperature and soil temperature. Other parameters are number of rainy days, total precipitable water, cloudiness evaporation and relative humidity. The rest are altitude, latitude, atmospheric pressure and albedo. The empirical models can be roughly classified into three categories: (a) sunshine based models, (b) cloud-based models, and (c) meteorological data-based models (Almorox, Benito and Hontoria, 2005).

The most commonly used parameter for estimating global solar radiation is sunshine duration. This is because sunshine duration can be easily and reliably measured, and data are widely available (Almorox, Benito and Hontoria 2008).

The empirical models for estimating global solar radiation have empirical constants which need to be determined from measured global solar radiation data. Therefore, in locations where measured global solar radiation data are not available, one of the available options to estimate the global solar radiation is to adopt a model whose empirical constants can be determined reliably from commonly available parameters. Angstrom-Prescott empirical model has been used to estimate the global solar radiation at the selected weather stations in Ghana for this study. The input parameters in this model are measured values of sunshine hour duration, computed values of extraterrestrial solar radiation and maximum day light duration. Angstrom – Prescott empirical model is simple to apply and so it is widely used for estimating global solar radiation at locations where global solar radiation data measured is not available (Duffie & Beckman, 1991).

Also, the lack of measured solar radiation records in Ghana requires that a model whose empirical constants can be determined reliably should be employed to determine the global solar radiation. The empirical constants in many of the models already discussed need to be determined from measured solar radiation. Furthermore, the models whose empirical constants have been determined and generalized were based on average values computed over wide range of latitudes, and so may not give reliable values when specific latitudes are being considered as in the present study. Research has been carried out extensively on Angstrom – Prescott empirical model and it is established to be suitable for Ghana with respect to availability of empirical constants. For example, a study conducted on global solar radiation estimate in Kumasi in the Asante region of Ghana indicated empirical constant of 0.25 and 0.45 (Jackson and Akuffo, 1992; Quansah, 2013). A similar study indicated empirical constant of 0.27 and 0.45 for the whole country (Danquah, 1990). However, the relationships that exist between the relative sunshine hours and the empirical constants are not straightforward. Therefore, it is very difficult to justify the use of a single set of empirical constants with regards to a vast region such as a country. This may lead to overestimation of the global solar radiation in the rainy season and underestimation in the dry season (Frère, 1975). In the present study, the empirical constants in Angstrom-Prescott empirical model have been determined for each weather station from the latitude of the location and the ratio of the sunshine duration to the day length. This approach is seen to be reliable since the global solar radiation depends largely on these factors.

Theoretical Background of Angstrom-Prescott empirical formula

The Angstrom-Prescott formula is expressed as,

$$H\ /H_o = a + b\ (S/S_o) \qquad (3.5.1.1)$$

Where H is the global solar radiation ($MJm^{-2}day^{-1}$), H_o is the extraterrestrial solar radiation on a horizontal surface ($MJm^{-2}day^{-1}$), S is number of hours of sunshine measured by the sunshine recorder, S_o is maximum daily sunshine duration whilst a and b are empirical constants. The values of a and b can be determined by statistical correlation using measured solar radiation data. However, where measured solar radiation data are not available, the values of a and b can be determined from empirical relations. For monthly average, the formula becomes

$$\bar{H}/\bar{H}_o = a + b\,(\bar{S}/\bar{S}_o) \qquad (3.5.1.2)$$

Where $\bar{H}$ is the monthly average daily global solar radiation on a horizontal surface, $\bar{H}_o$ is the monthly average daily extraterrestrial solar radiation on a horizontal surface, $\bar{S}$ is the monthly average daily number of hours of sunshine measured by the sunshine recorder and $\bar{S}_o$ is the monthly average daily maximum number of hours of sunshine.

Tiwari and Sangeeta (1997) and Frere (1980) obtained the empirical constants a and b using the relation below.

$$a = -0.110 + 0.235\cos\emptyset + 0.323(\bar{S}/\bar{S}_o) \qquad (3.5.1.3)$$

$$b = 1.449 - 0.553\cos\emptyset - 0.694(\bar{S}/\bar{S}_o) \qquad (3.5.1.4)$$

The extraterrestrial solar radiation on a horizontal surface (H_o) is calculated from the equation as

$$H_o = \frac{24\times3600}{\pi} I_{sc}[1+0.033\cos(360\frac{n}{365})]\,(\cos\delta\cos\emptyset\sin\omega_s + \frac{2\pi}{360}\omega_s\sin\delta\sin\emptyset) \qquad (3.5.1.5)$$

where I_{sc} is the solar constant ($1367 Wm^{-2}$), ϕ is the latitude of the site, δ is the solar declination, ω_s is the mean sunrise hour angle for the given month and n is the number of days of the year counting from first January to the day of observation.

The solar declination is calculated using the expression given as

$$\delta = 23.45\sin[360(\frac{284+n}{365})] \qquad (3.5.1.6)$$

The hour angle for a horizontal surface is found using Equation 3.5.1.7.

$$\omega_s = cos^{-1}(-tan\emptyset tan\delta) \qquad (3.5.1.7)$$

The day length S_o is the number of hours of sunshine within the 24 hours in a given day. For a horizontal surface, the day length is calculated by using the following equation:

$$S_o = \frac{2}{15} cos^{-1}(-tan\emptyset tan\delta) = \frac{2}{15}\omega_s \qquad (3.5.1.8)$$

Model Validation

Due to lack of measured solar radiation data in Ghana, measured global solar radiation reference values were not available for comparison. However, the results were compared with global solar radiation values reported by Energy Commission of Ghana (ECG) based on annual solar radiation values estimated for the whole country (ECG, 2005). Standard error was used to determine the uniformity in the values obtained from the model used. The standard error (σ_m) is a standard measure which describes the precision of measurement. That is, how well a number of measurements agree with each other.The closer the standard error (σ_m) is to 0, the greater the uniformity of data and the closer the standard error (σ_m) is to 1, the greater the variability of the data (American Gastroenterological Association [AGA], 2012). The standard error (σ_m) is calculated by using the formula below

$$\sigma_m = \frac{\sigma}{\sqrt{n}}$$

where n is the number of observations and σ is the standard deviation given by the formula

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}}$$

$\bar{x}$ is the arithmetic mean of a series of n numbers and $x_i$represents individual data points.

Also the performance of the model was evaluated by using a standardized test statistics (z-statistics). The z-statistics was chosen as it allows models to be compared and at the same time can induce whether or not a model's estimate is statistically significant at a particular significance level ($\alpha - level$). The z-values is calculated using the formula below

$$z = \frac{x-\mu_o}{\delta/_{\sqrt{n}}}$$

where x is the observed value, μ_o is the expected value (null hypothesis, H_o) and n is the number of observations.

To determine if a result is significant, a researcher would have to choose a significant level ($\alpha -$ level) depending on the research being conducted. The $\alpha -$ level is the smallest level of significance at which the observed value will be rejected when a specified test procedure is used on a given data set. Traditional levels of significance ($\alpha -$ levels) are 0.10, 0.05 and 0.01. In this study, the 0.05 significance level was used. The 0.05 level of significance was chosen because it is the most widely used level of significance. According to Devore (2004), an $\alpha -$ levels of 0.05 is the norm because for a 0.05 level, one is 95% confident that the result is a reflection of the reality. That is, it is significant but there is a 5% chance that the result is actually just due to chance. For a two tailed test as in this study, the rejection region for the $z -$values is given as

$z \geq z_{\alpha/2}$ or $z \leq -z_{\alpha/2}$.

If the computed z- value falls in the rejection region, the expected value (the null hypothesis) is rejected. This means that there is a strong evidence to support the claim that the observed value differs from the expected value.

CHAPTER FOUR

RESULTS AND DISCUSSION

Result of Monthly mean of daily extraterrestrial solar radiation

The values of the monthly mean of daily extraterrestrial solar radiation $\bar{H}_o$, on a horizontal surface outside the earth's atmosphere was calculated for each of the synoptic stations using Equation 3.5.1.5. The calculated values of monthly mean of daily extraterrestrial solar radiation for the period 2000 to 2010 are presented in Table 2 and graphically represented in Figures 8 and 9 for the eight synoptic stations used for this study.

It is observed that in all, highest values of the monthly mean of daily extraterrestrial solar radiation for all the stations occurred in April while the lowest values occurred in December (see Table 2). The highest and the lowest extraterrestrial solar radiation values for Akatsi were 37.60 $MJm^{-2}day^{-1}$ and 32.87$MJm^{-2}day^{-1}$ respectively. For Bole the highest value was 37.86 MJm^{-2} day^{-1} and the lowest was 31.43 $MJm^{-2}day^{-1}$. In Ho the values were 37.67 MJm^{-2} day^{-1} and 32.65$MJm^{-2}day^{-1}$ respectively. On the other hand, Kete Krachi recorded highest value of 37.77 $MJm^{-2}day^{-1}$ and lowest value of 32.06MJm^{-2} day^{-1}. As for Navrongo the highest was 37.97$MJm^{-2}day^{-1}$ and the lowest was 30.53$MJm^{-2}day^{-1}$. The highest and the lowest values of solar extra-terrestrial radiation for the rest of the stations are, Tamale; 37.89$MJm^{-2}day^{-1}$ and 31.28$MJm^{-2}day^{-1}$,Wa; 37.93$MJm^{-2}day^{-1}$ and 30.94$MJm^{-2}day^{-1}$ and Yendi 37.89 $MJm^{-2}day^{-1}$ and 31.26 $MJm^{-2}day^{-1}$.

This is might be explained that in April, longer days (approximately 12 hours) are experienced in Ghana and also during this period, the sun appears directly overhead and so more direct solar radiation is likely to be received. On the other hand, shorter days are experienced in December and also during this period the Northern hemisphere where Ghana is located is tilted away from the sun and so less direct solar radiation is likely to be received (Liou 2002,p.46).

Also from the results, both highest and lowest extraterrestrial solar radiation values among the stations occurred in Navrongo. From the calculated values of day length for all the stations, Navrongo recorded the highest and the lowest on the equinoxes and the December solstice respectively (see appendix 1).The equinoxes are the times of the year when the sun crosses the plane of the earth's equator, making night and day of approximately equal length in each hemisphere while the solstices are the times of the year when the sun is on the horizon giving rise to unequal day and night. This implies that on the equinoxes when the sun is directly overhead at both hemispheres, Navrongo is likely to receive direct solar extraterrestrial radiation for a longer period than all the stations. Also on the December solstice when shorter days are experienced in the Northern hemisphere, Navrongo is likely to receive solar extraterrestrial radiation for a shorter period.

Generally, the monthly mean of daily extraterrestrial solar radiation values for all the stations follow a similar trend along the months. For instance between January and April, there was a steady rise in monthly mean of daily extraterrestrial solar radiation values. This was followed by a gentle drop in June and a smooth rise between June and September. Between September and

December the monthly mean extraterrestrial solar radiation values dropped. This may be due to the annual change in the position of the Earth's axis relative to the Sun.The intensity of extraterrestrial radiation at a location increases with solar altitude and the length of day. Between January and April, the northern hemisphere where Ghana is located moves from the December solstice to the March equinox. On the December solstice, the sun is below the horizon and also shorter days are experienced in the northern hemisphere. The sun rises above the horizon from this point increasing the solar altitude and the length of day to the March equinox when the sun is directly over head (Pidwirny & Jones, 2006). This is likely to be the reason for increasing trend of solar extraterrestrial radiation values recorded between January and April.

Also from April to June, the northern hemisphere moves from the March equinox to the June solstice where the sun is below the horizon but the northern hemisphere is tilted toward the sun and longer days are experienced. However, the elevation angle of the sun decreases and so the area over which the radiation is distributed increases. Hence, the area over which the available solar energy has to be distributed is increased and the energy per unit area on the earth's surface is decreased.

In addition, the oblique rays have to traverse a larger distance through the atmosphere before they strike the surface of the earth. The longer their path, the larger the amount of energy lost by various processes of reflection, absorption, and scattering so solar extraterrestrial radiation dropped slightly.

On the other hand from June to September, the earth moves from the June solstice to the September equinox, where the sun once again rises above the horizon and so the intensity of the global solar radiation is likely to increase. Moving to December, the sun comes below the horizon and the length of day becomes shorter. Consequently, the intensity of the extraterrestrial radiation is expected to reduce.

Table 2: Monthly Mean of Daily Solar Extra-terrestrial Radiation, $\overline{H}_o$ in $MJm^{-2}day^{-1}$ for each of the Eight Synoptic Stations for the period 2000 to 2010.

Month	Stations							
	Akatsi	Bole	Ho	K.Krachi	Navrongo	Tamale	Wa	Yendi
Jan	33.62	32.30	33.41	32.86	31.42	32.12	31.81	32.11
Feb	35.75	34.82	35.61	35.22	34.17	34.69	34.46	34.68
Mar	37.42	37.04	37.32	37.16	36.67	36.98	36.88	36.92
Apr	37.60	37.86	37.67	37.77	37.97	37.89	37.93	37.89
May	36.55	37.86	36.72	37.03	37.75	37.39	37.54	37.42
Jun	35.68	36.64	35.85	36.26	37.22	36.76	36.96	36.78
Jul	35.95	36.81	36.07	36.44	37.30	36.90	37.08	36.91
Aug	36.95	37.40	37.00	37.20	37.64	37.44	37.54	37.44
Sep	37.25	37.13	37.25	37.20	36.99	37.10	37.02	37.10
Oct	36.04	35.36	35.98	35.68	34.83	35.25	34.98	35.24
Nov	33.98	32.76	33.85	33.34	32.01	32.66	32.38	32.65
Dec	32.87	31.46	32.65	32.06	30.53	31.28	30.94	31.26

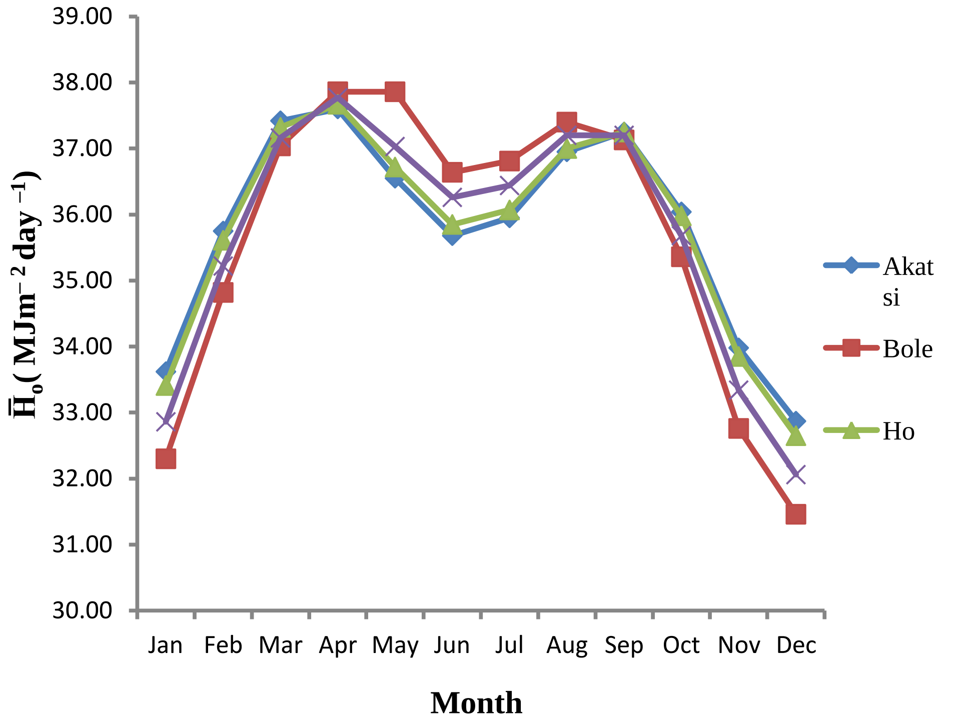


Figure 8: Graph of the 11-year Monthly mean of daily extra-terrestrial solar radiation values for the four of the Synoptic Stations.

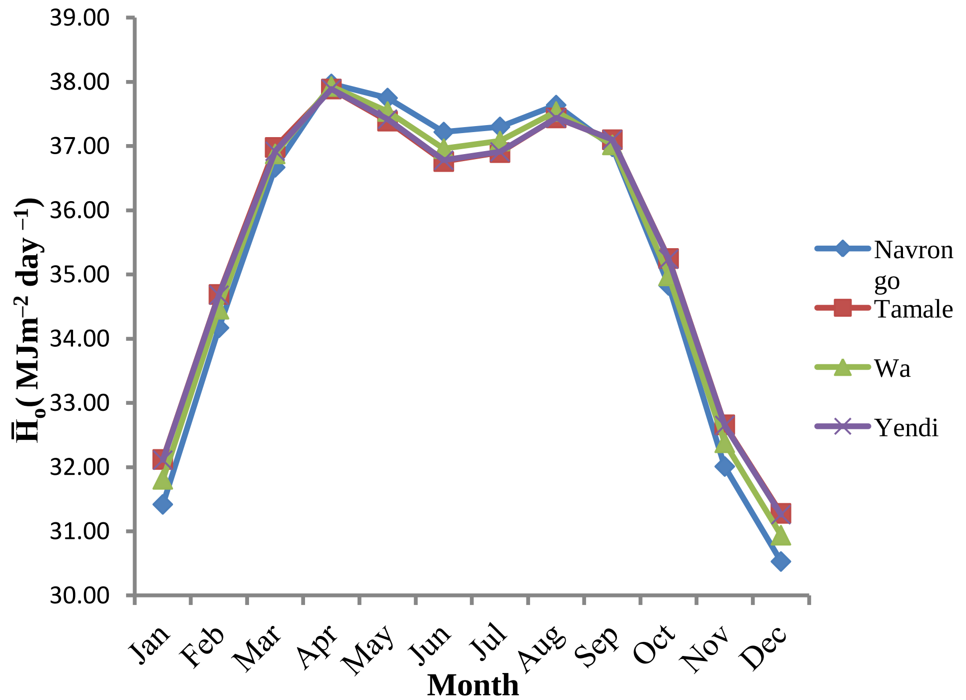


Figure 9: Graph of the 11-year Monthly mean of daily extra-terrestrial solar radiation values for the other four Synoptic Stations.

Result of Monthly mean of daily global solar radiation.

The values of the empirical constants '*a'* and *'b'* were calculated from Equations 3.5.1.3 and 3.5.1.4 respectively. Also, the monthly mean daily values of '*a'* and *'b'* for each of the synoptic stations were determined as presented in Appendix1. However, the yearly mean of monthly values of '*a'* and *'b'* for each of the synoptic stations for the period in study are presented in Table 3 and Table 4 respectively. As stated earlier, '*a'* and *'b'* are the empirical constants in the Angstrom-Prescott sunshine hour model used to estimate the global solar radiation for the Synoptic Stations in this study.

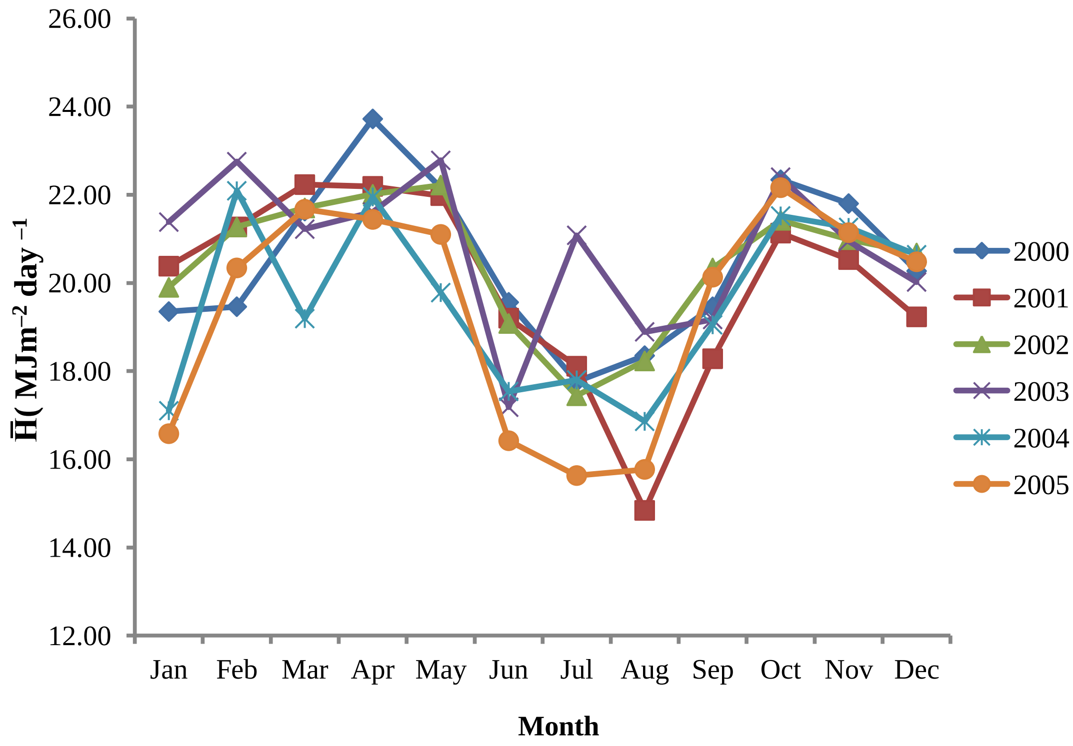
Table 3: Yearly mean of monthly values of empirical constant *a*, for Synoptic Stations.

Year	Stations							
	Akatsi	Bole	Ho	K. Krachi	Navrongo	Tamale	Wa	Yendi
2000	0.30	0.31	0.31	0.31	0.33	0.32	0.33	0.32
2001	0.29	0.31	0.30	0.32	0.34	0.33	0.34	0.32
2002	0.29	0.32	0.30	0.31	0.34	0.33	0.33	0.33
2003	0.30	0.32	0.31	0.32	0.34	0.33	0.33	0.34
2004	0.27	0.30	0.29	0.31	0.32	0.31	0.32	0.32
2005	0.28	0.29	0.28	0.32	0.32	0.31	0.32	0.33
2006	0.30	0.31	0.29	0.32	0.34	0.33	0.33	0.33
2007	0.28	0.29	0.28	0.31	0.33	0.31	0.33	0.32
2008	0.28	0.30	0.29	0.31	0.34	0.32	0.34	0.32
2009	0.29	0.30	0.29	0.31	0.34	0.32	0.33	0.33
2010	0.28	0.31	0.29	0.32	0.33	0.32	0.33	0.32

Table 4: Yearly mean of monthly values of empirical constant *b*, for Synoptic Stations

Year	Stations						
	Akatsi	Bole	Ho	K. Krachi	Navrongo	Tamale	Wa
2000	0.52	0.50	0.50	0.49	0.45	0.47	0.45
2001	0.55	0.49	0.52	0.48	0.42	0.46	0.43
2002	0.53	0.49	0.52	0.49	0.43	0.46	0.44
2003	0.51	0.49	0.50	0.48	0.44	0.46	0.45
2004	0.58	0.52	0.53	0.51	0.47	0.49	0.47
2005	0.56	0.53	0.57	0.49	0.46	0.49	0.47
2006	0.53	0.50	0.54	0.48	0.44	0.46	0.44
2007	0.56	0.53	0.56	0.50	0.45	0.48	0.46
2008	0.55	0.51	0.54	0.50	0.43	0.48	0.44
2009	0.53	0.51	0.54	0.49	0.44	0.47	0.45
2010	0.55	0.49	0.54	0.48	0.45	0.48	0.46

The monthly mean of daily global solar radiation ($\bar{H}$) on a horizontal surface were estimated using Angstrom-Prescott Sunshine Based Model for each of the selected Synoptic Stations using Equation 3.5.1.2 and the constants *a* and *b*. Due to data volume, the monthly mean of daily global solar radiation values for each of the Stations are presented in Appendix 1. However, graphical representations of the monthly mean of daily global solar radiation values for all the stations are displayed from Figures 10 to 17.



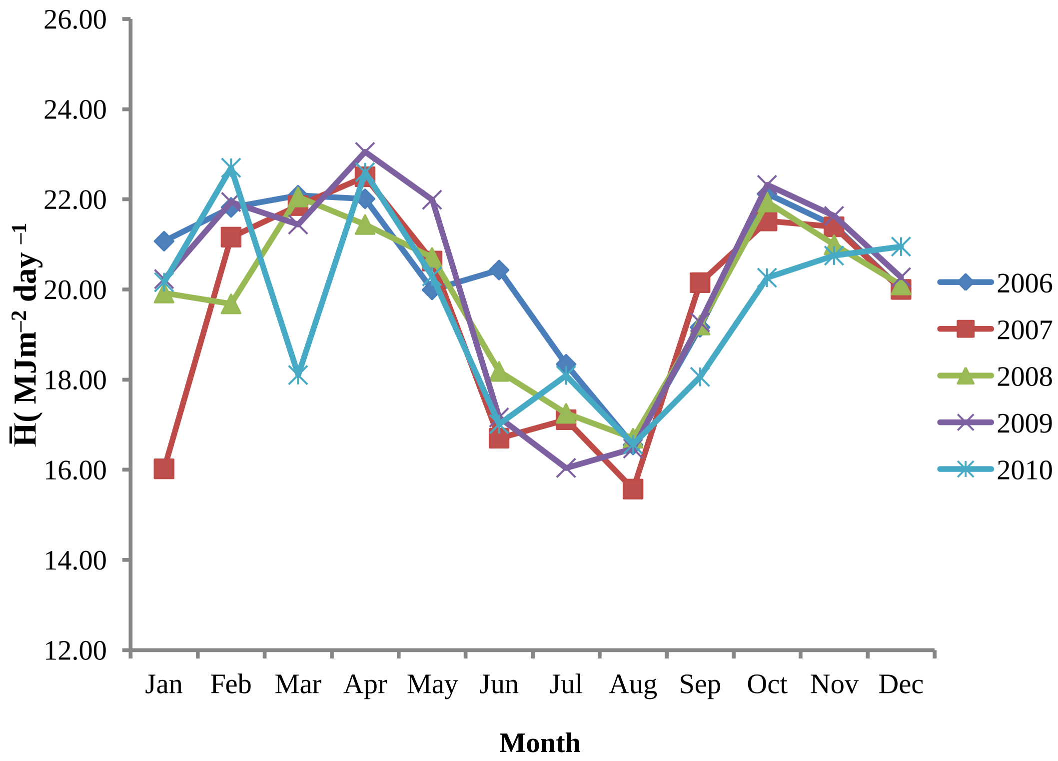
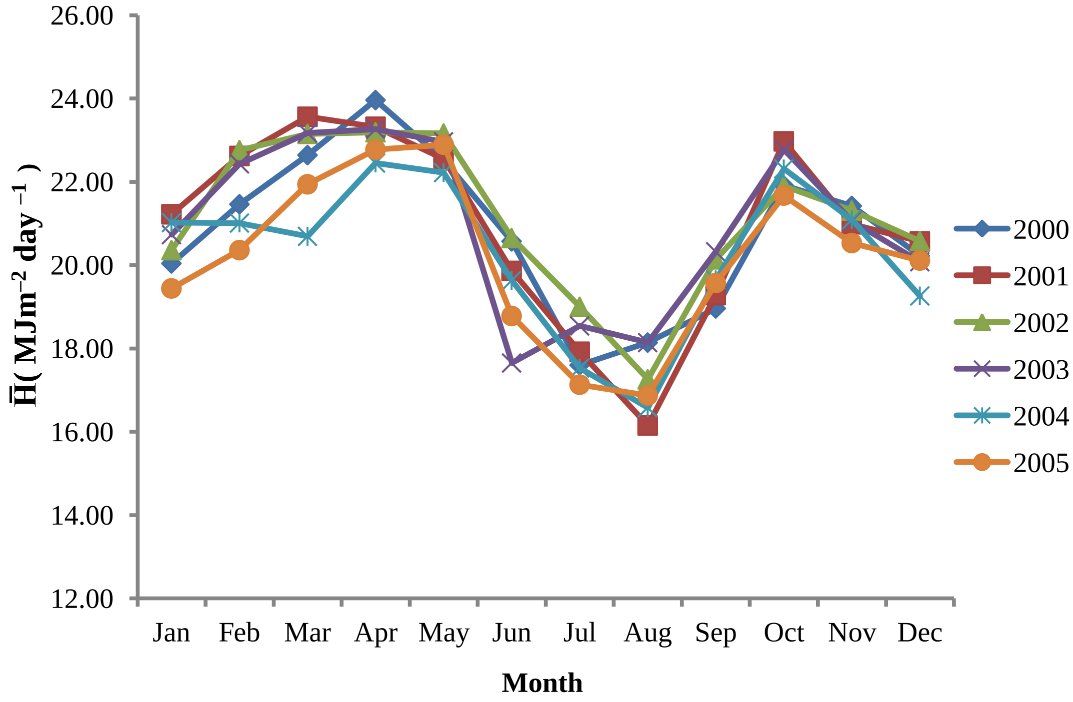


Figure 10: A set of graphs showing the Monthly mean of daily global solar radiation values for the period 2000 to 2010 for Akatsi.



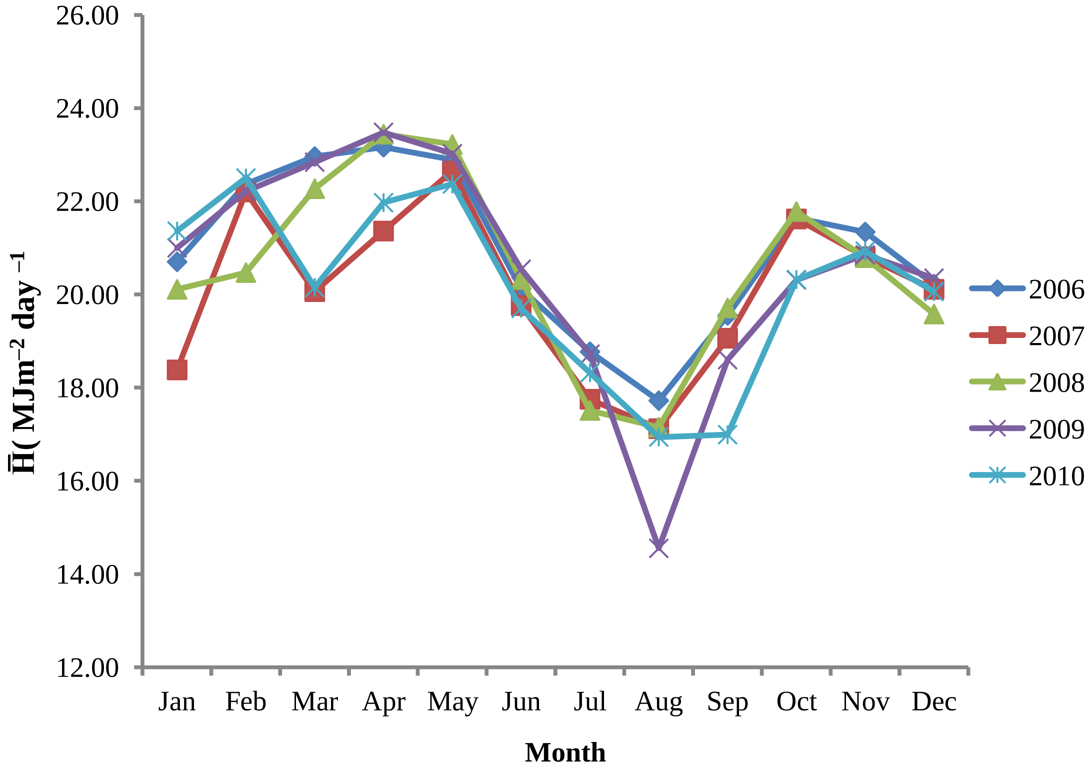
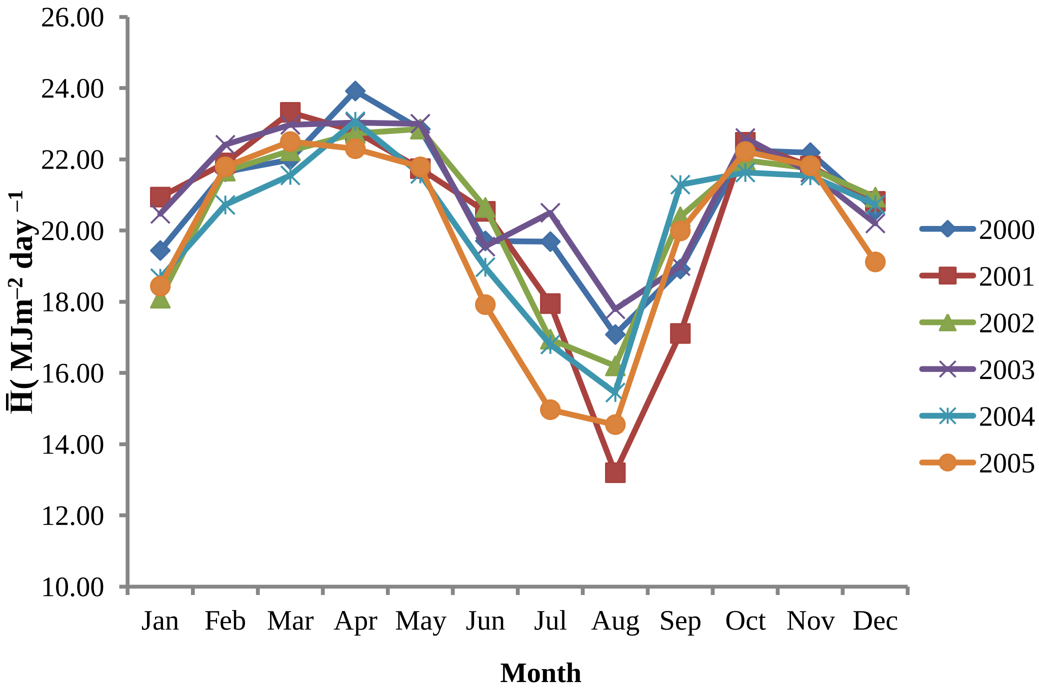


Figure 11: A set of graphs showing the Monthly mean of daily global solar radiation values for the period 2000 to 2010 for Bole.



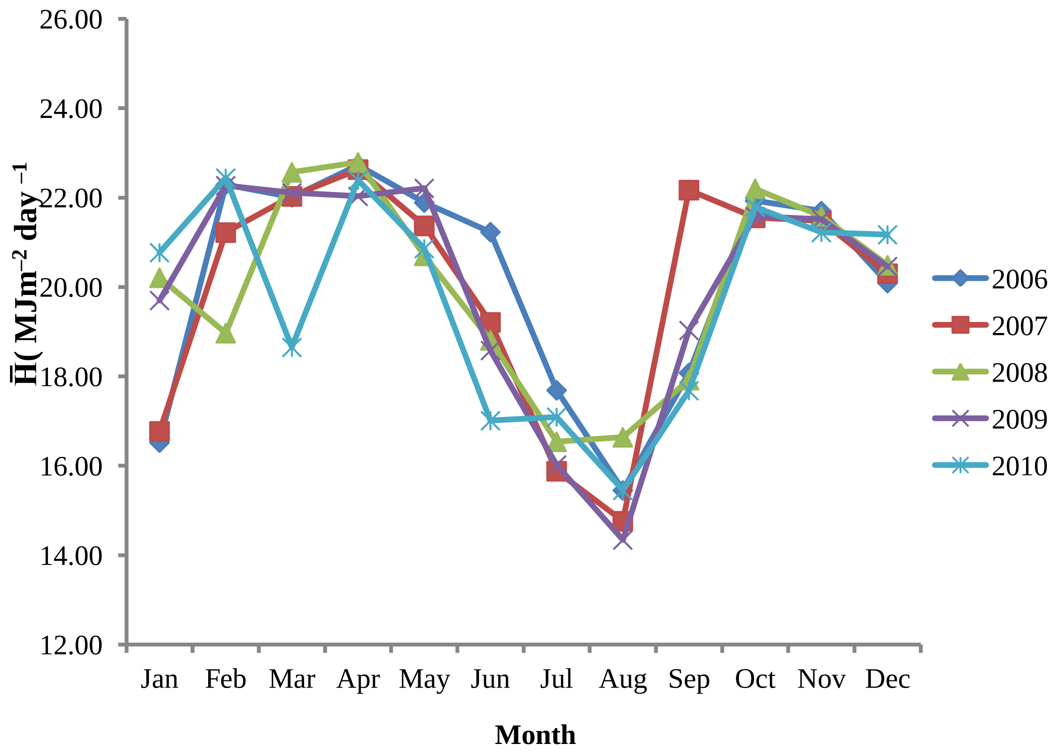


Figure 12: A set of graphs showing the Monthly mean of daily global solar radiation values for the period 2000 to 2010 for Ho.

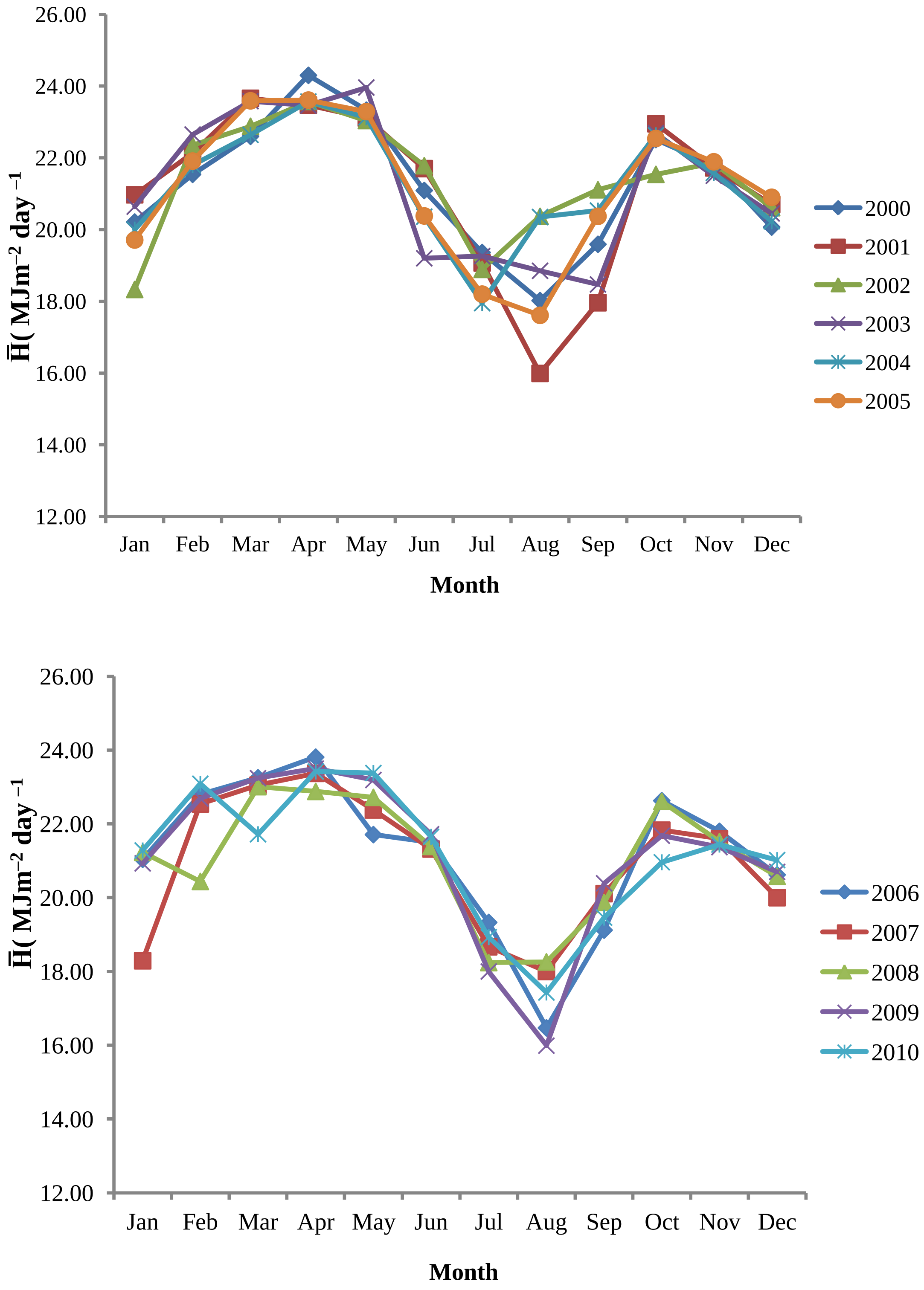


Figure 13: A set of graphs showing the Monthly mean of daily global solar radiation values for the period 2000 to 2010 for Kete Krachi.

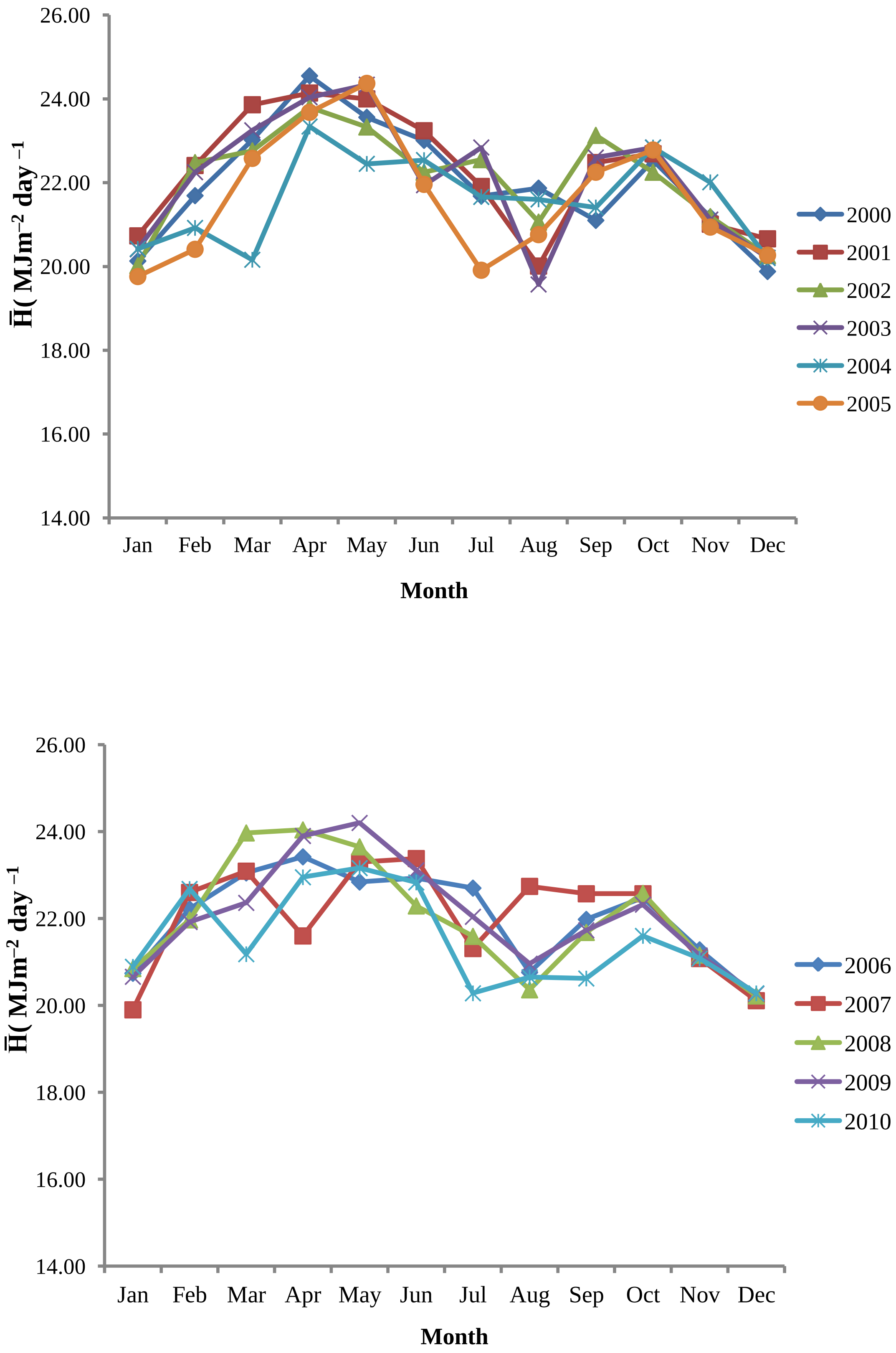
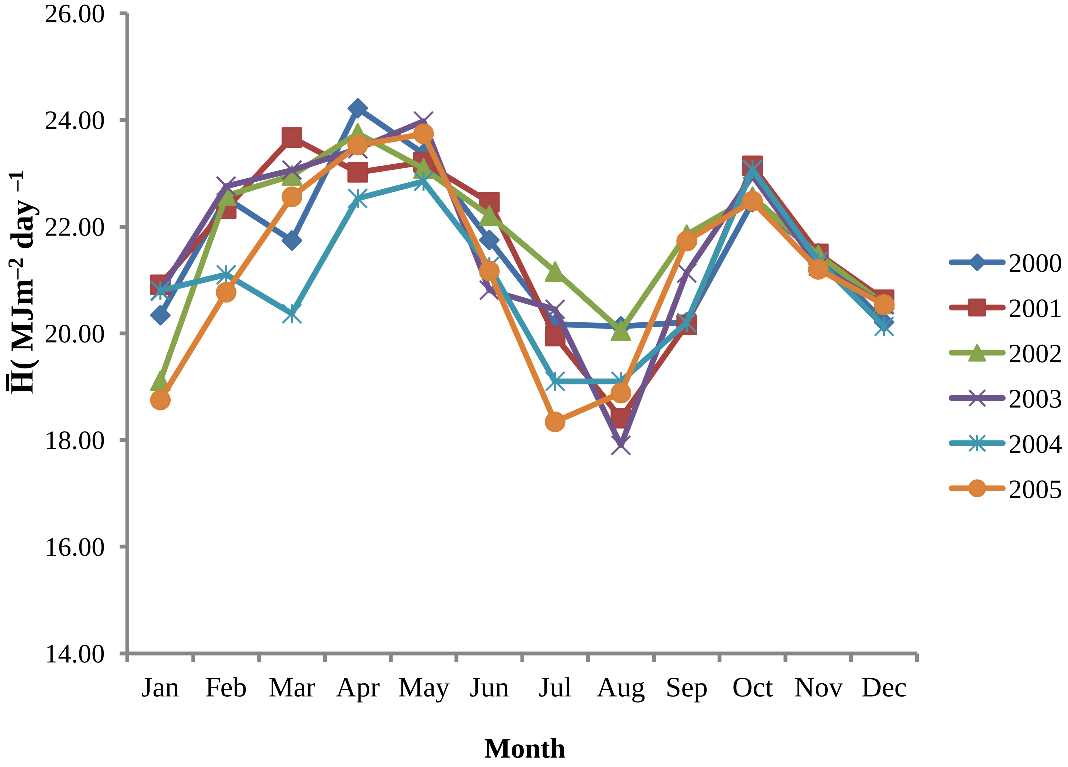


Figure 14: A set of graphs showing the Monthly mean of daily global solar radiation values for the period 2000 to 2010 for Navrongo.



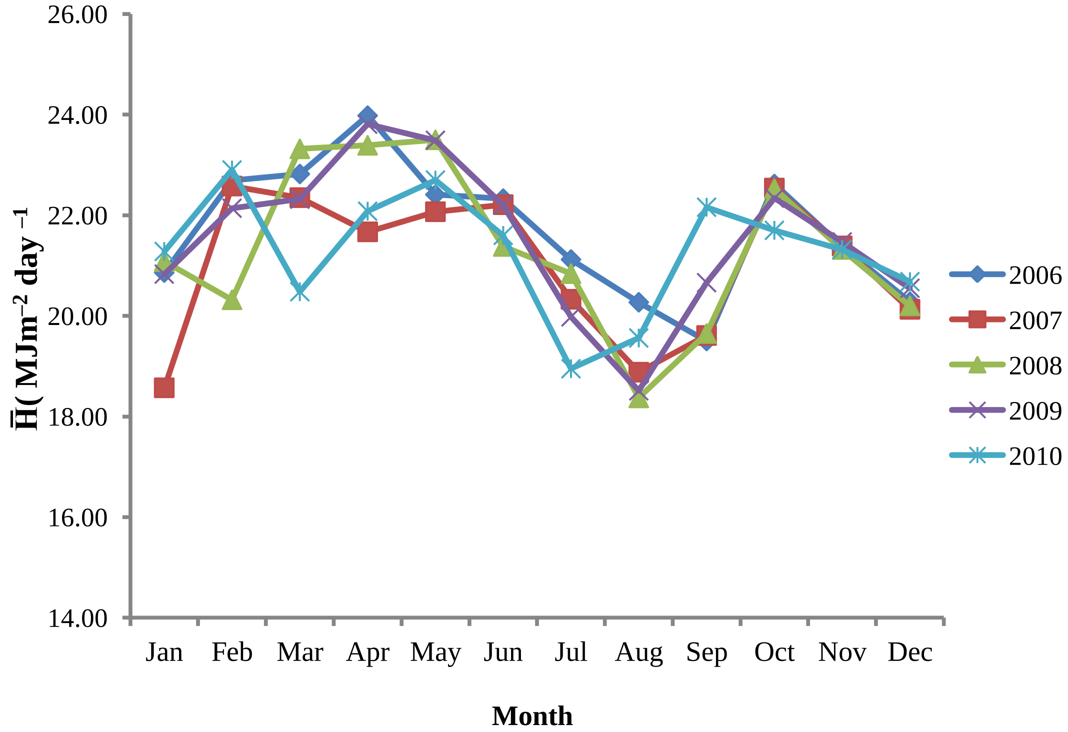
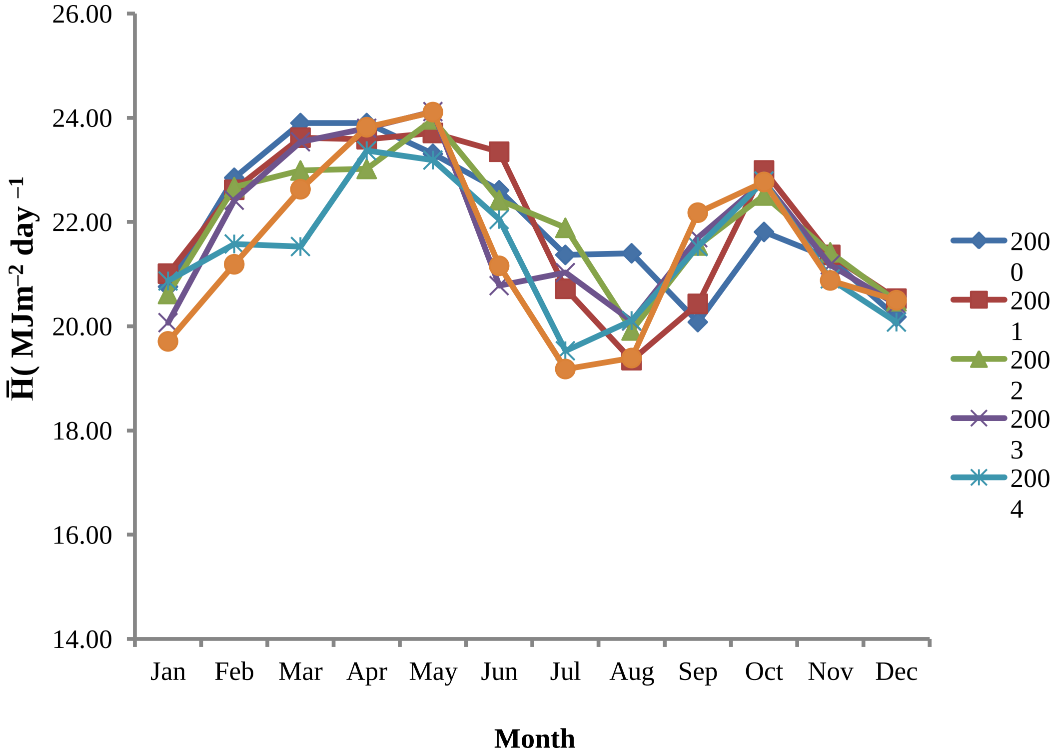


Figure 15: A set of graphs showing the Monthly mean of daily global solar radiation values for the period 2000 to 2010 for Tamale.



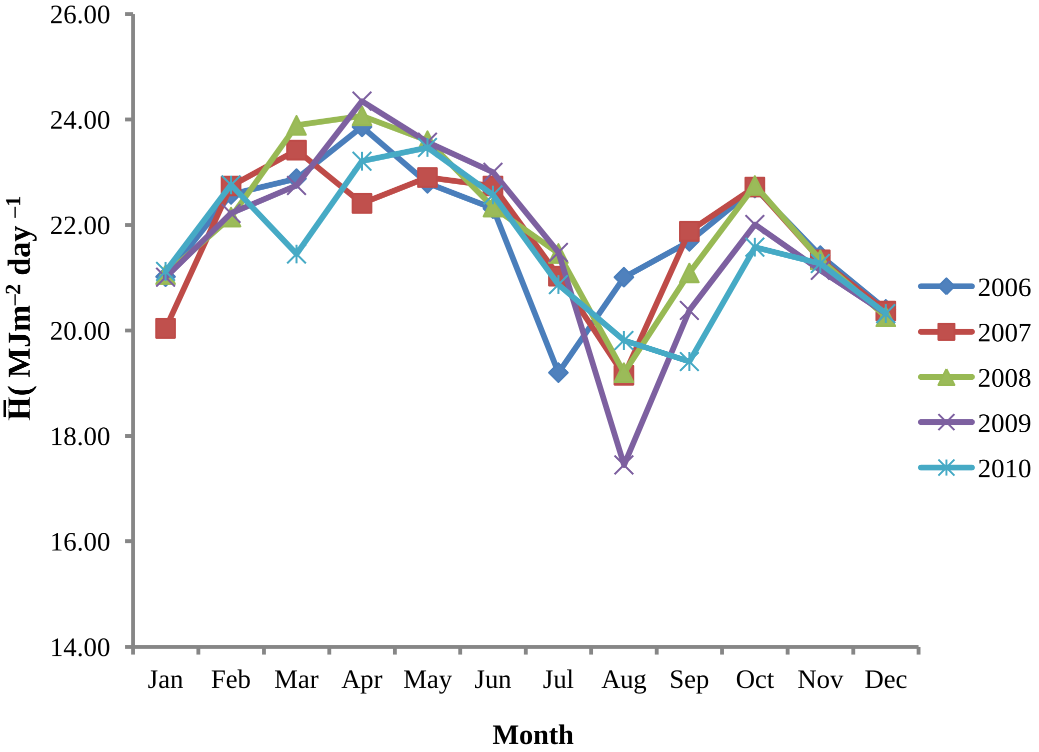
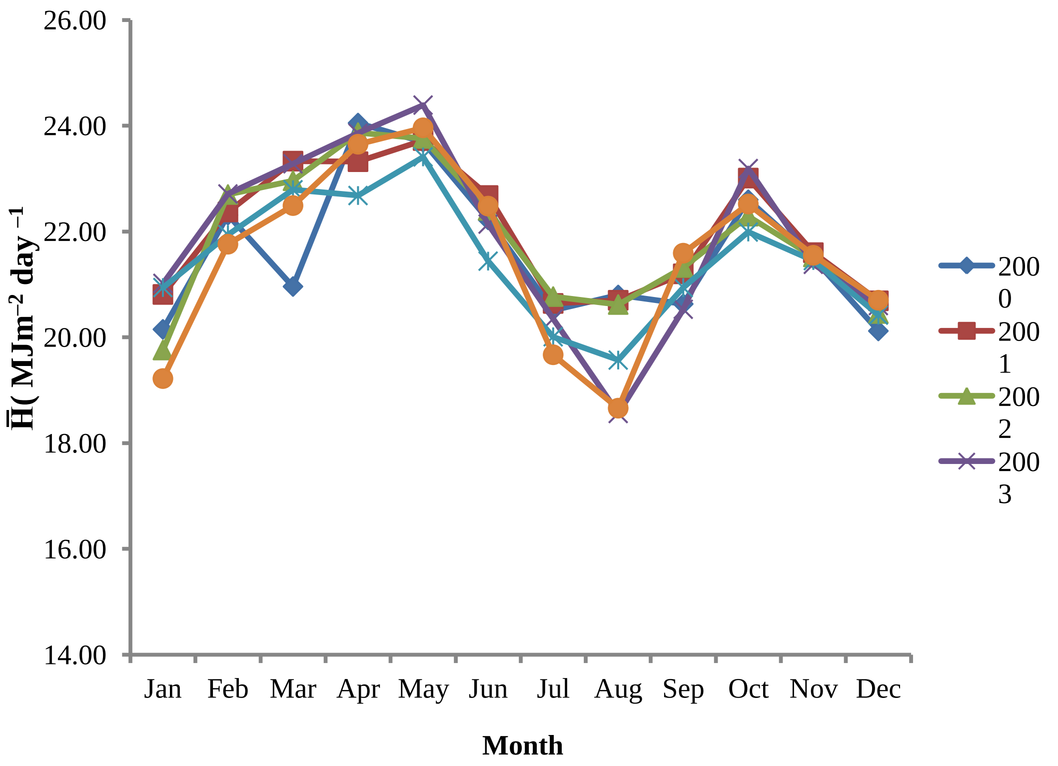


Figure 16: A set of graphs showing the Monthly mean of daily global solar radiation values for the period 2000 to 2010 for Wa.



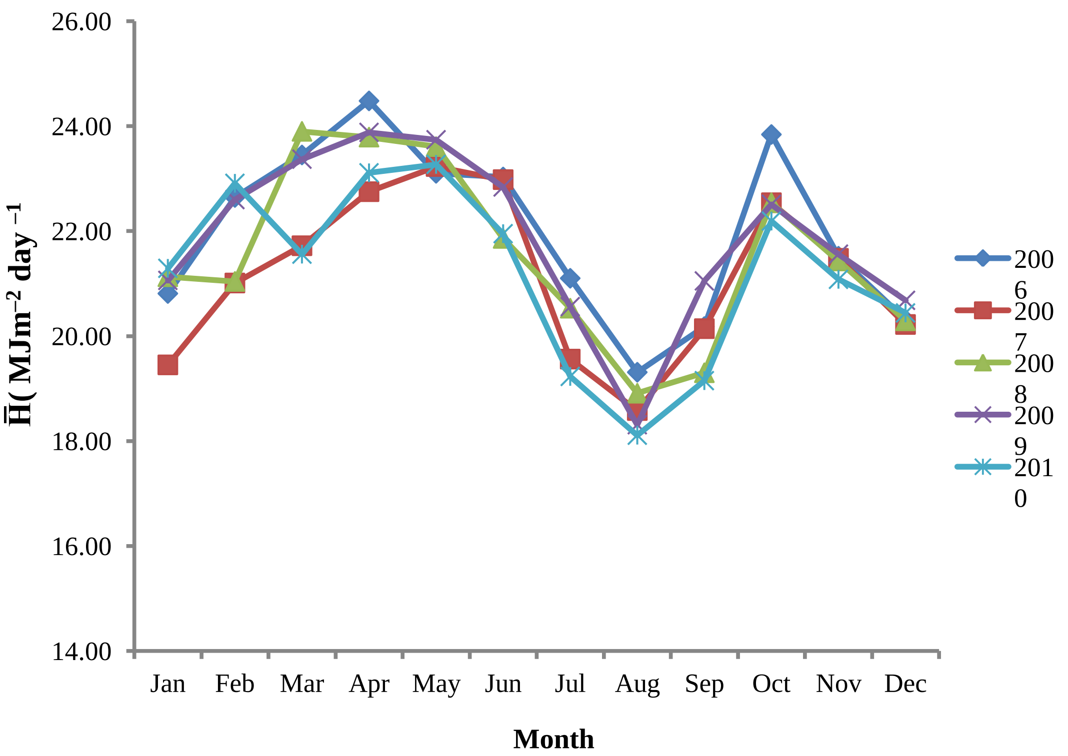


Figure 17: A set of graphs showing the Monthly mean global solar radiation values for the period 2000 to 2010 for Yendi.

Generally, for all the stations higher values of monthly mean of daily global solar radiation ($\bar{H}$) occurred in the month of March, April or May while lower values occurred in the month of June, July or August. However, higher values are recorded in the month of February for Akatsi in the years 2004 and 2010, follow by Bole in the year 2010 and Tamale in the years 2007 and 2010. Also, Navrongo, on the average recorded lower values in the month of December.

This observed pattern in the monthly mean of daily global solar radiation ($\bar{H}$) runs parallel to that of extraterrestrial radiation ($\bar{H}_o$) within the year as explained earlier. This is because $\bar{H}$ relates $\bar{H}_o$ in the equation given as

$$\bar{H}/\bar{H}_o = a + b(\bar{S} / \bar{S}_o)$$

As already indicated between January and April, the northern hemisphere where Ghana is located moves from the December solstice to the March equinox. On the December solstice, the sun is below the horizon and also shorter days are experienced because the earth's axis is tilted away from the sun. The sun rises above the horizon from the December solstice increasing the solar altitude and the length of day to the March equinox when the sun is directly over head (Pidwirny & Jones, 2006). This is likely to be the reason for increasing trend of global solar radiation recorded between January and May. In addition to the reason for the observed patterns, a study has also shown that maximum cloud cover is experienced in Ghana between the months of June and September which marks the period of the wet season (Frank, 2011). In a cloudy atmosphere, considerable depletion of the solar beam takes place. A major part of the solar radiation is reflected back to space, and other part is absorbed, while the rest of the radiation is transmitted downwards to the earth as diffuse radiation (Uiso, 1998). In the same report, it was shown that transmission through a cloud is mainly by nonselective multiple scattering on water droplets within the cloud. As scattering in this case is not wavelength dependent, the scattered solar radiation is equal for all wavelengths. Furthermore, it is established in Uiso's study that thin clouds may reflect about twenty percent of the incident solar radiation, whereas a thick and dense cloud may reflect over eighty percent and absorb about ten percent (Uiso, 1998).

These are possible reasons for the lower values of the global solar radiation that are recorded in June, July and August in the selected locations for this study. Also, the rise in the global solar radiation from September to October and a slight drop in December can be explained as follows. In September, the sun rises above the equator and becomes truly overheard on September 22 or 23 (the September or Autumnal equinox) and so more global solar radiation is likely to be received. However, the presence of low level and middle level clouds which absorb and reflect significant amount of the global solar radiation may account for the lower values of global solar radiation obtained in September than October. In October, the sun is still nearly overhead as the earth moves from the September equinox to the December solstice and more global solar radiation is likely to be received. However, at this time, the amount of clouds over the sky is likely to reduce as much of the water vapour in the air might have precipitated to form rain in September due to active vertical uplift or conversion of air that takes place in September as a result of hot and humid weather (Pidwirny & Jones, 2006). Thus, the attenuation of global solar radiation by clouds is significantly reduced giving rise to higher values in

October than September. In December, shorter days are experienced in Ghana as the Northern hemisphere is in the December Solstice. In addition, the presence of dust from the hammattan wind which blows from the Saharan desert through the north reaching its peak in December is likely to reduce the global solar radiation values.

The lowest value observed in Navrongo which is in the farther north of Ghana may be due to the effect of harmattan dust. Studies have shown that attenuation of solar radiation due to the effect of harmattan dust is very prominent in Northern Ghana. In Navrongo, the harmattan starts from November to mid- February usually reaching its peak in December (Arku, 2011). Dust particles affect the amount of solar radiation received per surface area due to non-selective scattering, reflection and partial absorption by the particles. Hence, dust is one of the major reducing agents of solar radiation (Liou, 2002).

Also, the higher values of monthly mean of daily global solar radiation obtained in February are due to higher sunshine hour values recorded during these periods (see Appendix1). As the sunshine hour increases, the direct component of the global solar radiation as expressed in Equation 3.5.1.2 dominates and so the intensity of the global solar radiation increases.

Also, it is observed that the variation in the estimated mean monthly global solar radiation from highest to lowest value for the eight stations is different. The largest variation is observed at Ho which varies between 22.77$MJm^{-2}day^{-1}$ in April and 15.54$MJm^{-2}day^{-1}$ in August. And the smallest variation is observed at Navrongo which varies between 23.59$MJm^{-2}day^{-1}$ in April and 20.23$MJm^{-2}day^{-1}$ in December**.**

The yearly mean of monthly global solar radiation values for the Selected Synoptic Stations do not follow a regular pattern from year to year. The yearly mean of monthly global solar radiation values for those Stations are presented in Table 5 and graphically represented in Figures 18 and 19.

Table 5: Yearly mean of monthly global solar radiation for the stations in $MJm^{-2}day^{-1}$

Year	Stations							
	Akatsi	Bole	Ho	K.Krachi	Navrongo	Tamale	Wa	Yendi
2000	20.49	20.79	20.86	21.20	22.02	21.55	22.06	21.63
2001	19.95	20.92	20.38	21.12	22.26	21.62	21.94	20.43
2002	20.44	21.12	20.33	21.36	22.09	21.78	21.96	21.87
2003	20.79	20.93	21.10	21.23	22.12	21.59	21.83	21.83
2004	18.81	20.29	20.17	21.23	21.63	20.99	21.46	21.47
2005	19.41	20.17	18.73	21.17	21.64	21.14	21.46	21.60
2006	20.42	20.95	20.13	21.17	22.05	21.69	21.82	21.98
2007	19.55	20.07	19.57	20.93	22.02	21.03	21.73	21.14
2008	19.85	20.53	19.95	21.06	22.00	21.33	21.93	21.84
2009	20.15	20.54	19.99	21.12	22.05	21.53	21.64	21.85
2010	19.51	20.13	19.61	21.15	21.52	21.28	21.49	21.19

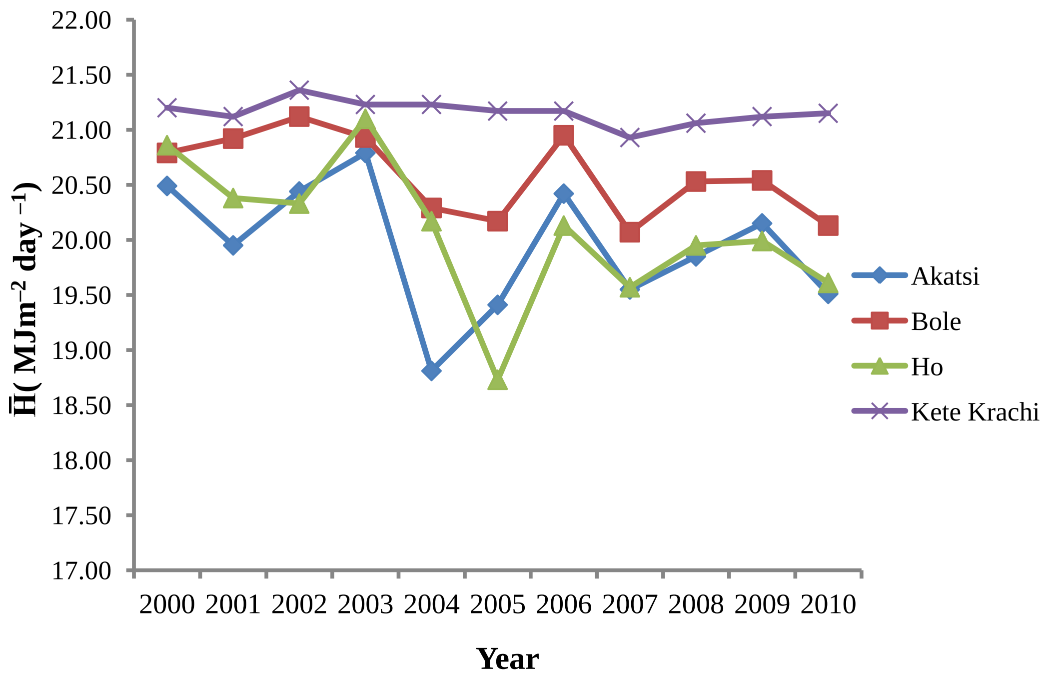


Figure 18: Graph showing Yearly mean of monthly global solar radiation for four of the Stations.

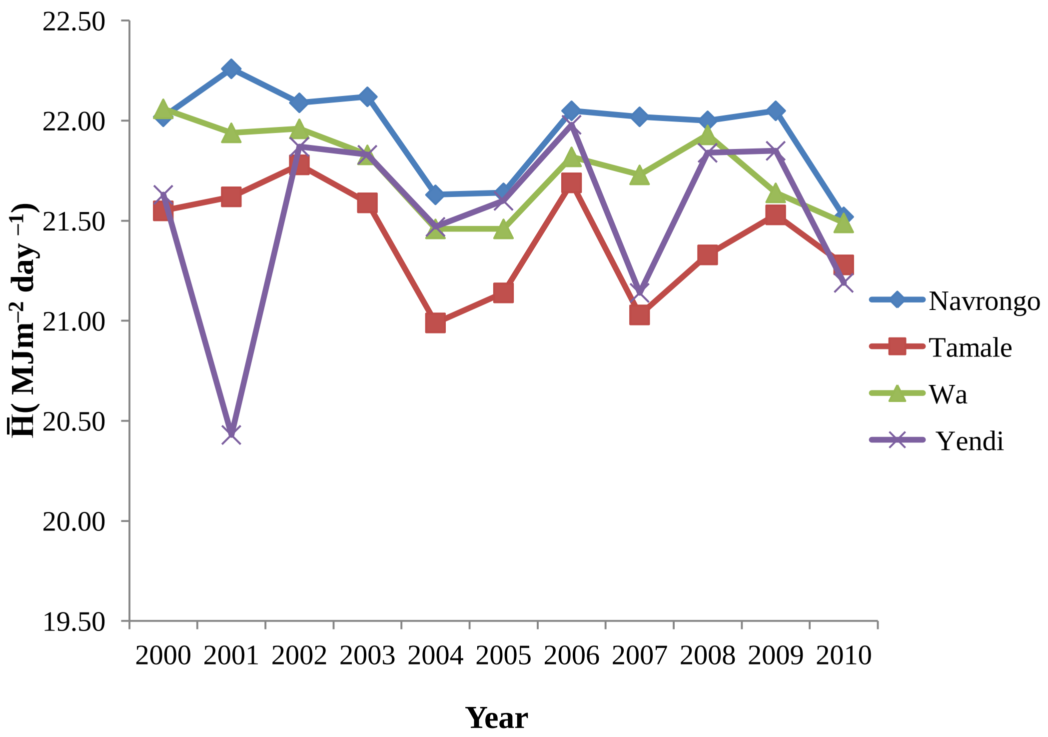


Figure 19: Graph showing Yearly mean of monthly global solar radiation for the other four Stations.

The overall average of the estimated global solar radiation over the period for the Synoptic Stations is presented in Table 6.

Table 6: Overall average of Yearly mean of monthly global solar radiation for the Synoptic Stations.

Stations	Global Solar Radiation	Standard Error
Akatsi	19.94	0.125
Bole	20.59	0.079
Ho	20.07	0.137
Kete Krachi	21.16	0.022
Navrongo	21.95	0.048
Tamale	21.41	0.056
Wa	21.76	0.045
Yendi	21.53	0.095

A comparison of the estimated yearly mean of monthly global solar radiation values, $\bar{H}$ obtained in this study by using the values of the empirical constants '*a'* and *'b'* deduced from Equations 3.5.1.3 and 3.5.1.4 for the period and a ten year average values of global solar radiation reported by Energy Commission of Ghana (ECG) in 2005 was done. The global solar radiation values provided in the ECG report were estimated using Angstrom-Prescott sunshine based model. The values of the empirical constants '*a'* and *'b' b* used by ECG to estimate the global solar radiation for all the Synoptic Stations were 0.27 and 0.45 respectively (ECG, 2005). In order to have a comprehensive comparison, the values of the constants '*a'* and *'b'* used by the ECG in their estimation were adopted in the running of the Matlab programme (see appendix 111) to obtain the yearly mean of monthly global solar radiation values ($\bar{H}_1$) for the Selected Stations. These values obtained were also compared with the ECG values. The z- statistics was used to determine whether there were significant differences in the two sets of values. From standard statistical tables, the z- value corresponding to the rejection (significance) region, $z \geq z_{\alpha/2}$ or $z \leq -z_{\alpha/2}$ is

$z \geq 1.96$ or $z \leq -1.96$ (Devore, 2004). This implies that when the z-value calculated falls within the range – 1.96 to 1.96, then the difference between the estimated global solar radiation value compared with the ECG value is not significant. On the other hand, there is significant difference if the z- value falls outside the range – 1.96 to 1.96. Table 7 shows the comparison of the estimated yearly mean of monthly global solar radiation values ($\bar{H}_1$ *)* using the constants '*a'* and *'b'* used by from ECG and the ECG values of yearly mean of monthly global solar radiation.

Table 7: Comparison of estimated values ($\bar{H}_1$) and ECG values of Yearly mean of monthly global solar radiation.

Stations	Estimated value, $\bar{H}_1$	ECG value	Difference	z- value
Akatsi	18.09	18.29	- 0.20	- 1.18
Bole	18.96	19.15	- 0.19	-1.75
Ho	18.22	18.43	- 0.21	- 1.14
Kete Krachi	19.06	19.01	0.05	1.66
Navrongo	19.82	19.80	0.02	0.29
Tamale	19.40	19.40	0.00	0.00
Wa	19.84	19.87	- 0.03	- 0.47
Yendi	19.51	19.33	0.18	1.36

From Table 7, it is observed that none of the z-values computed for the Stations falls within the rejection (significance) region.This indicates that the difference between the estimated values, $\overline{H}_1$ and the ECG values for the Stations are not significant at level 0.05. There is therefore no sufficient evidence that the estimated global solar radiation values $\overline{H}_1$ differ from the ECG values. Also, Table 8 is a comparison of the yearly mean of monthly global solar radiation values, obtained in this study and the ECG values of yearly mean of monthly global solar radiation for each of the Stations.

Table 8: Comparison of estimated values ($\overline{H}$) and ECG values of Yearly mean of monthly global solar radiation.

Stations	Estimated value, $\overline{H}$	ECG value	Difference	z- value
Akatsi	19.94	18.29	1.65	9.77
Bole	20.59	19.15	1.44	13.26
Ho	20.07	18.43	1.64	8.92
Kete Krachi	21.16	19.01	2.15	71.31
Navrongo	21.95	19.80	2.15	31.00
Tamale	21.41	19.40	2.01	25.64
Wa	21.76	19.87	1.89	29.85
Yendi	21.53	19.33	2.26	17.04

From Table 8, it is observed that all the z-values computed for the Stations fall within the rejection (significance) region.This indicates that the difference between the estimated values, $\overline{H}$ and the ECG values of yearly mean of monthly global solar radiation for the Stations are significant at level 0.05.

There is therefore sufficient evidence that the estimated values, $\overline{H}$ differ from the ECG values.

From the comparison in Tables 7 and 8, it is seen that the difference in the estimated values and the ECG values were due to the values of the empirical constants a and b used to estimate the global solar radiation for the Synoptic Stations. This is because when the same values of the empirical constants used by the ECG was used in the same Matlab program, the values obtained were in close agreement with the ECG values. The values of the empirical constants 'a' and 'b' used to estimate the global solar radiation in this study were unique for each of the Selected Synoptic Stations. However, the values of the empirical constants used by ECG to estimate the global solar radiation were average values obtained using data for locations throughout the whole country. Therefore the global solar radiation values obtained by ECG were not unique for the Synoptic Stations. As stated by Frère (1975), the relationships that exist between the relative sunshine hours and the empirical constants are not straightforward. Therefore, it is very difficult to justify the use of a single set of empirical constants with regards to a vast region such as a country. Therefore, the global solar radiation values estimated in this study appear to be more reasonable compared to ECG values since specific values of a and b were used instead of the generalized constants used by ECG.

Also from Table 6, it is evident that the values of the standard errors obtained for all the Synoptic Stations are close to zero. This indicates that the global solar radiation values obtained for the Selected Synoptic Stations are extensively uniform.

Based on the results, to estimate the monthly mean of daily global solar radiation, $\bar{H}$ in the Selected Synoptic Stations from sunshine hours, the following models have been proposed as presented in Table 9.

Table 9: Proposed Models for the Selected Synoptic Stations

Synoptic Stations	Models
Akatsi	$\bar{H}/\bar{H}_o = 0.29+0.54\ (\bar{S}\ /\ \bar{S}_o)$
Bole	$\bar{H}/\bar{H}_o = 0.31+0.51\ (\bar{S}\ /\ \bar{S}_o)$
Ho	$\bar{H}/\bar{H}_o = 0.29+0.56\ (\bar{S}\ /\ \bar{S}_o)$
Kete Krachi	$\bar{H}/\bar{H}_o = 0.31+0.49\ (\bar{S}\ /\ \bar{S}_o)$
Navrongo	$\bar{H}/\bar{H}_o = 0.33+0.44\ (\bar{S}\ /\ \bar{S}_o)$
Tamale	$\bar{H}/\bar{H}_o = 0.32+0.47\ (\bar{S}\ /\ \bar{S}_o)$
Wa	$\bar{H}/\bar{H}_o = 0.33+0.45\ (\bar{S}\ /\ \bar{S}_o)$
Yendi	$\bar{H}/\bar{H}_o = 0.33+0.46(\bar{S}\ /\ \bar{S}_o)$

The above models are developed for each of the synoptic stations and can be used with confidence since the empirical constants have been determined for each of the Synoptic Stations. The equations can also be applicable to locations which bear similar climates as the Selected Synoptic Stations.

CHAPTER FIVE

SUMMARY, CONCLUSSION AND RECOMMENDATION

Summary

An assessment of the solar resource potential has been developed for eight Synoptic Meteorological Stations in Ghana using empirical model that converts sunshine hour data obtained from the stations into solar resource estimates.The yearly mean of monthly global solar radiation values for the entire period for the Selected Synoptic Stations ranged from 19.94$MJm^{-2}day^{-1}$ to 21.95$MJm^{-2}day^{-1}$ respectively using Angstrom – Prescott sunshine hour model. The significance error analysis revealed the need to use specific values of the empirical constants *a* and *b* when using the Angstrom-Prescott sunshine hour model to estimate global solar radiation for any location. Also, the standard errors of estimate are close to zero which indicate that the values obtained are extensively uniform. The yearly mean of monthly global solar radiation data demonstrates some geographical and seasonal variations. The highest intensities of global solar radiation occur in the Northern belt and the lowest in the Forest belt. Also in general, maximum values of yearly mean of monthly global solar radiation for the Studied Synoptic Stations are observed between March and April while, minimum values are observed in August and December. The study shows that ample solar resource exist throughout the year for virtually all locations covered in this research for solar Photovoltaic (PV) applications, such as solar home systems and remote power applications.

Conclusion

Energy is a continuous steering power for the social and technological prospective development. Renewable energy is considered as the key source for the future as it is a vital and essential ingredient for all human transactions and without it human activities of all kind will not be progress at all. The research work reported in this thesis was an effort to get knowledge of the solar energy potential for practical and efficient utilisation in the catchment areas of the selected locations in Ghana. Yearly mean of monthly global solar radiation values ($\bar{H}$) were estimated for eight Synoptic Stations in Ghana based on sunshine hour duration. Angstrom-Prescott sunshine hour model has been employed for the estimation of the global solar radiation on horizontal surface. The values of the empirical constants *a* and *b* were calculated from well-known relation proposed by Tiwari and Sangeeta (1977) and Frere (1980).

Analysis of the estimated monthly mean of daily global solar radiation showed that for all locations of the study, the maximum values of global solar radiation occurred between March and April while minimum values were observed in August and December. The result also showed that Navrongo received the highest value of yearly mean of monthly global solar radiation of $21.95MJm^{-2}day^{-1}$ while Akatsi receives the lowest value of $19.94MJm^{-2}day^{-1}$.

The yearly mean of monthly global solar radiation values including their standard errors were obtained for the period under review. For example, Akatsi recorded $19.94 \pm 0.125MJm^{-2}day^{-1}$. That of Bole was $20.59 \pm 0.079MJm^{-2}day^{-1}$. In Ho, the yearly mean of monthly global solar radiation was $20.07 \pm 0.137MJm^{-2}day^{-1}$ and for Kete Krachi, $21.16 \pm 0.022MJm^{2}day^{-1}$ was recorded.

The rest are Navrongo, 95$\pm$0.048$MJm^{-2}day^{-1}$; Tamale, 21.41 $\pm$ 0.056MJm^{-2} day^{-1}; Wa, 21.76 $\pm$ 0.045$MJm^{-2}day^{-1}$ and Yendi, 21.53 $\pm$ 0.095$MJm^{-2}day^{-1}$. The average values of the empirical constants *a* and *b* which were calculated for the entire period, were used in modelling equations for each of the stations.

From analysis of the estimated values of the monthly mean of daily and yearly mean of monthly global solar radiation, it can be concluded that Angstrom- Prescott Sunshine Hour Model gave good results as the values obtained had low standard errors. Therefore, the model can be reliably used for the estimation of global solar radiation using sunshine hours for synoptic stations located in Ghana.

The result of this study indicates that with lack of available measured values of global solar radiation, an alternative approach can be used to obtain those values. This approach utilises empirical equations with specific average values of the empirical constants *a* and *b*, for solar radiation reaching the earth's surface at different locations in Ghana. In this work, the empirical constants have been determined for the stations used in the study.

It is also observed that the pattern of the availability of global solar radiation is quite steady over the period considered.

Therefore, the prospects of solar energy utilisation at these locations and Ghana in particular are very bright.

Recommendations

Analysis of the results indicates that Ghana has a huge solar radiation potential for rural electrification and other solar energy applications.

There are however, formidable challenges like low purchasing power, unfavourable public attitude towards the private sector and unfair regulations that work against development and dissemination of renewable energy technologies. It is therefore recommended that the government, nongovernmental organizations and the public make concerted efforts to overcome these challenges by using more flexible approaches to improve the current state of rural electrification in Ghana. Research and development in solar electricity should therefore focus on utilization problems particularly in the development of cost effective storage systems for solar energy with the view to reducing both the capital and operational and maintenance cost. These include chemical batteries, fuel cells and hybrid systems. Also attention is needed in the areas of long term financing, project development, and seed capital mobilisation, covering death and risk mitigation instruments.

In addition, it is recommended that the government as well as individuals and groups should consider the applications of solar radiation in agriculture such as crop and grain drying, and evapotranspiration estimates. The evapotranspiration estimates provide information about water requirement of crops. This will help farmers to know the water requirement of crops at particular locations, thereby reducing crop failure. Also, using the sun to dry crops and grain is one of the oldest and most widely used applications of solar energy. The simplest and least expensive technique is to allow crops to dry naturally in the field, or to spread grain and fruit out in the sun after harvesting. The disadvantage of these methods is that the crops and grain are subject to damage by animals and weather. Simple solar dryers can be used to protect grains and fruits, reduce losses, dry faster and more uniformly, and produce a better quality product than open-air methods.

Also, it is recommended that to estimate global solar radiation for any location in Ghana using empirical models, specific values of empirical constants should be used.

Finally, it is recommended that to know the exact solar resource potential of Ghana and to solve the problems of rural electrification and other solar radiation applications of the country, more studies should be conducted in the future.

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APPENDIX

APPENDIX I: Monthly mean of daily global solar radiation values $(\bar{H})$ and other parameters for each of the Selected Synoptic Stations for the period 2000 to 2010

AKATSI

2000

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	6.17	11.68	0.29	0.53	33.62	19.35
Feb	5.54	11.81	0.27	0.57	35.75	19.46
Mar	6.39	11.96	0.29	0.53	37.34	21.63
Apr	8.11	12.14	0.34	0.43	37.62	23.72
May	7.32	12.28	0.31	0.48	37.59	22.16
Jun	5.14	12.35	0.26	0.61	35.68	19.56
Jul	5.88	12.32	0.28	0.57	35.92	17.76
Aug	4.80	12.19	0.25	0.62	36.92	18.35
Sep	5.20	12.02	0.26	0.60	37.26	19.46
Oct	7.53	11.85	0.33	0.46	36.04	22.34
Nov	8.31	11.71	0.35	0.40	33.98	21.80
Dec	7.29	11.64	0.32	0.46	32.87	20.27

2001

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}\ day^{-1})$	$\bar{H}(MJm^{-2}\ day^{-1})$
Jan	6.98	11.68	0.31	0.48	33.62	20.38
Feb	6.73	11.80	0.31	0.50	35.75	21.27
Mar	6.88	11.96	0.31	0.50	37.38	22.23
Apr	6.78	12.13	0.30	0.51	37.62	22.19
May	7.17	12.28	0.31	0.49	36.59	21.98
Jun	5.66	12.35	0.27	0.58	35.69	19.20
Jul	4.98	12.32	0.25	0.62	35.92	18.11
Aug	3.28	12.20	0.21	0.71	36.92	14.84
Sep	4.62	12.03	0.25	0.63	37.28	18.26
Oct	6.51	11.86	0.30	0.52	36.10	21.13
Nov	6.91	11.71	0.31	0.49	34.04	20.53
Dec	6.38	11.64	0.30	0.52	32.88	19.23

2002

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	6.58	11.68	0.30	0.51	33.62	19.90
Feb	6.73	11.80	0.31	0.50	35.75	21.27
Mar	6.44	11.96	0.30	0.52	37.38	21.70
Apr	6.65	12.13	0.30	0.52	37.62	22.01
May	7.37	12.28	0.32	0.48	36.59	22.22
Jun	5.59	12.35	0.27	0.58	35.69	19.08
Jul	4.64	12.32	0.24	0.64	35.92	17.44
Aug	4.78	12.20	0.25	0.63	36.92	18.23
Sep	5.68	12.03	0.27	0.57	37.26	20.34
Oct	6.72	11.86	0.31	0.50	36.10	21.42
Nov	7.32	11.71	0.32	0.46	34.04	20.98
Dec	7.73	11.64	0.34	0.44	32.88	20.68

2003

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.03	11.68	0.34	0.42	33.62	21.38
Feb	8.13	11.80	0.34	0.42	35.75	22.75
Mar	6.13	11.96	0.29	0.54	37.38	21.22
Apr	6.83	12.13	0.30	0.51	37.62	21.61
May	7.89	12.28	0.33	0.45	36.59	22.78
Jun	4.58	12.35	0.24	0.64	35.69	17.18
Jul	6.80	12.32	0.30	0.51	35.92	21.08
Aug	5.07	12.20	0.26	0.61	36.92	18.89
Sep	5.05	12.03	0.26	0.61	37.26	19.17
Oct	7.55	11.86	0.33	0.44	36.10	22.40
Nov	7.29	11.71	0.32	0.47	34.04	20.95
Dec	7.04	11.64	0.32	0.48	32.88	20.02

2004

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	5.30	11.68	0.27	0.58	33.62	17.10
Feb	7.43	11.81	0.19	0.74	35.75	22.09
Mar	5.00	11.96	0.26	0.61	37.38	19.19
Apr	6.61	12.14	0.30	0.52	37.62	21.95
May	5.68	12.28	0.27	0.58	36.59	19.78
Jun	4.76	12.35	0.25	0.63	35.69	17.54
Jul	4.82	12.32	0.25	0.63	35.92	17.80
Aug	4.11	12.19	0.23	0.66	36.92	16.86
Sep	4.99	12.02	0.26	0.61	37.26	19.05
Oct	6.80	11.85	0.31	0.50	36.10	21.52
Nov	7.54	11.71	0.33	0.45	34.04	21.26
Dec	7.68	11.64	0.33	0.44	32.88	20.64

2005

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	4.53	11.68	0.25	0.63	33.62	16.58
Feb	6.08	11.80	0.29	0.54	35.75	20.34
Mar	6.42	11.96	0.30	0.52	37.38	21.67
Apr	6.27	12.13	0.29	0.54	37.62	21.44
May	6.51	12.28	0.29	0.53	36.59	21.10
Jun	4.22	12.35	0.23	0.66	35.69	16.42
Jul	3.81	12.32	0.22	0.68	35.92	15.63
Aug	3.65	12.20	0.22	0.69	36.92	15.77
Sep	5.56	12.03	0.27	0.58	37.26	20.13
Oct	7.33	11.86	0.32	0.47	36.10	22.16
Nov	7.48	11.71	0.33	0.45	34.04	21.14
Dec	7.50	11.64	0.33	0.45	37.88	20.48

2006

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	7.66	11.68	0.33	0.44	33.62	21.07
Feb	7.18	11.80	0.32	0.47	35.75	21.82
Mar	6.70	11.96	0.30	0.51	37.42	22.09
Apr	6.66	12.13	0.30	0.52	37.60	22.01
May	5.82	12.28	0.27	0.57	36.55	19.99
Jun	6.45	12.35	0.29	0.53	35.68	20.43
Jul	5.09	12.32	0.26	0.61	35.95	18.34
Aug	3.97	12.20	0.23	0.67	36.95	16.55
Sep	5.05	12.03	0.26	0.61	37.25	19.16
Oct	7.32	11.86	0.32	0.47	36.04	22.12
Nov	7.82	11.71	0.34	0.43	33.98	22.12
Dec	7.04	11.64	0.32	0.48	32.87	20.01

2007

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	4.25	11.68	0.24	0.64	33.62	16.02
Feb	6.65	11.80	0.31	0.49	35.75	21.16
Mar	6.55	11.96	0.30	0.52	37.38	21.86
Apr	7.01	12.13	0.31	0.50	37.62	22.50
May	6.40	12.28	0.29	0.54	36.59	20.63
Jun	4.35	12.35	0.24	0.65	35.69	16.70
Jul	4.48	12.32	0.24	0.65	35.92	17.11
Aug	3.57	12.20	0.22	0.69	36.92	15.57
Sep	5.57	12.03	0.27	0.58	37.26	20.15
Oct	6.80	11.86	0.31	0.50	36.10	21.52
Nov	7.75	11.71	0.34	0.44	34.04	21.39
Dec	7.02	11.64	0.32	0.48	32.88	20.00

2008

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	6.60	11.68	0.20	0.50	33.62	19.92
Feb	5.67	11.81	0.28	0.56	35.75	19.68
Mar	6.68	11.96	0.30	0.51	37.38	22.05
Apr	6.27	12.14	0.29	0.54	37.62	21.44
May	6.25	12.28	0.29	0.54	36.59	20.71
Jun	5.09	12.35	0.25	0.61	35.69	18.18
Jul	4.55	12.32	0.24	0.64	35.92	17.25
Aug	4.04	12.19	0.23	0.67	36.92	16.70
Sep	5.07	12.02	0.26	0.60	37.26	19.21
Oct	7.14	11.85	0.32	0.48	36.10	21.94
Nov	7.33	11.71	0.32	0.46	34.04	20.99
Dec	7.12	11.64	0.32	0.47	32.88	20.10

2009

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	6.85	11.68	0.31	0.49	33.62	20.23
Feb	7.29	11.80	0.32	0.47	35.75	21.94
Mar	6.27	11.96	0.29	0.53	37.38	21.44
Apr	7.46	12.13	0.32	0.50	37.62	23.05
May	7.18	12.28	0.31	0.49	36.59	21.99
Jun	4.57	12.35	0.24	0.64	35.69	17.16
Jul	3.99	12.32	0.23	0.67	35.92	16.04
Aug	3.92	12.20	0.23	0.67	36.92	16.47
Sep	5.10	12.03	0.26	0.60	37.26	19.27
Oct	7.48	11.86	0.33	0.45	36.10	22.32
Nov	8.03	11.71	0.34	0.42	34.04	21.63
Dec	7.28	11.64	0.32	0.46	32.88	20.27

2010

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	6.79	11.68	0.31	0.49	33.21	20.16
Feb	8.08	11.80	0.34	0.42	35.75	22.70
Mar	4.48	11.96	0.24	0.64	37.38	18.10
Apr	7.09	12.13	0.31	0.49	37.62	22.60
May	6.00	12.28	0.28	0.56	36.60	20.29
Jun	4.50	12.35	0.24	0.64	35.69	17.01
Jul	4.96	12.32	0.25	0.62	35.92	18.09
Aug	3.98	12.20	0.23	0.67	36.91	16.56
Sep	4.52	12.03	0.24	0.64	37.26	18.06
Oct	5.95	11.86	0.28	0.55	38.12	20.26
Nov	6.98	11.71	0.31	0.48	38.17	20.75
Dec	8.06	11.64	0.35	0.42	37.86	20.95

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2000

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	7.31	11.53	0.33	0.46	32.30	19.97
Feb	7.29	11.72	0.32	0.47	34.81	21.40
Mar	7.28	11.95	0.32	0.48	37.04	22.59
Apr	8.22	12.21	0.34	0.43	37.86	23.98
May	7.34	12.42	0.31	0.49	37.30	22.59
Jun	6.26	12.53	0.28	0.56	36.64	20.62
Jul	4.58	12.47	0.24	0.65	36.79	17.63
Aug	4.63	12.29	0.24	0.64	37.38	18.15
Sep	4.99	12.04	0.25	0.61	37.13	18.95
Oct	7.46	11.79	0.33	0.46	35.36	21.87
Nov	8.77	11.57	0.37	0.38	32.83	21.35
Dec	8.15	11.47	0.35	0.41	31.47	20.14

2001

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	9.06	11.53	0.37	0.36	32.30	21.14
Feb	8.70	11.71	0.36	0.39	34.82	22.57
Mar	8.22	11.94	0.34	0.42	36.98	23.54
Apr	7.58	12.20	0.32	0.47	37.86	23.33
May	7.34	12.41	0.31	0.49	37.32	22.59
Jun	5.82	12.52	0.27	0.58	36.65	19.90
Jul	4.73	12.48	0.24	0.64	36.79	17.95
Aug	3.76	12.30	0.22	0.69	37.38	16.16
Sep	5.15	12.05	0.26	0.61	37.13	19.27
Oct	8.75	11.79	0.36	0.39	35.36	22.92
Nov	8.05	11.58	0.35	0.42	32.83	20.91
Dec	8.77	11.47	0.37	0.37	31.47	20.48

2002

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	7.66	11.53	0.34	0.44	32.30	20.28
Feb	8.96	11.71	0.37	0.37	34.82	22.70
Mar	7.77	11.94	0.33	0.45	36.98	23.12
Apr	7.47	12.20	0.32	0.48	37.86	23.20
May	7.88	12.41	033	0.46	37.32	23.20
Jun	6.31	12.52	0.28	0.55	36.65	20.69
Jul	5.28	12.48	0.26	0.61	36.79	19.03
Aug	4.23	12.30	0.23	0.66	37.38	17.27
Sep	5.61	12.05	0.27	0.58	37.13	20.13
Oct	7.45	11.79	0.33	0.46	35.36	21.86
Nov	8.56	11.58	0.36	0.39	32.83	21.24
Dec	8.80	11.47	0.37	0.37	31.47	20.50

2003

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.13	11.53	0.35	0.41	32.30	20.64
Feb	8.40	11.71	0.35	0.40	34.82	22.38
Mar	7.79	11.94	0.33	0.45	37.98	23.14
Apr	7.53	12.20	0.32	0.47	37.86	23.27
May	7.69	12.41	0.32	0.47	37.32	23.00
Jun	4.65	12.52	0.24	0.64	36.65	17.68
Jul	5.04	12.48	0.25	0.62	36.79	18.57
Aug	4.63	12.30	0.24	0.64	37.38	18.15
Sep	5.71	12.05	0.27	0.57	37.13	20.31
Oct	8.45	11.79	0.35	0.40	35.36	22.73
Nov	8.16	11.58	0.35	0.41	32.83	20.99
Dec	7.94	11.47	0.41	0.42	31.47	20.00

2004

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.62	11.53	0.36	0.38	32.30	20.94
Feb	6.90	11.72	0.31	0.49	34.82	20.96
Mar	5.91	11.95	0.28	0.56	37.04	20.64
Apr	6.89	12.21	0.30	0.51	37.86	22.46
May	7.09	12.42	0.31	0.51	37.30	22.27
Jun	5.69	12.53	0.27	0.59	36.64	19.67
Jul	4.54	12.47	0.24	0.65	36.81	17.55
Aug	3.94	12.29	0.22	0.68	37.38	16.59
Sep	5.35	12.04	0.26	0.59	37.09	19.65
Oct	7.92	11.79	0.34	0.44	35.28	22.31
Nov	8.27	11.57	0.35	0.41	32.76	21.06
Dec	7.02	11.47	0.32	0.48	31.46	19.19

2005

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	6.75	11.53	0.31	0.50	32.30	19.37
Feb	6.40	11.71	0.30	0.52	34.82	20.31
Mar	6.75	11.94	0.30	0.51	36.98	21.92
Apr	7.13	12.20	0.31	0.50	37.86	22.78
May	7.63	12.41	0.32	0.48	37.32	22.93
Jun	5.22	12.52	0.26	0.61	36.65	18.82
Jul	4.36	12.48	0.23	0.66	36.79	17.16
Aug	4.06	12.30	0.23	0.67	37.38	16.88
Sep	5.30	12.05	0.26	0.60	37.13	19.56
Oct	7.23	11.79	0.32	0.48	35.36	21.62
Nov	7.51	11.58	0.33	0.45	32.83	20.46
Dec	7.99	11.47	0.35	0.42	31.47	20.03

2006

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.10	11.53	0.35	0.41	32.30	20.62
Feb	8.31	11.71	0.35	0.41	34.37	22.31
Mar	7.56	11.94	0.33	0.46	37.04	22.91
Apr	7.45	12.20	0.32	0.48	37.86	23.18
May	7.23	12.41	0.31	0.50	37.86	22.45
Jun	5.98	12.41	0.28	0.57	36.64	20.17
Jul	5.15	12.52	0.25	0.62	36.81	18.78
Aug	4.43	12.48	0.24	0.65	37.40	17.72
Sep	5.29	12.05	0.26	0.60	37.13	19.54
Oct	7.21	11.79	0.32	0.48	35.36	21.60
Nov	8.70	11.58	0.36	0.38	32.76	21.31
Dec	8.16	11.47	0.35	0.41	31.46	20.15

2007

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	5.93	11.53	0.29	0.54	32.30	18.32
Feb	8.09	11.71	0.34	0.42	34.82	22.15
Mar	5.56	11.94	0.27	0.58	36.98	20.04
Apr	6.16	12.20	0.28	0.55	37.86	21.37
May	7.42	12.41	0.31	0.49	37.32	22.69
Jun	5.76	12.52	0.27	0.58	36.65	19.79
Jul	4.65	12.48	0.24	0.64	36.79	17.78
Aug	4.17	12.30	0.23	0.67	37.38	17.13
Sep	5.04	12.05	0.26	0.61	37.13	19.05
Oct	7.19	11.79	0.32	0.48	35.36	21.58
Nov	7.83	11.58	0.34	0.43	32.83	20.74
Dec	7.99	11.47	0.35	0.42	31.47	20.32

2008

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.80	11.53	0.37	0.37	32.30	21.03
Feb	6.48	11.72	0.30	0.52	34.82	20.42
Mar	7.00	11.95	0.31	0.50	36.98	22.25
Apr	7.69	12.21	0.32	0.46	37.86	23.45
May	7.96	12.42	0.33	0.46	37.30	23.28
Jun	6.10	12.53	0.28	0.56	36.64	20.36
Jul	4.53	12.47	0.24	0.65	36.81	17.52
Aug	4.18	12.29	0.23	0.67	37.40	17.15
Sep	5.38	12.04	0.27	0.59	37.09	19.71
Oct	7.37	11.79	0.32	0.47	35.28	21.78
Nov	7.86	11.57	0.34	0.43	32.76	20.76
Dec	7.35	11.47	0.33	0.46	31.46	19.51

2009

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.58	11.53	0.36	0.39	32.30	20.92
Feb	8.10	11.71	0.34	0.42	34.82	22.16
Mar	7.48	11.94	0.32	0.47	36.98	22.82
Apr	7.73	12.20	0.33	0.46	37.86	23.49
May	7.74	12.41	0.32	0.47	37.32	23.05
Jun	6.24	12.52	0.28	0.56	36.65	20.58
Jul	5.13	12.48	0.25	0.62	36.79	18.75
Aug	3.13	12.30	0.20	0.73	37.38	14.56
Sep	4.81	12.05	0.25	0.62	37.13	18.59
Oct	6.19	11.79	0.29	0.54	35.36	20.27
Nov	7.89	11.58	0.34	0.43	32.83	20.78
Dec	8.36	11.47	0.36	0.40	31.47	20.27

2010

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	9.53	11.53	0.39	0.33	32.30	21.28
Feb	8.50	11.71	0.36	0.40	34.82	22.44
Mar	5.61	11.94	0.27	0.58	36.90	20.13
Apr	6.55	12.20	0.29	0.53	37.86	21.97
May	7.19	12.41	0.31	0.50	37.32	22.40
Jun	5.73	12.52	0.27	0.58	36.65	19.74
Jul	4.93	12.48	0.25	0.63	36.79	18.35
Aug	4.09	12.30	0.23	0.67	37.38	16.95
Sep	4.08	12.05	0.23	0.67	37.13	16.98
Oct	6.20	11.79	0.29	0.54	35.36	20.28
Nov	7.98	11.58	0.34	0.42	32.83	20.85
Dec	7.92	11.47	0.34	0.42	31.47	19.98

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2000

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	6.31	11.65	0.30	0.52	33.41	19.44
Feb	7.10	11.80	0.32	0.48	35.61	21.65
Mar	6.66	11.96	0.30	0.51	37.32	21.99
Apr	8.31	12.15	0.34	0.42	37.67	23.92
May	7.89	12.30	0.33	0.45	36.72	22.85
Jun	5.93	12.38	0.28	0.57	35.85	19.71
Jul	5.83	12.34	0.28	0.57	36.07	19.69
Aug	4.20	12.21	0.23	0.66	37.01	17.08
Sep	4.93	12.03	0.25	0.61	37.25	18.92
Oct	7.47	11.84	0.33	0.46	35.98	22.25
Nov	9.18	11.69	0.38	0.35	33.85	22.19
Dec	7.74	11.62	0.34	0.44	32.65	20.57

2001

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	7.64	11.65	0.33	0.44	33.41	20.94
Feb	7.32	11.79	0.32	0.47	35.61	21.90
Mar	7.77	11.96	0.33	0.45	37.32	23.32
Apr	7.22	12.15	0.31	0.49	37.67	22.79
May	6.93	12.30	0.30	0.51	36.72	21.74
Jun	6.47	12.38	0.29	0.54	35.85	20.54
Jul	4.87	12.35	0.25	0.62	36.07	17.95
Aug	2.66	12.22	0.19	0.75	37.00	13.20
Sep	4.10	12.03	0.23	0.66	37.25	17.11
Oct	7.69	11.85	0.33	0.45	35.98	22.48
Nov	8.44	11.69	0.36	0.40	33.85	21.81
Dec	8.06	11.62	0.35	0.42	32.65	20.82

2002

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	5.42	11.65	0.27	0.58	33.41	18.10
Feb	7.12	11.79	0.32	0.48	35.61	21.67
Mar	6.84	11.96	0.31	0.50	37.32	22.24
Apr	7.17	12.15	0.31	0.49	36.67	22.73
May	7.89	12.30	0.33	0.45	36.72	22.85
Jun	6.55	12.38	0.29	0.53	35.85	20.65
Jul	4.38	12.35	0.24	0.65	36.07	16.95
Aug	3.82	12.22	0.22	0.68	37.00	16.20
Sep	5.71	12.03	0.28	0.57	37.25	20.39
Oct	7.21	11.85	0.32	0.48	35.98	21.97
Nov	8.35	11.69	0.35	0.40	33.85	21.75
Dec	8.23	11.62	0.35	0.41	32.65	20.94

2003

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	7.16	11.65	0.32	0.47	33.41	20.47
Feb	7.83	11.79	0.34	0.44	35.61	22.41
Mar	7.44	11.96	0.32	0.47	37.32	22.97
Apr	7.41	12.15	0.32	0.48	37.67	23.02
May	8.05	12.30	0.33	0.44	36.72	23.00
Jun	5.83	12.38	0.26	0.59	35.85	19.55
Jul	6.34	12.35	0.29	0.54	36.07	20.50
Aug	4.52	12.22	0.24	0.64	37.00	17.79
Sep	4.97	12.03	0.26	0.61	37.25	19.00
Oct	7.82	11.85	0.34	0.44	35.98	22.60
Nov	8.17	11.69	0.35	0.41	33.85	21.63
Dec	7.33	11.62	0.33	0.46	32.65	20.20

2004

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	5.77	11.65	0.28	0.55	33.41	18.66
Feb	6.38	11.79	0.30	0.52	35.61	20.72
Mar	6.36	11.96	0.29	0.53	37.32	21.55
Apr	7.46	12.15	0.32	0.47	37.67	23.07
May	6.82	12.30	0.30	0.51	36.72	21.59
Jun	5.49	12.38	0.27	0.59	35.85	18.97
Jul	4.31	12.35	0.24	0.66	36.07	16.80
Aug	3.51	12.22	0.22	0.70	37.00	15.45
Sep	6.26	12.03	0.29	0.54	37.25	21.29
Oct	6.93	11.85	0.31	0.49	35.98	21.63
Nov	8.05	11.69	0.34	0.42	33.85	21.54
Dec	7.94	11.62	0.34	0.42	32.65	20.73

2005

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	5.63	11.65	0.28	0.56	33.41	18.44
Feb	7.22	11.79	0.32	0.47	35.61	21.79
Mar	7.04	11.96	0.31	0.49	37.32	22.50
Apr	6.87	12.15	0.31	0.51	37.67	22.30
May	6.97	12.30	0.31	0.51	36.72	21.79
Jun	4.92	12.38	0.25	0.62	35.85	17.92
Jul	3.51	12.35	0.21	0.70	36.07	14.97
Aug	3.16	12.22	0.21	0.72	37.00	14.55
Sep	5.49	12.03	0.27	0.58	37.25	19.99
Oct	7.44	11.85	0.33	0.46	35.98	22.22
Nov	8.45	11.69	0.37	0.40	33.85	21.82
Dec	6.38	11.62	0.16	0.82	32.65	19.12

2006

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	4.54	11.65	0.25	0.63	33.40	16.52
Feb	7.70	11.79	0.33	0.45	35.61	22.29
Mar	6.65	11.96	0.30	0.51	37.65	22.01
Apr	7.17	12.15	0.31	0.49	37.67	22.73
May	7.05	12.30	0.31	0.50	36.72	21.89
Jun	6.98	12.38	0.30	0.51	35.85	21.23
Jul	4.74	12.35	0.25	0.63	36.07	17.69
Aug	3.51	12.22	0.22	0.70	37.00	15.45
Sep	4.53	12.03	0.24	0.64	37.25	18.08
Oct	7.18	11.85	0.32	0.48	35.98	21.93
Nov	8.28	11.69	0.35	0.41	33.85	21.70
Dec	7.22	11.62	0.32	0.47	32.65	20.09

2007

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	4.67	11.65	0.20	0.74	33.41	16.77
Feb	6.75	11.79	0.31	0.50	35.61	21.22
Mar	6.69	11.96	0.30	0.51	37.32	22.03
Apr	7.12	12.15	0.31	0.49	37.67	22.63
May	6.66	12.30	0.30	0.52	36.72	21.37
Jun	5.63	12.38	0.27	0.58	35.85	19.21
Jul	3.90	12.35	0.22	0.68	36.07	15.88
Aug	3.24	12.22	0.21	0.71	37.00	14.76
Sep	4.95	12.03	0.26	0.61	37.25	22.17
Oct	6.87	11.85	0.31	0.50	35.98	21.55
Nov	7.98	11.69	0.34	0.42	33.85	21.48
Dec	7.44	11.62	0.33	0.45	32.64	20.30

2008

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	6.93	11.65	0.31	0.47	33.41	20.21
Feb	5.30	11.80	0.27	0.59	35.61	18.97
Mar	7.10	11.96	0.31	0.49	37.32	22.57
Apr	7.22	12.15	0.31	0.49	37.67	22.79
May	6.21	12.30	0.29	0.55	36.72	20.70
Jun	5.40	12.38	0.26	0.60	35.85	18.81
Jul	4.19	12.34	0.20	0.66	36.07	16.54
Aug	4.00	12.21	0.23	0.67	37.03	16.64
Sep	4.46	12.03	0.24	0.64	37.23	17.92
Oct	7.45	11.84	0.33	0.46	35.92	22.20
Nov	8.11	11.69	0.35	0.42	33.84	21.58
Dec	7.65	11.62	0.34	0.44	32.65	20.49

2009

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	6.51	11.65	0.30	0.51	33.41	19.70
Feb	7.68	11.79	0.33	0.45	35.61	22.27
Mar	6.75	11.96	0.30	0.51	37.32	22.11
Apr	6.65	12.15	0.30	0.52	37.67	22.03
May	7.31	12.30	0.31	0.49	36.72	22.21
Jun	5.27	12.38	0.26	0.60	35.85	18.58
Jul	3.96	12.35	0.23	0.68	36.07	16.02
Aug	3.08	12.22	0.20	0.72	37.00	14.34
Sep	4.99	12.03	0.26	0.61	37.25	19.03
Oct	6.89	11.85	0.31	0.50	35.98	21.58
Nov	8.03	11.69	0.34	0.42	33.85	21.52
Dec	7.61	11.62	0.33	0.44	32.65	20.46

2010

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	7.46	11.65	0.33	0.45	33.41	20.77
Feb	7.87	11.79	0.34	0.44	35.61	22.44
Mar	4.74	11.96	0.25	0.62	37.32	18.65
Apr	6.91	12.15	0.31	0.50	37.67	23.39
May	6.31	12.30	0.29	0.54	36.72	20.86
Jun	4.47	12.38	0.24	0.65	35.85	17.01
Jul	4.50	12.35	0.24	0.65	36.07	17.09
Aug	3.51	12.22	0.22	0.70	37.00	15.45
Sep	4.34	12.03	0.24	0.65	37.25	17.68
Oct	7.06	11.85	0.31	0.49	35.98	21.79
Nov	7.67	11.69	0.33	0.44	33.85	21.22
Dec	8.61	11.62	0.36	0.38	32.65	21.17

KETE KRACHI

2000

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	7.19	11.59	0.32	0.47	32.86	20.21
Feb	7.18	11.76	0.32	0.48	35.22	21.54
Mar	7.17	11.95	0.32	0.48	37.21	22.60
Apr	8.71	12.18	0.35	0.40	37.77	24.30
May	8.22	12.36	0.34	0.44	37.03	23.33
Jun	6.73	12.45	0.30	0.52	36.26	21.09
Jul	5.55	12.41	0.27	0.59	36.44	19.36
Aug	4.60	12.25	0.24	0.64	37.20	18.02
Sep	5.29	12.03	0.26	0.60	37.20	19.59
Oct	7.90	11.81	0.34	0.44	35.68	22.51
Nov	8.94	11.63	0.37	0.37	33.34	21.80
Dec	7.54	11.55	0.33	0.45	32.05	20.07

2001

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.05	11.59	0.35	0.42	32.86	20.97
Feb	7.75	11.75	0.33	0.44	35.22	22.13
Mar	8.23	11.95	0.34	0.42	37.16	23.66
Apr	7.77	12.17	0.33	0.46	37.77	23.47
May	7.99	12.36	0.33	0.45	37.03	23.11
Jun	7.20	12.45	0.31	0.50	36.26	21.72
Jul	5.39	12.41	0.26	0.60	36.44	19.07
Aug	3.71	12.26	0.22	0.69	37.20	15.99
Sep	4.49	12.04	0.24	0.64	37.20	17.96
Oct	8.45	11.82	0.35	0.40	35.68	22.95
Nov	8.79	11.63	0.37	0.38	33.34	21.72
Dec	8.38	11.55	0.36	0.40	32.06	20.70

2002

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	5.72	11.59	0.28	0.56	32.86	18.33
Feb	8.01	11.75	0.34	0.43	35.22	22.35
Mar	7.43	11.95	0.32	0.47	37.16	22.88
Apr	7.86	12.17	0.33	0.45	37.77	23.57
May	7.92	12.36	0.33	0.46	37.03	23.04
Jun	7.26	12.45	0.31	0.50	36.26	21.78
Jul	5.29	12.41	0.26	0.60	36.44	18.89
Aug	5.72	12.26	0.27	0.58	37.20	20.37
Sep	6.16	12.04	0.29	0.55	37.20	21.11
Oct	6.98	11.82	0.31	0.49	35.68	21.54
Nov	9.09	11.63	0.37	0.36	33.34	21.86
Dec	8.23	11.55	0.35	0.41	32.06	20.61

2003

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	7.64	11.59	0.33	0.44	32.86	20.64
Feb	8.40	11.75	0.35	0.40	35.22	22.65
Mar	8.13	11.95	0.34	0.43	37.16	23.58
Apr	7.76	12.17	0.33	0.46	37.77	23.46
May	9.05	12.36	0.36	0.39	37.03	23.96
Jun	6.00	12.45	0.28	0.57	36.26	19.20
Jul	5.49	12.41	0.26	0.59	36.44	19.26
Aug	5.00	12.26	0.25	0.62	37.20	18.85
Sep	4.73	12.04	0.25	0.63	37.20	18.47
Oct	8.11	11.82	0.34	0.42	35.68	22.69
Nov	8.39	11.63	0.35	0.40	33.34	21.50
Dec	8.00	11.55	0.34	0.42	32.06	20.45

2004

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	6.99	11.59	0.32	0.48	32.86	20.00
Feb	7.42	11.76	0.33	0.46	35.22	21.80
Mar	7.20	11.95	0.32	0.48	37.21	22.64
Apr	7.86	12.18	0.33	0.45	37.77	23.57
May	8.01	12.36	0.33	0.45	37.03	23.13
Jun	6.23	12.45	0.28	0.55	36.26	20.36
Jul	4.80	12.41	0.25	0.63	36.46	17.95
Aug	5.34	12.25	0.26	0.60	37.20	20.35
Sep	5.81	12.03	0.28	0.56	37.20	20.53
Oct	8.04	11.83	0.26	0.60	35.63	22.63
Nov	8.59	11.63	0.36	0.39	33.28	21.58
Dec	7.73	11.55	0.34	0.44	32.05	20.23

2005

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	6.74	11.59	0.31	0.50	32.86	19.71
Feb	7.53	11.75	0.33	0.46	35.22	21.91
Mar	8.14	11.95	0.34	0.43	37.16	23.59
Apr	7.90	12.17	0.33	0.45	37.77	23.61
May	8.17	12.36	0.34	0.44	37.03	23.29
Jun	6.24	12.45	0.28	0.55	36.26	20.38
Jul	4.93	12.41	0.25	0.62	36.44	18.20
Aug	4.41	12.26	0.24	0.65	37.20	17.61
Sep	5.72	12.04	0.28	0.57	37.20	20.37
Oct	7.93	11.82	0.34	0.43	35.68	24.54
Nov	9.18	11.63	0.38	0.35	33.34	21.89
Dec	8.74	11.55	0.37	0.37	32.06	20.90

2006

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.14	11.59	0.35	0.41	32.86	21.04
Feb	8.63	11.75	0.36	0.39	35.22	22.80
Mar	7.75	11.95	0.33	0.45	37.21	23.25
Apr	8.11	12.17	0.34	0.44	37.77	23.93
May	6.80	12.36	0.30	0.52	37.03	21.71
Jun	7.04	12.45	0.30	0.51	36.26	21.50
Jul	5.53	12.41	0.27	0.59	36.44	19.33
Aug	3.91	12.26	0.22	0.68	37.20	16.47
Sep	5.05	12.04	0.26	0.61	37.20	19.12
Oct	8.04	11.82	0.34	0.43	35.68	22.63
Nov	9.04	11.63	0.37	0.36	33.28	21.80
Dec	8.25	11.55	0.35	0.40	32.05	20.62

2007

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	5.69	11.59	0.28	0.56	32.86	18.29
Feb	8.24	11.75	0.35	0.41	35.22	22.54
Mar	7.59	11.95	0.33	0.46	37.16	23.05
Apr	7.67	12.17	0.33	0.46	37.77	23.37
May	7.32	12.36	0.31	0.49	37.03	22.38
Jun	6.90	12.45	0.30	0.52	36.26	21.32
Jul	5.17	12.41	0.26	0.61	36.34	18.67
Aug	4.59	12.26	0.24	0.64	37.20	18.00
Sep	5.57	12.04	0.27	0.58	37.20	20.11
Oct	7.23	11.82	0.32	0.48	35.68	21.83
Nov	8.56	11.63	0.36	0.39	33.34	21.60
Dec	7.45	11.55	0.33	0.45	32.06	20.00

2008

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.43	11.59	0.36	0.40	32.86	21.23
Feb	6.32	11.76	0.30	0.53	35.22	20.44
Mar	7.55	11.95	0.33	0.46	37.16	23.01
Apr	7.25	12.18	0.31	0.49	37.77	22.88
May	7.61	12.36	0.32	0.47	37.03	22.72
Jun	6.95	12.45	0.30	0.51	36.26	21.39
Jul	4.95	12.41	0.25	0.62	36.44	18.24
Aug	4.71	12.25	0.25	0.63	37.20	18.26
Sep	5.44	12.03	0.27	0.59	37.20	19.87
Oct	8.01	11.81	0.34	0.43	35.68	22.61
Nov	8.43	11.63	0.36	0.40	33.34	21.52
Dec	8.18	11.55	0.35	0.41	32.06	20.58

2009

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.00	11.59	0.34	0.42	32.86	20.93
Feb	8.45	11.75	0.35	0.40	35.22	22.69
Mar	7.77	11.95	0.33	0.45	37.16	23.24
Apr	7.80	12.17	0.33	0.46	37.77	23.50
May	8.07	12.36	0.33	0.45	37.03	23.19
Jun	7.21	12.45	0.31	0.50	36.26	21.72
Jul	4.98	12.41	0.25	0.62	36.44	18.00
Aug	3.71	12.26	0.22	0.69	37.20	15.99
Sep	5.73	12.04	0.28	0.57	37.20	20.39
Oct	7.10	11.82	0.32	0.48	35.68	21.68
Nov	8.20	11.63	0.35	0.41	33.34	21.37
Dec	8.38	11.55	0.36	0.40	32.06	20.70

2010

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.51	11.59	0.36	0.39	32.86	21.28
Feb	9.18	11.75	0.37	0.36	35.22	23.09
Mar	6.51	11.95	0.30	0.52	37.21	22.72
Apr	7.72	12.17	0.33	0.46	37.77	23.42
May	8.27	12.36	0.34	0.44	37.77	23.95
Jun	7.16	12.45	0.31	0.50	36.26	21.65
Jul	5.31	12.41	0.26	0.60	36.44	18.93
Aug	4.33	12.26	0.24	0.66	37.20	17.43
Sep	5.22	12.04	0.26	0.60	37.20	19.46
Oct	6.54	11.82	0.30	0.52	35.68	20.96
Nov	8.31	11.63	0.35	0.40	33.34	21.44
Dec	9.01	11.55	0.37	0.36	32.06	21.02

NAVRONGO

2000

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	7.99	11.43	0.34	0.42	31.42	20.13
Feb	7.89	11.65	0.34	0.43	34.17	21.69
Mar	7.80	11.93	0.33	0.45	33.67	23.02
Apr	8.85	12.24	0.35	0.40	37.97	24.55
May	8.04	12.50	0.33	0.46	37.75	23.56
Jun	7.91	12.63	0.32	0.47	37.22	23.01
Jul	6.77	12.58	0.29	0.53	37.30	21.68
Aug	6.65	12.36	0.29	0.53	37.64	21.87
Sep	6.23	12.06	0.28	0.54	36.99	21.10
Oct	8.51	11.75	0.35	0.40	34.83	22.53
Nov	9.40	11.49	0.38	0.33	32.01	21.18
Dec	8.46	11.36	0.36	0.39	30.53	19.88

2001

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	9.15	11.43	0.38	0.35	31.42	20.73
Feb	8.99	11.65	0.37	0.37	34.17	22.41
Mar	8.86	11.93	0.36	0.39	36.67	23.86
Apr	8.34	12.24	0.34	0.43	37.97	24.14
May	8.51	12.50	0.34	0.43	37.75	24.00
Jun	8.14	12.63	0.33	0.46	37.22	23.24
Jul	6.94	12.58	0.30	0.52	37.30	21.91
Aug	5.61	12.36	0.26	0.59	37.64	20.01
Sep	7.22	12.06	0.31	0.49	36.99	22.48
Oct	8.77	11.75	0.36	0.39	34.84	22.69
Nov	9.14	11.49	0.37	0.35	32.01	21.01
Dec	9.76	11.36	0.40	0.31	31.10	20.66

2002

Month	$\bar{S}(hr)$	$\bar{S}_o\ (hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.03	11.43	0.34	0.42	31.42	20.02
Feb	9.16	11.65	0.37	0.36	31.42	22.48
Mar	7.55	11.93	0.32	0.46	36.67	22.76
Apr	7.98	12.24	0.33	0.45	37.97	23.80
May	7.82	12.50	0.34	0.42	37.75	23.33
Jun	7.49	12.63	0.31	0.49	37.22	22.25
Jul	7.43	12.58	0.31	0.49	37.30	22.55
Aug	6.13	12.36	0.28	0.56	37.64	21.06
Sep	7.80	12.06	0.33	0.48	36.99	23.13
Oct	8.13	11.75	0.34	0.42	34.83	22.25
Nov	9.44	11.49	0.38	0.33	32.01	21.19
Dec	9.56	11.36	0.39	0.32	30.53	20.26

2003

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.43	11.43	0.36	0.39	31.42	20.41
Feb	8.67	11.65	0.36	0.39	34.17	22.25
Mar	8.05	11.93	0.34	0.44	36.67	23.25
Apr	8.23	12.24	0.34	0.44	37.97	24.04
May	8.95	12.50	0.35	0.41	37.75	24.34
Jun	7.02	12.63	0.30	0.52	37.22	21.94
Jul	7.68	12.58	0.32	0.48	37.30	22.84
Aug	5.30	12.36	0.26	0.61	37.64	19.57
Sep	7.04	12.06	0.31	0.50	36.99	22.60
Oct	9.06	11.75	0.37	0.37	34.83	22.84
Nov	9.19	11.49	0.38	0.35	32.01	21.12
Dec	9.32	11.36	0.38	0.33	30.53	20.21

2004

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.91	11.43	0.37	0.36	31.42	20.42
Feb	7.11	11.66	0.32	0.48	34.17	20.92
Mar	5.70	11.93	0.27	0.57	36.67	20.16
Apr	7.55	12.25	0.32	0.48	37.97	23.34
May	7.51	12.51	0.31	0.49	37.22	22.45
Jun	7.42	12.64	0.31	0.50	37.30	22.54
Jul	6.51	12.57	0.29	0.54	37.64	21.66
Aug	6.23	12.35	0.28	0.55	37.64	21.60
Sep	6.43	12.05	0.29	0.53	36.99	21.41
Oct	9.05	11.74	0.37	0.37	34.83	22.84
Nov	8.90	11.48	0.37	0.37	32.01	22.01
Dec	9.30	11.36	0.38	0.34	30.53	20.20

2005

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	7.52	11.43	0.33	0.45	31.42	19.76
Feb	6.68	11.65	0.30	0.51	34.17	20.41
Mar	7.39	11.93	0.32	0.47	36.67	22.58
Apr	7.86	12.24	0.33	0.46	37.97	23.68
May	8.99	12.50	0.35	0.40	37.75	24.37
Jun	7.04	12.63	0.30	0.52	37.22	21.97
Jul	5.67	12.58	0.26	0.59	37.30	19.91
Aug	5.95	12.36	0.27	0.57	37.64	20.76
Sep	7.03	12.06	0.31	0.50	36.99	22.25
Oct	8.94	11.75	0.36	0.38	34.83	22.78
Nov	8.75	11.49	0.36	0.38	32.01	20.94
Dec	9.68	11.36	0.39	0.31	30.53	20.27

2006

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	9.16	11.43	0.38	0.35	31.42	20.74
Feb	8.62	11.65	0.36	0.39	34.17	22.22
Mar	7.83	11.93	0.33	0.45	36.67	23.05
Apr	7.62	12.24	0.32	0.47	37.97	23.42
May	7.40	12.50	0.31	0.49	37.75	22.84
Jun	7.84	12.63	0.32	0.47	37.22	22.93
Jul	7.56	12.58	0.31	0.49	37.30	22.70
Aug	5.95	12.36	0.27	0.57	37.64	20.76
Sep	6.83	12.06	0.30	0.51	36.99	21.98
Oct	8.44	11.75	0.35	0.41	34.83	22.48
Nov	10.00	11.49	0.40	0.30	32.02	21.28
Dec	9.28	11.36	0.38	0.34	30.53	20.53

2007

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	7.69	11.43	0.34	0.44	31.42	19.90
Feb	9.48	11.65	0.38	0.34	34.17	22.60
Mar	7.87	11.93	0.33	0.45	36.67	23.09
Apr	6.29	12.24	0.28	0.55	37.97	21.60
May	7.79	12.50	0.32	0.47	37.75	23.30
Jun	8.28	12.63	0.33	0.45	37.22	23.38
Jul	6.52	12.58	0.29	0.54	37.30	21.31
Aug	5.37	12.36	0.26	0.60	37.64	22.74
Sep	7.29	12.06	0.31	0.48	36.99	22.57
Oct	8.58	11.75	0.35	0.40	34.83	22.57
Nov	9.08	11.49	0.37	0.36	32.01	21.08
Dec	8.98	11.36	0.37	0.36	30.53	20.11

2008

Month	$\bar{S}$(hr)	$\bar{S}_o$(hr)	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	9.65	11.43	0.39	0.32	31.42	20.85
Feb	8.24	11.66	0.35	0.41	34.17	21.97
Mar	8.79	11.93	0.36	0.39	36.75	23.97
Apr	8.22	12.25	0.34	0.44	37.98	24.04
May	8.15	12.51	0.33	0.45	37.73	23.65
Jun	7.30	12.64	0.31	0.50	37.21	22.29
Jul	6.70	12.57	0.29	0.53	37.31	21.59
Aug	5.72	12.35	0.27	0.58	37.64	20.36
Sep	6.63	12.05	0.30	0.52	36.94	21.68
Oct	8.68	11.74	0.36	0.39	38.56	22.58
Nov	9.50	11.48	0.39	0.33	31.94	21.16
Dec	9.39	11.36	0.39	0.33	30.52	20.22

2009

Month	$\bar{S}$(hr)	$\bar{S}_o$(hr)	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.95	11.43	0.37	0.36	31.42	20.66
Feb	8.18	11.65	0.35	0.42	34.17	21.92
Mar	7.20	11.93	0.31	0.49	36.67	22.36
Apr	8.08	12.24	0.33	0.45	37.75	23.90
May	8.76	12.50	0.35	0.42	37.22	24.20
Jun	8.01	12.63	0.32	0.46	37.22	22.11
Jul	7.03	12.58	0.30	0.52	37.30	22.04
Aug	6.07	12.36	0.28	0.56	37.64	20.96
Sep	6.65	12.06	0.30	0.52	36.99	21.73
Oct	8.22	11.75	0.34	0.42	34.83	22.32
Nov	9.28	11.49	0.38	0.34	32.01	21.15
Dec	9.64	11.36	0.39	0.32	30.53	20.27

2010

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	10.11	11.43	0.40	029	31.42	20.89
Feb	9.82	11.65	0.39	0.32	34.17	22.68
Mar	6.33	11.93	0.29	0.54	36.67	21.18
Apr	7.23	12.24	0.31	0.49	37.97	22.95
May	7.67	12.50	0.32	0.48	37.75	23.16
Jun	7.67	12.63	0.31	0.48	37.30	22.83
Jul	5.88	12.58	0.27	0.58	37.30	20.28
Aug	5.89	12.36	0.27	0.57	37.64	20.65
Sep	5.93	12.06	0.28	0.56	36.99	20.62
Oct	7.42	11.75	0.32	0.47	34.83	21.60
Nov	9.08	11.49	0.37	0.36	32.01	21.08
Dec	9.71	11.36	0.39	0.31	30.53	20.28

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2000

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	7.76	11.51	0.34	0.43	32.12	20.34
Feb	8.68	11.70	0.36	0.39	34.69	22.54
Mar	6.63	11.95	0.30	0.52	36.92	21.74
Apr	8.50	12.22	0.35	0.42	37.89	24.22
May	8.03	12.44	0.33	0.45	37.42	23.37
Jun	7.04	12.55	0.30	0.51	36.77	21.75
Jul	5.91	12.49	0.27	0.57	36.90	20.17
Aug	5.63	12.30	0.27	0.58	37.44	20.13
Sep	5.66	12.04	0.27	0.58	37.10	20.21
Oct	8.11	11.78	0.34	0.42	35.25	22.46
Nov	9.18	11.55	0.38	0.35	32.66	21.50
Dec	8.31	11.45	0.36	0.40	31.28	20.21

2001

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.61	11.51	0.36	0.38	32.12	20.91
Feb	8.37	11.70	0.35	0.41	34.69	22.34
Mar	8.39	11.94	0.35	0.41	36.92	23.67
Apr	7.32	12.21	0.31	0.49	37.89	23.02
May	7.88	12.43	0.33	0.46	37.42	23.21
Jun	7.62	12.55	0.32	0.48	36.77	22.46
Jul	5.78	12.50	0.27	0.58	36.90	19.95
Aug	4.75	12.31	0.25	0.63	37.44	18.44
Sep	5.60	12.05	0.27	0.58	37.10	20.11
Oct	9.20	11.78	0.37	0.36	37.25	23.14
Nov	9.17	11.56	0.38	0.35	32.66	21.49
Dec	9.23	11.45	0.38	0.34	31.28	20.63

2002

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	6.55	11.51	0.30	0.51	32.12	19.11
Feb	8.76	11.70	0.36	0.38	34.69	22.58
Mar	7.62	11.94	0.33	0.46	36.92	22.96
Apr	7.98	12.21	0.33	0.45	37.89	23.75
May	7.76	12.43	0.32	0.47	37.42	23.09
Jun	7.41	12.55	0.31	0.49	36.77	22.21
Jul	6.54	12.50	0.29	0.54	36.90	21.16
Aug	5.59	12.31	0.27	0.59	37.44	20.05
Sep	6.69	12.05	0.30	0.52	37.10	21.85
Oct	8.24	11.78	0.35	0.42	35.25	22.56
Nov	9.10	11.56	0.38	0.36	32.66	21.47
Dec	9.01	11.45	0.38	0.36	31.28	20.55

2003

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.39	11.51	0.36	0.40	32.12	20.79
Feb	9.12	11.70	0.37	0.36	34.69	22.76
Mar	7.71	11.94	0.33	0.45	36.92	23.06
Apr	7.70	12.21	0.32	0.46	37.89	23.46
May	8.73	12.43	0.35	0.42	37.42	23.98
Jun	6.38	12.55	0.29	0.55	36.77	20.81
Jul	6.08	12.50	0.28	0.56	36.90	20.45
Aug	4.51	12.31	0.24	0.65	37.44	17.90
Sep	6.21	12.05	0.29	0.54	37.10	21.13
Oct	8.84	11.78	0.36	0.38	35.25	22.96
Nov	8.64	11.56	0.36	0.38	32.66	21.26
Dec	8.98	11.45	0.37	0.36	31.28	20.54

2004

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.42	11.51	0.36	0.39	32.12	20.80
Feb	7.03	11.71	0.31	0.49	34.69	21.10
Mar	5.74	11.95	0.28	0.57	37.98	20.37
Apr	6.94	12.22	0.30	0.51	37.89	22.53
May	7.57	12.44	0.32	0.48	37.39	22.85
Jun	6.68	12.55	0.29	0.53	36.76	21.25
Jul	5.31	12.49	0.26	0.61	36.90	19.10
Aug	5.09	12.30	0.25	0.62	37.44	19.10
Sep	5.65	12.04	0.27	0.58	37.10	20.20
Oct	9.06	11.78	0.37	0.37	35.25	23.07
Nov	8.83	11.55	0.37	0.37	32.66	21.35
Dec	8.18	11.45	0.35	0.41	31.28	20.13

2005

Month	$\bar{S}$(hr)	$\bar{S}_o$(hr)	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	6.26	11.51	0.28	0.53	32.12	18.75
Feb	6.76	11.70	0.31	0.50	34.69	20.77
Mar	7.27	11.94	0.32	0.48	36.92	22.56
Apr	7.76	12.21	0.33	0.46	37.89	23.53
May	8.43	12.43	0.34	0.43	37.42	23.74
Jun	6.62	12.55	0.29	0.54	36.77	21.17
Jul	4.92	12.50	0.25	0.63	36.90	18.34
Aug	4.98	12.31	0.25	0.62	37.44	18.88
Sep	6.61	12.05	0.30	0.52	37.10	21.73
Oct	8.13	11.78	0.34	0.42	35.25	22.48
Nov	8.54	11.56	0.36	0.39	32.64	21.20
Dec	8.97	11.45	0.37	0.36	31.28	20.54

2006

Month	$\bar{S}$(hr)	$\bar{S}_o$(hr)	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.52	11.51	0.36	0.39	32.12	20.86
Feb	8.96	11.70	0.37	0.37	34.69	22.69
Mar	7.49	11.94	0.32	0.47	36.92	22.82
Apr	8.22	12.21	0.34	0.44	37.89	23.98
May	7.19	12.43	0.31	0.50	37.42	22.41
Jun	7.51	12.55	0.31	0.49	36.77	22.30
Jul	6.51	12.50	0.29	0.54	36.90	21.12
Aug	5.71	12.31	0.27	0.58	37.44	20.27
Sep	5.27	12.05	0.26	0.60	37.10	19.50
Oct	8.32	11.78	0.35	0.41	35.25	22.62
Nov	8.88	11.56	0.37	0.37	32.66	21.38
Dec	8.42	11.45	0.36	0.39	31.28	20.28

2007

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	6.13	11.51	0.29	0.39	32.12	18.57
Feb	8.76	11.70	0.36	0.38	34.69	22.58
Mar	7.09	11.94	0.31	0.49	36.92	22.35
Apr	6.35	12.21	0.29	0.54	37.67	21.67
May	6.93	12.43	0.30	0.51	37.42	22.07
Jun	7.41	12.55	0.31	0.49	36.77	22.21
Jul	6.01	12.50	0.28	0.57	36.90	20.33
Aug	4.98	12.31	0.25	0.62	37.44	18.88
Sep	5.33	12.05	0.26	0.60	37.10	19.61
Oct	8.21	11.78	0.35	0.42	32.25	22.54
Nov	8.92	11.56	0.37	0.37	32.66	21.39
Dec	8.17	11.45	0.35	0.41	31.28	20.13

2008

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.98	11.51	0.37	0.36	31.12	21.08
Feb	6.46	11.71	0.30	0.52	34.69	20.32
Mar	7.98	11.95	0.34	0.44	36.92	23.32
Apr	7.63	12.22	0.32	0.47	37.89	23.39
May	8.19	12.44	0.33	0.45	37.39	23.50
Jun	6.77	12.55	0.30	0.53	36.77	21.38
Jul	6.33	12.49	0.28	0.55	36.90	20.84
Aug	4.73	12.30	0.25	0.64	37.44	18.37
Sep	5.35	12.04	0.26	0.59	37.10	19.65
Oct	8.20	11.78	0.35	0.42	35.25	22.53
Nov	8.76	11.55	0.37	0.38	32.66	21.32
Dec	8.28	11.45	0.35	0.40	31.28	20.20

2009

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.47	11.51	0.36	0.39	32.12	20.83
Feb	8.10	11.70	0.34	0.42	34.69	22.14
Mar	7.06	11.94	0.31	0.49	36.92	22.32
Apr	8.04	12.21	0.33	0.45	37.89	23.81
May	8.16	12.43	0.33	0.45	37.42	23.49
Jun	7.40	12.55	0.31	0.49	36.77	22.20
Jul	5.80	12.50	0.27	0.58	36.90	19.98
Aug	4.80	12.31	0.25	0.63	37.44	18.51
Sep	5.92	12.05	0.28	0.56	37.10	20.66
Oct	7.97	11.78	0.34	0.43	35.25	22.34
Nov	9.10	11.56	0.38	0.36	32.66	21.47
Dec	9.00	11.45	0.37	0.36	31.28	20.55

2010

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	9.70	11.51	0.39	0.32	32.12	21.28
Feb	9.50	11.70	0.38	0.34	34.69	22.90
Mar	5.82	11.94	0.28	0.56	36.92	20.48
Apr	6.62	12.21	0.30	0.53	37.89	20.08
May	7.42	12.43	0.31	0.49	37.42	22.70
Jun	6.93	12.55	0.30	0.52	36.77	21.60
Jul	5.23	12.50	0.26	0.61	36.90	18.95
Aug	5.27	12.31	0.26	0.61	37.44	19.56
Sep	6.29	12.05	0.29	0.54	37.10	22.16
Oct	7.31	11.78	0.32	0.47	35.25	21.70
Nov	8.77	11.56	0.37	0.38	32.66	21.32
Dec	9.45	11.45	0.39	0.33	31.28	20.68

WA

2000

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.65	11.47	0.36	0.38	31.87	20.76
Feb	9.59	11.68	0.38	0.33	34.56	22.85
Mar	7.58	11.93	0.32	0.46	36.88	22.90
Apr	8.11	12.22	0.33	0.44	37.93	23.90
May	7.91	12.46	0.32	0.46	37.54	23.31
Jun	7.67	12.58	0.32	0.48	36.96	22.61
Jul	6.62	12.53	0.29	0.54	37.09	21.37
Aug	6.36	12.32	0.29	0.54	37.54	21.40
Sep	5.61	12.05	0.27	0.58	37.02	20.08
Oct	7.55	11.77	0.33	0.46	34.98	21.81
Nov	9.24	11.53	0.38	0.35	32.31	21.30
Dec	8.60	11.41	0.36	0.38	30.94	20.18

2001

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	9.30	11.47	0.38	0.34	31.81	21.01
Feb	9.10	11.69	0.37	0.36	34.46	22.62
Mar	8.40	11.94	0.35	0.41	36.82	23.62
Apr	7.80	12.23	0.32	0.46	37.93	23.59
May	8.30	12.47	0.33	0.44	37.57	23.71
Jun	8.40	12.59	0.33	0.44	36.97	23.35
Jul	6.20	12.53	0.28	0.56	37.08	20.72
Aug	5.20	12.32	0.26	0.61	37.53	19.35
Sep	5.80	12.04	0.27	0.57	37.08	20.43
Oct	9.10	11.76	0.37	0.36	35.07	22.99
Nov	9.30	11.52	0.38	0.34	32.38	21.37
Dec	9.70	11.41	0.39	0.31	30.95	20.53

2002

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.40	11.47	0.35	0.39	31.81	20.62
Feb	9.20	11.69	0.37	0.36	34.46	22.67
Mar	7.70	11.94	0.33	0.45	36.82	22.99
Apr	7.30	12.23	0.31	0.49	37.93	23.02
May	8.60	12.47	0.34	0.42	37.57	23.97
Jun	7.50	12.59	0.31	0.49	36.97	22.42
Jul	7.00	12.53	0.30	0.51	37.08	21.89
Aug	5.50	12.32	0.26	0.59	37.53	19.92
Sep	6.50	12.04	0.29	0.53	37.06	21.55
Oct	8.30	11.76	0.35	0.41	35.07	22.51
Nov	9.50	11.52	0.38	0.33	32.38	21.42
Dec	9.40	11.41	0.38	0.33	30.95	20.48

2003

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.60	11.47	0.36	0.38	31.87	20.07
Feb	8.70	11.69	0.36	0.39	34.46	22.42
Mar	8.30	11.94	0.34	0.42	36.82	23.54
Apr	8.00	12.23	0.33	0.45	37.93	23.80
May	8.80	12.47	0.35	0.41	37.57	24.12
Jun	6.30	12.59	0.28	0.56	36.97	20.78
Jul	6.40	12.53	0.28	0.55	37.08	21.03
Aug	5.60	12.32	0.27	0.59	37.53	20.10
Sep	6.60	12.04	0.30	0.52	37.06	21.70
Oct	8.70	11.76	0.36	0.39	35.07	22.78
Nov	8.80	11.52	0.37	0.37	32.38	21.18
Dec	9.20	11.41	0.38	0.34	30.95	20.42

2004

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.90	11.47	0.37	0.36	31.81	20.87
Feb	7.60	11.68	0.33	0.45	34.46	21.58
Mar	6.50	11.93	0.30	0.52	36.88	21.53
Apr	7.60	12.22	0.32	0.47	37.93	23.37
May	7.80	12.46	0.32	0.47	37.54	23.19
Jun	7.20	12.58	0.30	0.51	36.96	22.05
Jul	5.50	12.53	0.26	0.60	37.09	19.53
Aug	5.60	12.32	0.27	0.59	37.54	20.11
Sep	6.50	12.05	0.29	0.53	37.02	21.53
Oct	8.80	11.77	0.36	0.38	34.98	22.79
Nov	8.40	11.53	0.35	0.40	32.31	20.91
Dec	8.40	11.41	0.36	0.39	30.94	20.08

2005

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	7.24	11.47	0.32	0.46	31.81	19.71
Feb	7.22	11.68	0.32	0.47	34.46	21.19
Mar	7.37	11.93	0.32	0.47	36.82	22.63
Apr	8.02	12.22	0.33	0.45	37.93	23.82
May	8.79	12.46	0.35	0.41	37.66	24.11
Jun	6.55	12.58	0.29	0.54	36.97	21.16
Jul	5.32	12.53	0.26	0.61	37.08	19.18
Aug	5.22	12.32	0.26	0.61	37.53	19.39
Sep	6.95	12.05	0.30	0.50	37.06	22.18
Oct	8.69	11.77	0.36	0.39	35.07	22.77
Nov	8.27	11.53	0.35	0.40	32.38	20.88
Dec	9.5	11.41	0.39	0.32	30.95	20.50

2006

Month	$\bar{S}(hr)$	$\bar{S}_o\,(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	9.32	11.47	0.38	0.34	31.81	21.02
Feb	8.99	11.68	0.37	0.37	34.40	22.58
Mar	7.59	11.93	0.32	0.46	36.82	22.88
Apr	8.07	12.22	0.33	0.44	37.93	23.86
May	7.45	12.46	0.31	0.49	37.54	22.79
Jun	7.41	12.58	0.31	0.49	36.96	22.31
Jul	6.99	12.53	0.30	0.52	31.36	19.20
Aug	6.12	12.32	0.28	0.56	37.54	21.01
Sep	6.61	12.05	0.30	0.52	37.02	21.69
Oct	8.66	11.77	0.36	0.39	34.98	22.70
Nov	9.72	11.53	0.39	0.32	32.31	21.42
Dec	9.14	11.41	0.38	0.35	30.94	20.40

2007

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	7.60	11.47	0.33	0.44	31.81	20.04
Feb	9.42	11.68	0.38	0.34	34.46	22.74
Mar	8.16	11.93	0.34	0.43	36.82	23.42
Apr	6.84	12.22	0.30	0.51	37.93	22.41
May	7.53	12.46	0.31	0.58	37.57	22.90
Jun	7.78	12.58	0.32	0.47	36.97	22.74
Jul	6.40	12.53	0.28	0.55	37.08	21.03
Aug	5.10	12.32	0.25	0.62	37.53	19.15
Sep	6.73	12.05	0.30	0.52	37.06	21.88
Oct	8.61	11.77	0.36	0.39	35.07	22.72
Nov	9.19	11.53	0.38	0.35	32.38	21.34
Dec	9.02	11.41	0.37	0.35	30.95	20.37

2008

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	9.51	11.47	0.39	0.33	31.81	21.06
Feb	8.27	11.69	0.35	0.41	34.46	22.15
Mar	8.72	11.94	0.36	0.40	36.88	23.89
Apr	8.29	12.23	0.34	0.43	37.93	24.07
May	8.20	12.47	0.33	0.45	37.54	23.60
Jun	7.44	12.59	0.31	0.49	36.96	22.34
Jul	6.69	12.53	0.29	0.53	37.08	21.46
Aug	5.12	12.32	0.25	0.61	37.54	19.20
Sep	6.21	12.04	0.29	0.54	37.02	21.09
Oct	8.78	11.76	0.36	0.38	34.98	22.75
Nov	9.19	11.52	0.38	0.35	32.38	21.34
Dec	8.77	11.41	0.37	0.37	30.94	20.26

2009

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	9.29	11.47	0.38	0.34	31.81	21.01
Feb	8.38	11.68	0.35	0.41	34.46	22.22
Mar	7.47	11.93	0.32	0.47	36.82	22.75
Apr	8.63	12.22	0.35	0.41	37.93	24.35
Ma	8.15	12.46	0.33	0.45	37.57	23.57
Jun	8.03	12.58	0.33	0.46	36.97	23.00
Jul	6.70	12.53	0.29	0.53	37.08	21.48
Aug	4.30	12.32	0.23	0.66	37.53	17.47
Sep	5.77	12.05	0.27	0.57	37.06	20.38
Oct	7.71	11.77	0.33	0.38	35.07	22.01
Nov	8.73	11.53	0.36	0.38	32.38	21.14
Dec	8.90	11.41	0.37	0.36	30.95	20.32

2010

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	9.85	11.47	0.40	0.30	31.81	21.12
Feb	9.47	11.68	0.38	0.34	34.46	22.76
Mar	6.46	11.93	0.29	0.53	36.82	21.45
Apr	7.46	12.22	0.32	0.48	37.93	23.21
May	8.05	12.46	0.33	0.45	37.57	23.47
Jun	7.63	12.58	0.32	0.48	36.97	22.57
Jul	6.30	12.53	0.28	0.55	37.08	20.87
Aug	5.44	12.32	0.26	0.60	37.53	19.81
Sep	5.24	12.05	0.26	0.60	37.06	19.41
Oct	7.29	11.77	0.32	0.47	35.07	21.58
Nov	9.02	11.53	0.37	0.36	32.38	21.27
Dec	8.90	11.41	0.37	0.36	30.95	20.32

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2000

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	7.54	11.50	0.33	0.45	32.11	20.15
Feb	8.34	11.71	0.35	0.41	34.68	22.31
Mar	6.11	11.95	0.28	0.55	36.92	20.96
Apr	8.30	12.22	0.34	0.43	37.89	24.05
May	8.40	12.44	0.34	0.43	37.40	23.69
Jun	7.42	12.55	0.31	0.49	36.77	22.22
Jul	6.11	12.50	0.28	0.56	36.92	20.51
Aug	6.01	12.30	0.28	0.56	37.45	20.80
Sep	5.91	12.04	0.28	0.56	37.06	20.63
Oct	8.36	11.77	0.35	0.41	35.16	22.60
Nov	9.33	11.55	0.38	0.34	32.58	21.49
Dec	8.18	11.45	0.35	0.41	31.25	20.12

2001

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.44	11.50	0.36	0.39	32.25	20.81
Feb	8.43	11.70	0.35	0.40	34.68	22.37
Mar	8.00	11.94	0.34	0.44	36.92	23.33
Apr	7.57	12.21	0.32	0.47	37.42	23.72
May	8.41	12.43	0.34	0.43	36.78	23.25
Jun	7.82	12.55	0.32	0.47	36.78	22.68
Jul	6.20	12.50	0.19	0.76	36.91	20.64
Aug	5.96	12.31	0.16	0.82	37.44	20.70
Sep	6.25	12.05	0.29	0.54	37.10	21.20
Oct	8.94	11.78	0.36	0.38	35.24	23.01
Nov	9.55	11.56	0.39	0.33	32.65	21.60
De	9.5	11.45	0.39	0.32	31.26	20.69

2002

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	7.13	11.50	0.32	0.47	32.11	19.76
Feb	9.00	11.70	0.37	0.37	34.68	22.70
Mar	7.62	11.94	0.33	0.46	36.92	22.96
Apr	8.10	12.21	0.34	0.44	37.89	23.87
May	8.45	12.43	0.34	0.43	37.42	23.76
Jun	7.57	12.55	0.32	0.48	36.78	22.40
Jul	6.28	12.50	0.28	0.55	36.91	20.77
Aug	5.91	12.31	0.28	0.55	37.44	20.62
Sep	6.33	12.05	0.29	0.54	37.10	21.32
Oct	7.91	11.78	0.34	0.44	35.24	22.29
Nov	9.26	11.56	0.38	0.35	32.65	21.52
Dec	8.96	11.45	0.37	0.36	31.26	20.45

2003

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.86	11.50	0.37	0.37	32.11	21.02
Feb	9.02	11.70	0.37	0.37	34.68	22.71
Mar	7.94	11.94	0.34	0.44	36.92	23.28
Apr	8.09	12.21	0.33	0.44	37.89	23.86
May	9.36	12.43	0.36	0.38	37.42	24.39
Jun	7.35	12.55	0.31	0.50	36.78	22.14
Jul	6.02	12.50	0.28	0.57	36.91	20.35
Aug	4.82	12.31	0.25	0.63	37.44	18.56
Sep	5.84	12.05	0.28	0.57	37.10	20.53
Oct	9.35	11.78	0.38	0.35	35.24	23.19
Nov	8.91	11.56	0.37	0.37	32.65	21.38
Dec	9.16	11.45	0.38	0.35	31.26	20.60

2004

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.68	11.50	0.36	0.38	32.11	20.94
Feb	7.87	11.71	0.34	0.44	34.68	21.94
Mar	7.46	11.95	0.32	0.47	36.92	22.79
Apr	7.05	12.22	0.31	0.50	37.89	22.68
May	8.09	12.44	0.33	0.45	37.40	23.41
Jun	6.81	12.55	0.30	0.53	36.77	21.44
Jul	5.81	12.50	0.27	0.58	36.92	20.01
Aug	5.32	12.30	0.26	0.60	37.45	19.57
Sep	6.10	12.04	0.28	0.55	37.06	20.94
Oct	7.64	11.77	0.33	0.45	35.16	21.99
Nov	9.19	11.55	0.38	0.35	38.58	21.45
Dec	8.73	11.45	0.37	0.37	31.25	20.42

2005

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	6.64	11.50	0.31	0.50	32.11	19.22
Feb	7.67	11.70	0.33	0.45	34.68	21.76
Mar	7.20	11.94	0.32	0.48	36.92	22.49
Apr	7.88	12.21	0.33	0.45	37.89	23.65
May	8.70	12.43	0.35	0.42	37.42	23.96
Jun	7.64	12.55	0.32	0.48	36.77	22.51
Jul	5.62	12.50	0.27	0.59	36.91	19.67
Aug	4.87	12.31	0.25	0.63	37.44	18.66
Sep	6.51	12.05	0.30	0.53	37.10	21.59
Oct	8.19	11.78	0.35	0.42	35.24	22.52
Nov	9.37	11.56	0.38	0.34	32.65	21.55
Dec	9.57	11.45	0.39	0.32	31.26	20.70

2006

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.44	11.50	0.36	0.39	31.26	20.81
Feb	8.87	11.70	0.37	0.38	39.12	22.64
Mar	8.13	11.94	0.34	0.43	36.92	23.45
Apr	8.85	12.21	0.35	0.40	37.89	24.48
May	7.77	12.43	0.32	0.47	37.42	23.10
Jun	7.71	12.55	0.32	0.48	36.42	23.03
Jul	6.57	12.50	0.29	0.54	36.78	20.10
Aug	5.42	12.31	0.26	0.60	36.91	19.31
Sep	5.66	12.05	0.27	0.58	37.44	20.18
Oct	8.54	11.78	0.35	0.40	37.10	23.84
Nov	9.26	11.56	0.38	0.35	32.65	21.52
Dec	8.49	11.45	0.36	0.39	31.26	20.31

2007

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	6.84	11.50	0.31	0.49	32.11	19.45
Feb	8.83	11.70	0.36	0.38	32.11	21.01
Mar	7.62	11.94	0.33	0.46	34.68	21.72
Apr	7.43	12.21	0.32	0.48	36.92	22.75
May	7.49	12.43	0.32	0.48	37.89	23.23
Jun	7.66	12.55	0.32	0.48	37.42	22.98
Jul	5.56	12.50	0.26	0.59	36.91	19.56
Aug	4.83	12.31	0.25	0.63	37.44	18.58
Sep	5.62	12.05	0.27	0.58	37.10	20.14
Oct	8.21	11.78	0.35	0.42	35.24	22.54
Nov	9.16	11.56	0.38	0.35	38.92	25.58
Dec	8.33	11.45	0.36	0.40	31.26	20.22

2008

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	a	b	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	9.12	11.50	0.38	0.35	32.11	21.13
Feb	6.99	11.71	0.31	0.49	34.68	21.04
Mar	8.66	11.95	0.35	0.40	36.98	23.90
Apr	8.02	12.22	0.33	0.45	37.89	23.79
May	8.28	12.44	0.34	0.44	37.42	23.61
Jun	7.12	12.55	0.30	0.51	36.78	21.86
Jul	6.13	12.50	0.28	0.56	36.91	20.53
Aug	4.99	12.30	0.25	0.62	37.44	18.91
Sep	5.17	12.04	0.26	0.60	37.10	19.30
Oct	8.22	11.77	0.35	0.42	35.24	22.54
Nov	9.03	11.55	0.37	0.36	32.65	21.43
Dec	8.46	11.45	0.36	0.39	31.26	20.29

2009

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	8.95	11.50	0.37	0.36	32.11	21.06
Feb	8.80	11.70	0.36	0.38	34.68	22.60
Mar	8.04	11.94	0.34	0.44	36.92	23.37
Apr	8.11	12.21	0.34	0.44	37.89	23.88
May	8.43	12.43	0.34	0.44	37.42	23.74
Jun	7.98	12.55	0.33	0.46	36.78	22.84
Jul	6.15	12.50	0.28	0.56	36.91	20.56
Aug	4.70	12.31	0.24	0.64	37.44	18.31
Sep	6.16	12.05	0.29	0.55	37.10	21.05
Oct	8.05	11.78	0.34	0.43	35.24	22.41
Nov	9.42	11.56	0.38	0.34	32.65	21.56
Dec	9.47	11.45	0.39	0.33	31.26	20.68

2010

Month	$\bar{S}(hr)$	$\bar{S}_o(hr)$	*a*	*b*	$\bar{H}_o(MJm^{-2}day^{-1})$	$\bar{H}(MJm^{-2}day^{-1})$
Jan	9.80	11.50	0.40	0.31	32.11	21.29
Feb	9.57	11.70	0.39	0.33	34.68	22.91
Mar	6.51	11.94	0.30	0.52	36.92	21.56
Apr	7.39	12.21	0.32	0.48	37.89	23.11
May	7.93	12.43	0.33	0.46	37.42	23.27
Jun	7.19	12.55	0.31	0.50	36.78	21.95
Jul	5.38	12.50	0.26	0.60	36.91	19.23
Aug	4.61	12.31	0.24	0.64	37.44	18.11
Sep	5.09	12.05	0.26	0.61	37.10	19.15
Oct	7.80	11.78	0.33	0.44	35.24	22.19
Nov	8.35	11.56	0.35	0.40	32.65	21.08
Dec	8.75	11.45	0.37	0.37	31.26	20.44

APPENDIX II: Mat Lab program for estimating monthly mean of daily global solar radiation ($\bar{H}$) for the Selected Stations.

```
%solar radiation estimation in ghana
Gsc=1367;%extraterrestrial solar radiation in W/m/m.
S=input('what is the sunshine hour in hrs');
lamda=input('what is the latitude in degrees');
N=input('what is the day number');
%
%
delta=23.45*sind(360*(284+N)/365);
%
%
Gon=Gsc*(1+(0.033*cosd(360*N/365)));
%
%
A=sind(lamda)*sind(delta);
%
%
Hss=acosd(-tand(delta)*tand(lamda));
%
%
B=cosd(lamda)*cosd(delta);
%
%
So=(2/15)*acosd(-tand(delta)*tand(lamda));
%
%
a=-0.110+(0.235*cosd(lamda))+(0.323*(S/So));
%
%
b=1.449-(0.553*cosd(lamda))-(0.694*(S/So));
%
%
Go=(24*3600/pi)*Gon*(A*((2*pi/360)*Hss)+(B*sind(Hss)));
%
%
G=Go*(a+(b*S/So));
```

APPENDIX III: Mat Lab program for estimating monthly mean of daily global solar radiation ($\bar{H}_1$) for the Selected Stations.

```
%solar radiation estimation in ghana
Gsc=1367;%extraterrestrial solar radiation in W/m/m.
S=input('what is the sunshine hour in hrs');
lamda=input('what is the latitude in degrees');
N=input('what is the day number');
%
%
delta=23.45*sind(360*(284+N)/365);
%
%
Gon=Gsc*(1+(0.033*cosd(360*N/365)));
%
%
A=sind(lamda)*sind(delta);
%
%
Hss=acosd(-tand(delta)*tand(lamda));
%
%
B=cosd(lamda)*cosd(delta);
%
%
So=(2/15)*acosd(-tand(delta)*tand(lamda));
%
%
a=0.27;
%
%
b=0.45;
%
%
Go=(24*3600/pi)*Gon*(A*((2*pi/360)*Hss)+(B*sind(Hss)));
%
%
G=Go*(a+(b*S/So));
```