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On the use of sunshine duration to estimate global solar radiation in Hebron city, Palestine

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Dedication

This thesis is dedicated to the sake of Allah, my Creator and my Master, and to my great Messenger, Mohammed (peace be upon him), to my homeland Palestine and to the martyrs.

This thesis is also dedicated to my father who has been a constant source of support and encouragement, and to my mother, brothers, sisters, and to everyone who taught and tutored me.

My special gratitude goes to all professors at Al –Quds University in general, and especially, the Department of Physics. Besides, to someone who gave me a dose of hope, to my friends and all the people in my life who touch my heart.

Declaration

I hereby declare that this thesis is based on the result found by my Supervisor and myself. Materials of works found by other researchers are mentioned by references. This thesis, neither in whole nor in part, has been previously submitted for any degree. The work was done under the supervision of Dr. Husain Alsamamra at Al – Quds University – Palestine.

Signed: …………………..

Momeneh Suliman Hasan Dawabsheh

Date: ..8/10/2016………

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Abstract

An accurate knowledge of solar radiation distribution at a particular geographical location is of vital importance for the development of many solar energy devices. In this study, global solar radiation received on horizontal surfaces and sunshine duration for Hebron city, Palestine for the period of 2011-2014 were analyzed and tabulated. A set of constants for Angstrom-type correlation were obtained to establish the regression model capable of generating solar radiation at any given location in the region of study. Moreover, Four sunshine-based models of linear, exponential, logarithmic and quadratic to estimate monthly average global solar radiation has also been obtained employing sunshine hour's data in the period of study. In general, the Four sunshine-based models performed well in terms of their coefficient of determination with R^2 = 98.8% given by the linear model, for the exponential model, R^2 =96.5%, for the logarithmic model, R^2 = 93.2%, while the quadratic model, R^2=98.7. The linear model provides the best estimation in winter months while the quadratic model more suitable in summer months. The calculated global solar radiation is in good agreement with the four sunshine based models. In order to test for the performance of statistical significance of the models, mean absolute percentage error (MAPE), root mean square error (RMSE), the results shows that despite overestimation and underestimation of the models, there are fairly good level of significance. The results of the coefficient of determination indicate that the calculated clearness index and relative sunshine duration shows excellent data.

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Chapter One

Introduction

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Just as the fossil fuel based energy industry relies on exploration and proven reserves for discovery and economic support of energy markets, the renewable energy sector depends upon the assessment of resources for planning and selling their energy production technology. For solar-based renewable energy technologies such as solar thermal or photovoltaic conversion systems, the basic resource or fuel available is solar radiation [9]. Solar energy can be considered as the most abundant continuing source of energy available to the human species. While solar energy is not being used as a primary source of fuel energy at the present time, a large research and development effort is underway to develop economical systems to harness solar energy and make it a major source of fuel energy. As a result of technological development, the world need for more energy. Therefore, the energy sources are diverse according to technological progress. Renewable energy is the main source of the world in the future because of the decrease of fossil fuels and price increases. A prerequisite to the design of solar collector systems is the availability of solar irradiance data at the required location. It would be cost effective for solar collector system when the utility load and solar resource profiles are well matched.Solar power can be used in both large-scale applications and in smaller systems for the home. Businesses and industry can diversify their energy sources, improve efficiency, and save money by choosing solar technologies for heating and cooling, industrial processes, electricity, and water heating. Homeowners can also use solar technologies for heating and cooling and water heating, and may even be able to produce enough electricity by photovoltaic solar cells and concentrated solar power.There are many natural sources of energy on the planet, including the natural terrestrial radioactivity and the geothermal heat flux from the interior to the surface of the Earth but these sources relatively unimportant compared with solar radiation. Solar energy emitted by sun rays are considered the most effective and usable, energy of sunshine supports all aspects of life on Earth through photosynthesis. The sun is emitting electromagnetic radiation on a wide range of wavelengths.

However, most of the radiation is being sent out in the visible spectrum due to its surface temperature. As an object gets hotter, the peak radiation will come from shorter wavelengths, and vice-versa. Energy transmitted from the sun to the earth in the form of electromagnetic radiation similar to radio waves, but differs in the frequency band. Available solar energy is often expressed in units of energy per time per unit area, such as watts per square meter (W/m2).The amount of energy available from the sun outside the Earth's atmosphere about $1367.7\, w/m^2$ and this is called the solar constant but this amount does not fully reach the ground because part of it is absorbed when passing from the earth's atmosphere. As a result, theamount of solar energy reaching the earth on a clear day is estimated at about $1000\, w/m^2$. Theavailable solar energy isprimarily dependent upon how high the sun is inthe sky andWeather conditions (clouds, snow, ...), and location.Also the amount of energy that is emitted by the Sun, and therefore, the amount of solar energy falling on the earth, is critically dependent upon this surface temperature.This means a change 1% of the temperature of the sun can result in a change of 4% in the amount of energy per unit area that the world receives. This is what told us Stefan-Boltzmann’s Law.When solar radiation passes through the atmosphere, it exposed to absorption or scattering by atmospheric components, and therefore, the amount of solar radiation that reaches to the ground in the end depends on the concentration of pollutants and particles and the concentration of water in the air and sky, which can further attenuate the solar energy and change the diffuse and direct radiation ratio. In the earth’s atmosphere, solar radiation is received directly (direct radiation which have not been scattered) and by diffusion in air, dust, water, etc., contained in the atmosphere (diffuse radiation which results from scattering caused by gases in the Earth’s atmosphere). Global radiation is the sum of the reflected radiation, direct irradiation and the diffuse solar radiation on any plane. Values of global and diffuse radiations for individual hours are essential for research and engineering applications.

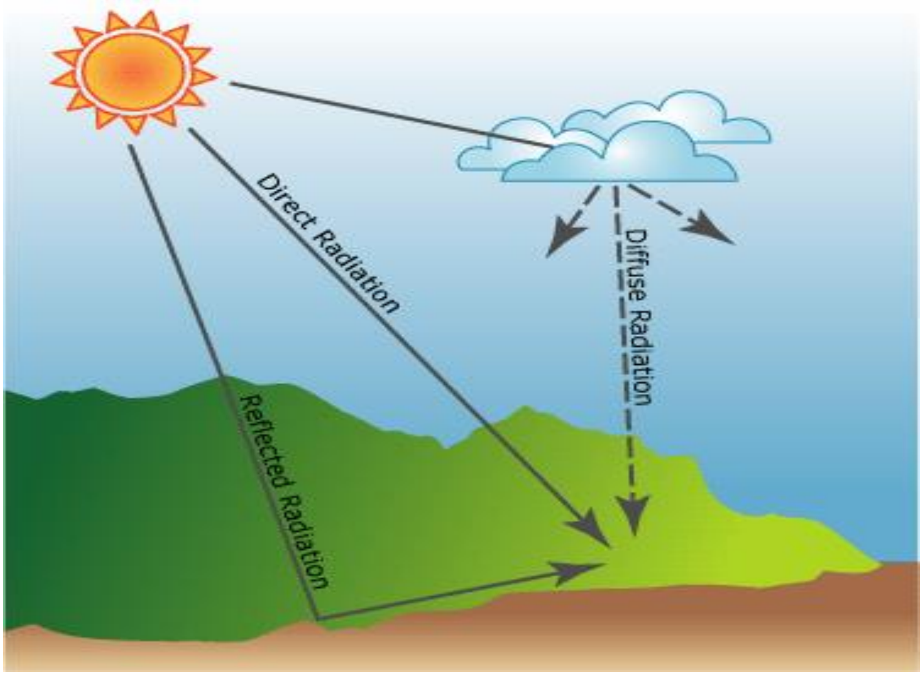


Figure 1.1 Direct, diffuse and reflected solar radiation[6].

1.2 Literature Survey

Systematic long-term data measurements are regarded as the most effective and accurate method of setting up the solar irradiance database. In many parts of the world, however, the basic solar irradiance data for the surfaces of interest are not always readily obtainable. Conventionally, different mathematical models have been developed in the literature to predict the solar irradiance on various inclined-surfaces using horizontal data [20-17]. For places where measured data are not obtainable, generating the required solar radiance data from conversion solar-radiance models would also be an appropriate solution [34]. Research takes advantages of the knowledge which has been accumulated in the past as a result of constant human endeavor. In this section i will talk about literature survey for the estimation of Solar Radiation.

1.2.1 Previous Studies

Sekar et al. (2012) in the estimation of global solar radiation for Chennai, Quadratic equation gives a better result than linear equation and the derived correlation is expected to estimate monthly average global solar radiation for Chennai location. The result and correlation may then be used for location with similar meteorological and geographical characteristics at which solar data are not available [26].

Abdel-Ghany and Al-Helal (2010) reveals that beams radiation transmitted through a net can be divided into diffused beams added to the transmitted diffuse radiation, some beam reflected and another unscattered beam, which passes directly through the pores. From 2% to 20% of the beam was diffused, from 11% to 52% was reflected forward and from 29% to 83% was unscattered. Based on the net parameters [1].

Robaa (2009) Said there is a difference in the global radiation that reaches to the urban and rural areas, where the rural areas receive a larger amount. The global radiation rise very regularly from minimum value (mainlyDecember) to maximum value (mainly June) at the urban and rural areas. The global radiation loss in the atmosphere of the urban area is always higher than that for the rural area [25].

Solanki and Sangani (2008) suggest a new method called elevation angle constant method for the estimation of direct normal solar radiation for any location in the world. The elevation angle constant method is based on empirical relations. And calculates the elevation angle constant for given location and time [28].
Shetaee (2007) radiation methods based on cloud fraction are good estimators for prediction of solar radiation energy in arid and semi-arid regions. They suggested height-depended model estimates the direct and diffuse monthly mean radiation with mean MPE error of less than 3% [27].

Francisco Meza and Eduardo Vavas (2000) using Empirical models to estimate global solar radiation area convenient tool if the parameters can be calibrated for different locations. These models have the advantage of using meteorological data which are commonly available. The models proposed by Allen and Bristow-Campbell are adequate and allow estimates of mean average global solar radiation as a function of airtemperature variation .

The results from Parishwad*et al*. (1998) study can be used to estimate solar radiation for any locations in India, as the places selected for evaluation of constraints and prediction thereof are fairly distributed over the whole of India[23].

Aksoy (1996)Said a quadratic relationship between solar insolation and duration of solar radiation data, in order to estimate monthly average global irradiance for Ankara, Antalya, Samsun, Konya, Urfa and Izmir. A general quadratic formula was found that represents the whole of Turkey[3].

Ulgen and Hepbasli (2008) establish a relationship between the monthly average daily diffuse fraction and the monthly average daily diffuse coefficient with the monthly average daily clearness index and monthly-average daily sunshine fraction by used solar radiation data for Ankara, Istanbul and Izmir of Turkey.

Ulgen and Hepbasli (2001) showed the monthly-average global and diffuse solar radiation data. As a result, the value of the monthly-average global radiation varied from 5964 kJ/m^2 in December to 27.154kJ/m^2 in June. The values of the monthly-average daily clearness index ranged from 0.45 to 0.66 .

Ulgen and Hepbasli (2002) establish a relationship between the daily diffuse fraction and the daily clearness index for Izmir, Turkey by used hourly global and diffuse radiation measurements over a 5 year period [33].

Ulgen and Hepbasli (2004) reviewed solar radiation models for Turkey in general and some of its provinces. 41 models used to estimate the monthly average daily global solar radiation on a horizontal surface were categorized in four groups namely; linear models, polynomial or quadratic models, angular models, and modified Angstrom-type models [32].

Gunes (2001) examined the variation of monthly-average daily global solar radiation in 11 stations located in 9 cities in Turkey[13].

Kaygusuz and Ayhan (1997) made analysis of measured solar data in the form of hourly-average solar irradiation, monthly-average daily global solar radiation and percentage frequency distribution in Trabzon[15].

Bakirci (2006) Measured data taken from Turkish State Meteorological Service for four years. And presented a third-order equation for the calculation of the monthly-average daily global solar radiation for Erzurum, Turkey (lat. 39°5 ’N, long. 41°16’E, alt. 1869 m) .

KadirBakirci (2009) correlation models giving the best results can be reliably used to estimate monthly average daily global solar radiation in the Provinces of Turkey and in elsewhere with similar climatic conditions [7].

Ogulata (2001) calculated the monthly-average daily and hourly global, diffuse and direct radiations on a horizontal surface in Adana, Turkey (lat. ~37°00’N, long. ~35°20’E, alt. ~20 m). They concluded that the maximum monthly average daily global radiation was recorded as 18.51 MJ/m²day in July. Diffuse radiation values range from 9.1 MJ/m²day in July to 2.8 MJ/m²day in January [21].

Tarhan and Sari (2004) A quadratic polynomial equation was empirically developed to predict the monthly average daily global radiation. By analyzed global and diffuse solar radiation in 5 cities in theCenter for Bibliographical Studies and Research(CBSR) [29].

Aras et al. (2005) developed 12 new models for estimating monthly average daily diffuse solar radiation on a horizontal surface in the Central Anatolia Region CAR and the diffuse solar radiation models in the literature were analyzed in detail. In conclusion, the provinces in the CAR have almost the same diffuse solar radiation values[5].

Aras et al. (2006) developed empirical models to predict the monthly-average daily global solar radiation over twelve provinces in the (CAR) of Turkey .

Jiang (2008) used nine diffuse radiation models for the daily data between January 1, 1994 and December 31, 1998 from 16 stations all over China. Validation of 9 models for predicting monthly mean daily diffuse solar radiation has been performed by using the statistical errors MPE, MBE and RMSE[14].

Che et al. (2010) used forty years of daily global and diffuse radiation data to characterize the atmospheric conditions at 14 stations in China[8].

Angstrom proposed first theoretical model for estimating global solar radiation based on sunshine duration. Page and Prescott reconsidered this model in order to make it possible to calculate monthly average of the daily global solar radiation on a horizontal surface from monthly average daily total insolation on an extraterrestrial horizontal surface.

Diez-Mediavilla, et al. (2004) made an analysis of 10 arithmetic models used to calculate diffuse solar irradiance on inclined surfaces in Valladolid, Spain. The actual data readings were taken hourly and daily basis from the 1st of August, 1998 until the 15th of March, 2000. Three statistical methods have been used to confirm the results[11].

Akpabio et al. (2004) presented a quadratic form of the Angstrom-Prescott model to estimate global solar radiation at Onne (lat. 4°46′N, long. 7°10′E), a tropical location[2].

KewinWan *et al*. (2008) believe that modeled Global Solar Radiation data from the 2-Parameter regression models could be used for building energy simulation where measured Global Solar Radiation is not available.

Mubiru and Banda (2008) developed an artificial neural network model that could be used to estimate monthly average daily global solar radiation on a horizontal surface for locations in Uganda and others with similar climate and terrain[19].

1.3 Solar Radiation in Palestine

The West Bank and Gaza Strip who usually called the Palestinian Territories (PT) are located at the geographic latitude of approximately 30° N, where the annual incident solar irradiance is about 2000 kWh $/m^2$. Palestinians, like other developing country people need a lot of energy for achievement of sustainable development. Nevertheless, many obstacles are facing them, namely; political, economical, social, and environmental problems. Palestinian people import all of its needs of petroleum from the Israeli market and also about 92% of electrical energy from the Israeli Electrical Corporation. The production of renewable energy contributes only 1.9% of the total energy during the year 2009. In fact, Palestine is blessed with huge amounts of renewable energy resources, particularly solar and wind energies. The current tendency in Palestine is to use in future various solar energy applications in the overall mix of energy in Palestine, as well as identifying potential areas for utilizing future technologies and recommending future courses of action to encourage the commercial utilization of solar energy technologies.The Palestinian Authority (PA) has no economic domestic supplies of primary energy, except for some solar and biomass energy, supplying 9percent of total energy needs. The lack of available energy contributes to relatively high prices for all forms of energy. As a result, the Palestinian Authority uses relatively small amounts of energy per capita.

A number of barriers exist to improving the energy sector, including, among others:

- The unit price of energy is high.
- Energy resources are either dwindling or non-existent.
- Lack of accurate data needed for any planning program.
- Supply of conventional energy (electricity and petroleum products) is monopolized by the Israeli authority. This creates unrealistic price control, energy shortage and future energy crisis.
- Shortage of financing for energy-projects.
- Lack of capability to evaluate and prioritize new distribution line projects and to assess the potential to reduce demand or slow its growth through, for example, solar applications in the industrial sector.

The climate of Palestine for the greater part of the year is pleasant. Winter lasts for three months, from mid-December to mid-March, and can be severe, during the remainder of the year. Palestine receives an average of seven hours of sunshine a day during the winter and thirteen hours during the summer. The average annual relative humidity is 60% and reaches its highest rates during the months of January and February. In May, however, humidity levels are at their lowest. Night dew may occur in up to 180 days per year.Palestine is located within the solar belt countries and considered as one of the highest solar potential energy, the climate conditions of the Palestinian Territories are predominantly very sunny with an average solar radiation on a horizontal surface about 5.4 kWh/m^2.day, and the lowest solar energy average is in January it amounts to 2.47 kWh/m^2.day, and the highest one is in June, it amounts to 6.93 kWh/m^2-day.The measured values in the different areas show that the annual average insulation values are about 5.24 kWh/m^2.day, 5.63 kWh/m^2.day, 5.38 kWh/m^2.day in the coastal area, hilly area and Jordan valley respectively, Hassan et. al. Annual monthly averages solar radiation amounts in the three climatic zones are shown in figure:

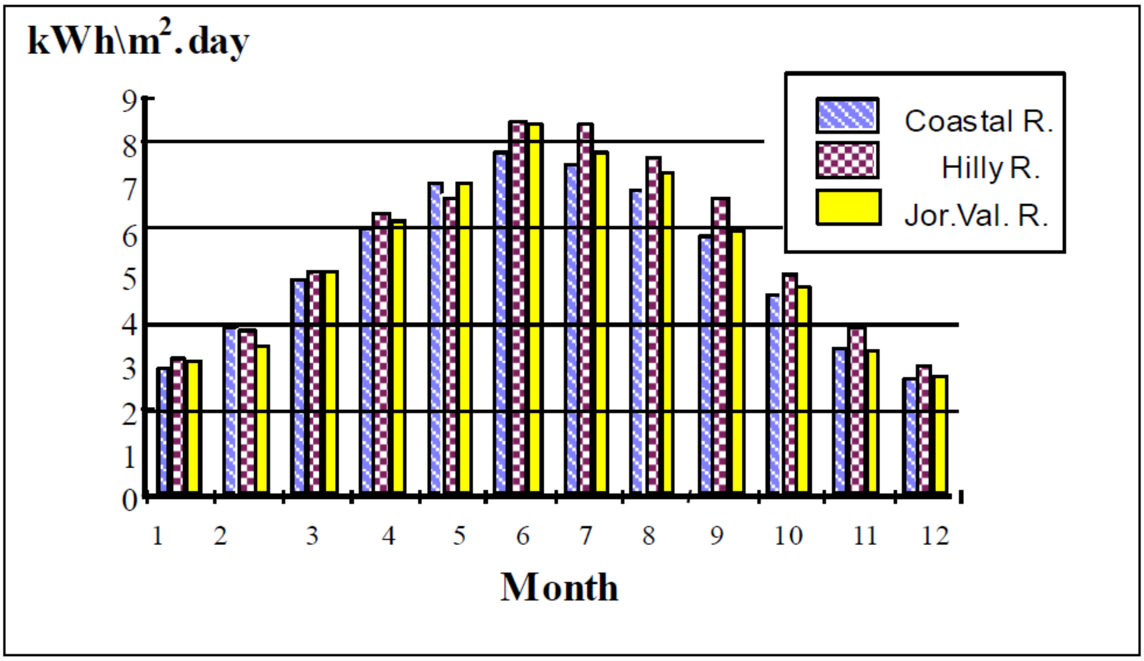


Figure 1.2 Annual monthly average variation in solar radiation in the three climate Zones of the Palestinian Territories .

1.4 Statement of the problem

In the present work, I will use Angstrom empirical model and its modified versions namely linear, Exponential, Logarithmic, and Quadratic models. To estimate global solar radiation in Hebron city, Palestine. As Hebron is located at latitude of 31°57' N, it would be useful to determine the solar-irradiance data on a horizontal surface with a tilt angle of 31°57' facing south. The calculation of global radiation energy was numerically simplified. Hourly values were calculated for the mean day. Daily values were obtained as a sum of hourly energies. The annual global radiation energy was calculated with the sum of energy over four years. All the calculations were preformed in Matlab, which is optimized for working with matrices and it is relatively easy to program, other software like origin will be used to graph the results.The thesis will be conduct as the following; in chapter two I will discuss the methodology whereas chapter three will contain the results and its discussion and in chapter four I will conclude my work.

Chapter Two

Methodology

CHAPTER TWO

METHODOLOGY

2.1 Introduction

The most convenient and widely used correlation for predicting solar radiation was developed by Angstrom. Angstrom [4] proposed the first theoretical model for estimating global solar radiation based on sunshine duration. Page [22] and Prescott [24] reconsidered this model in order to make it possible to calculate monthly average of daily global radiation $\bar{H}$ (MJ/m^2 day) on a horizontal surface from monthly average daily total insolation on an extraterrestrial horizontal surface. The methodology used in this study consists of data gathering, description of model and the utilization and implementation of MATLAB. In this chapter, the study area and database used in this work are first introduced. Then, a brief description of the models used to estimate global solar radiation is presented and finally adscription of the statistical evaluation of the models will be given.

2.2 Study area and dataset

The area of the study is the region of Hebron city,Hebron is a Palestinian city located in the southern West Bank, 30 km south of Jerusalem. It lies more than 900 meters above sea level. It is the largest city in the West Bank. Hebron long benefited from its mountainous climate.

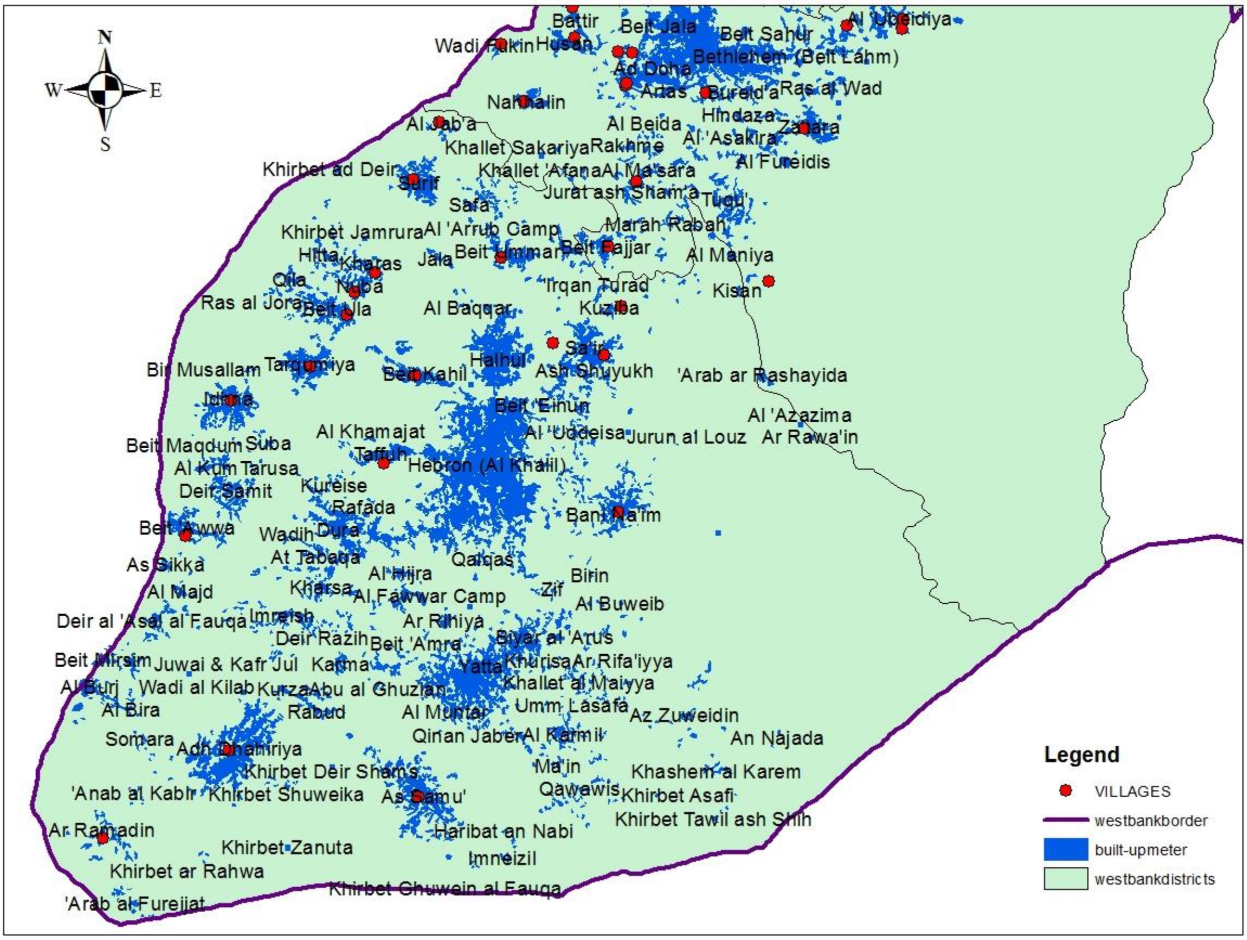


Figure 2.1. Map showing the location of the study area.

The Geographical coordinates of Hebron city are between longitude 35° 06' 00" E and latitude 31° 32' 00" N.Hebron is characterized in moderately climate, and the temperature in summer months rate of 21°C, while the rate drops to 7°C winters, and the annual rate of rain up to 580 mm, as the Hebron climate is the same as the Mediterranean basin, where temperatures drop in winter affected by depressions that coming from Cyprus and Europe. Generally they heat rates in winter range from between 5-9°C and vary depending on the height of the region. So the climate conditions are cold winter and mild summer with relative humidity of 51– 83%.

Therefore, the study area presents a challenge due to the wide range of climatic characteristics, topographic variability and the lake of climatic data.The global solar radiation data and sunshine duration data employed in this work gathered by Kipp and Zonen pyranometer (instrumental error of about 5%) and were supplied by the Palestinian meteorological office. A radiometric station was established at the Hebron city (900 m above sea level). The measurements are carried out in a continuous manner since January 2011 to December 2014, being recorded at a 10 minute interval, data for other periods were checked but unfortunately there were big gaps encountered. Data collection started before sunrise and finished after sunset and all measurements were referred to true solar-time.

2.3 Solar Radiation Estimation

Several empirical models for calculating solar radiation have been suggested in literature. Some of these models use variables like sunshine hours, air temperature, relative humidity, and cloudiness factor. Solar radiation can be easily estimated from sunshine duration; the Angstrom-Prescott models are sunshine-based and have widely applied to estimate global solar radiation. However, sunshine and cloud observations are data that are not available at most of the meteorological stations [35]. In this context, global solar radiation estimation models based on sunshine duration provides more accurate results. Modeling global radiation can be divided into two groups: The first group called prognostic or physical modeling based on the astrophysical properties of the Earth, atmospheric physics and geometry of location for which global radiation needs to be estimated. The second group is called statistical modeling, includes those models which are based on statistical data or data obtained from satellite observations.

Empirical models which have been used to calculate solar radiation are usually based on the following factors [12]:

(1) Astronomical factors (solar constant,earth-sun distance,solar declination and hour angle).

(2) Geographical factors(latitude, longitude and elevation of the site).

(3) Geometrical factors(azimuth angle of the surface, tilt angle of the surface, sun elevation angle, sun azimuth angle).

(4) Physical factors(scattering of air molecules ,water vapor content, scattering of dust and other atmospheric constituents such as O_2, N_2, CO_2, O, etc.).

(5) Meteorological factors(extraterrestrial solar radiation, sunshine duration, temperature, precipitation, relative humidity, effects of cloudiness, soil temperature, evaporation, reflection of the environs,etc.).

In this work we will use Angstrom-type models that depends on the sunshine duration to estimate global solar radiation in Hebron city.

2.3.1 *Estimation of Global Solar Radiation Using Angstrom - Type Models*

Angstrom [4] proposed the first theoretical model for estimating global solar radiation based on sunshine duration. Page [22] and Prescott [24] reconsidered this model in order to make it possible to calculate monthly average of the daily global radiation (MJ/m^2day) on a horizontal surface from monthly average daily total insolation on an extraterrestrial horizontal surface as per the following relation:

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) \qquad (1)$$

where $H$is the monthly average global radiation on horizontal surface, $S$is the monthly average daily bright sunshine hours, $S_0$is the maximum possible monthly average daily sunshine hours

or the day length, $a$and $b$are constants, and $H_0$is the monthly average daily extraterrestrial radiation (MJ/m^2day) [16].

$$H_0 = \frac{24}{\pi} I_{sc}\left[1 + 0.33cos\left(\frac{360D_n}{365}\right)\right]$$

$$\times\left[\cos L \cos\delta\ sinw_s + \frac{2\pi w_s}{360}\sin L \sin\delta\right], \qquad (2)$$

Where w_s is sunset hour angle in degree and defined as:

$$w_s = cos^{-1}\left(-tan\varphi \tan\delta\right) \qquad (3)$$

Where φ is latitude angle of the site.

The value of 1367 W/m^2 has been recommended for the solar constant I_{sc}. L is the latitude of location under consideration; D_n is the day of the year starting from January 1 to December 31 and δ is the declination angle as given below [10]:

$$\delta = 23.45\, sin\left[\frac{360(284 + D_n)}{365}\right]. \qquad (4)$$

For a given month, the maximum possible sunshine duration (monthly average day length (S_0) which is related to W_s, the mean sunrise hour angle can be computed by using the following equation (5) [10].

$$S_0 = \frac{2}{15} w_s \qquad (5)$$

Then, the monthly mean of daily global solar radiation H was normalized by dividing with monthly mean of daily extraterrestrial radiation H_0. We can define clearness index K_T as the ratio of the observed/measured horizontal terrestrial solar radiation, to the calculated/predicted horizontal/extraterrestrial solar radiation [30].

$$K_T = \frac{H}{H_0} \qquad (6)$$

In this study, H_0 and S_0 were computed for each month by using Equations (2) and (5), respectively.

The regression coefficient aand bin equation (1)has been calculated from the relationship given by Tiwari *et al*, 1997,[31].

$$a = -0.110 + 0.235cos\varphi + 0.323\left(\frac{S}{S_0}\right) \qquad (7)$$

$$b = 1.449 - 0.553cos\varphi - 0.694\left(\frac{S}{S_0}\right) \qquad (8)$$

To compute the estimated values of the monthly average daily global solar radiation, the values of a and bcalculated from equation (7) and (8) were substituted in Equation (1).

2.3.2 Estimation of Global Solar Radiation Using Higher Order Correlations

Page [22] pointed out that linear-type equation based on climatologically means cannot necessarily be expected to be applicable extreme values for a particular day, as it overestimates the total radiation on cloudless days, that is, when $\frac{S}{S_0}$ =1 and on overcast days that is, when $\frac{S}{S_0}$ =0. And quadratic form for the relationship between daily global/extraterrestrial radiation and actual/maximum possible hours of sunshine greater than zero was employed as [18]:

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + c\left(\frac{S}{S_0}\right)^2 \quad (9)$$

Higher order correlations (higher than quadratic) also have the same property as quadratic correlations. In general, a higher order correlation is written as:

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + c\left(\frac{S}{S_0}\right)^2 + d\left(\frac{S}{S_0}\right)^3 \quad (10)$$

where $a$to $d$are regression coefficients.

Table 2.1. Regression models used in this study

Model No.	Model Type	Regression equation	Source
1	**Linear**	$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right)$	Angstrom and Prescott
2	**Exponential**	$\frac{H}{H_0} = a + bexp\left(\frac{S}{S_0}\right)$	Akinoglu and Ecevit
3	**Logarithmic**	$\frac{H}{H_0} = a + blog\left(\frac{S}{S_0}\right)$	Almorox and Hontoria
4	**Quadratic**	$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + c\left(\frac{S}{S_0}\right)^2$	Bakirci

.

2.4 Statistical Criterion:

Most of the technology used (e.g. Excel, graphing calculators, Matlab) can be used to find regression curves and a variable monitoring the validity of the model, the coefficient of determination usually denoted by R^2. This coefficient takes values in interval [0,1] and indicates how close the data points are to be exactly on the regression curve. If R^2 is close to 1, the model is reliable. If R^2 is close to 0, other model should be considered. Also, the correlation coefficient (R^2) was used to measure the relation between measured and estimated global solar radiation.Following Isaaks and Srivastava (1989), two different scores were used: the Mean Absolute Error (MAPE) and the Root Mean Square Error (RMSE), computed as follows:MAPE indicates the extent to which the process leads to error. The RMSE is mainly a joint measure of bias in the mean and in the variance as obviously the square of individual differences between estimated and observed values put the emphasis on the errors in outliers or higher differences (Ashraf et al., 1997; Nalder and Wein, 1998). The combination of MAPE and RMSE errors give the possibility to analyze if the errors in the estimates are only due to bias in the mean values (i.e. MAPE≈RMSE) or if there is also a contribution of the errors in the variability or in stronger values (i.e. RMSE>MAPE).

Chapter Three

Results & Discussion

CHAPTER THREE

RESULTS& DISCUSSION

3.1 Introduction

In this chapter, we will discuss the estimated values of global solar radiation obtained by the models used in this study as well as the regression parameters of Angstrom and its modified models. The assessment criterion results will also be discussed.

3.2 Discussion the measured and estimated monthly global solar radiation

Table 3.1 presents the measured values of the monthly average of daily global solar radiation (MJ/m^2), the extraterrestrial solar radiation (H_0), the average values of the actual sunshine hours (S), and finally the average values of the maximum possible sunshine hours (S_0) for each month. By comparing the measured values with the extraterrestrial radiation, the lowest values were obtained in winter months (December, 11.34MJ/m^2day) while the maximum values in summer months; the measured value in June (30.24MJ/m^2day) while the extraterrestrial value in July (38.46MJ/m^2day).

Table 3.1: Input parameters of monthly mean average of global solar radiation.

Month	**Measured** (MJ/m^2day)	**H_0** (MJ/m^2day)	**S (hr)**	**S_0(hr)**
JAN	12.22	18.32	6.35	8.44
FEB	15.25	21.63	7.4	8.96
MAR	19.54	24.74	7.8	9.14
APR	24.49	29.84	9.91	11.45
MAY	28.22	34.66	10.12	11.94
JUN	30.24	36.93	11.62	12.86
JUL	29.76	38.46	11.82	13.25
AUG	27.35	35.41	11.22	12.95
SEP	23.68	28.13	9.97	11.57
OCT	18.49	25.54	8.35	10.53
NOV	13.99	22.37	6.15	8.34
DEC	11.34	19.34	5.94	8.16

The actual and calculated values of sunshine hours are consist with the values of global solar radiation. However, the maximum values of actual sunshine duration obtained in summer months (July, 11.82 hr) while the minimum values in winter months (December, 5.94hr).

Figure 3.1 presents the distribution of the measured monthly values of global solar radiation during the period of study, while figure 3.2 presents the monthly average values of the actual sunshine hours.

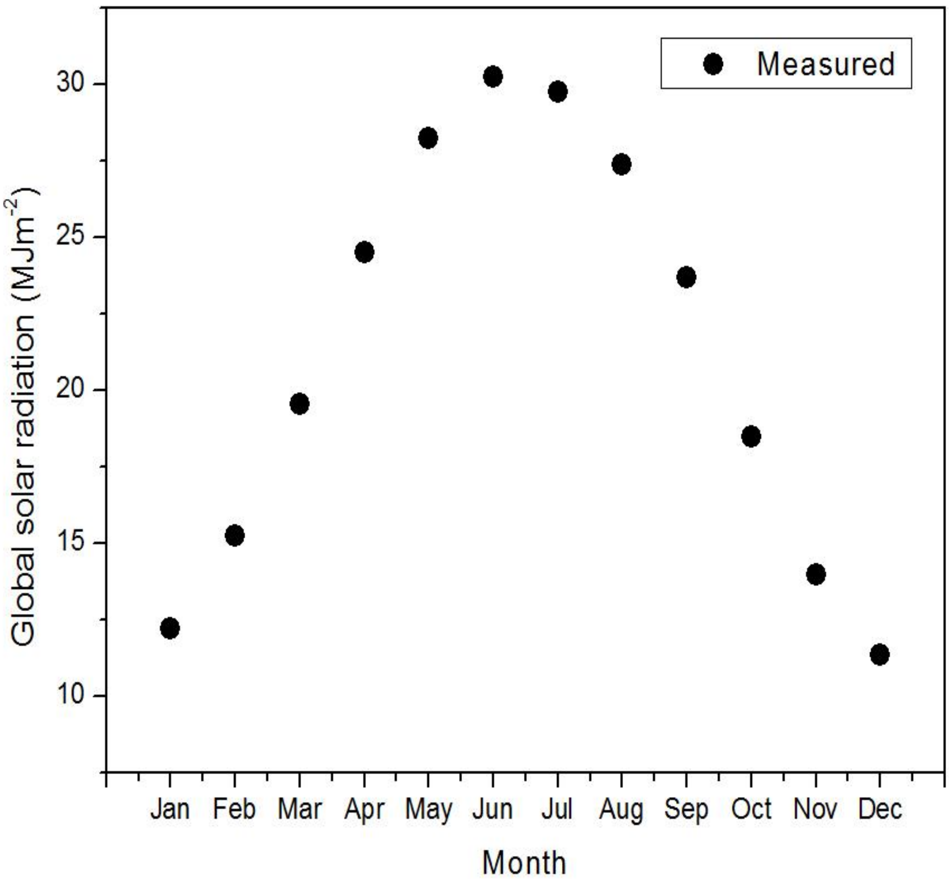


Figure 3.1. The monthly average values of global solar radiation (MJ/m^2) during the period of study.

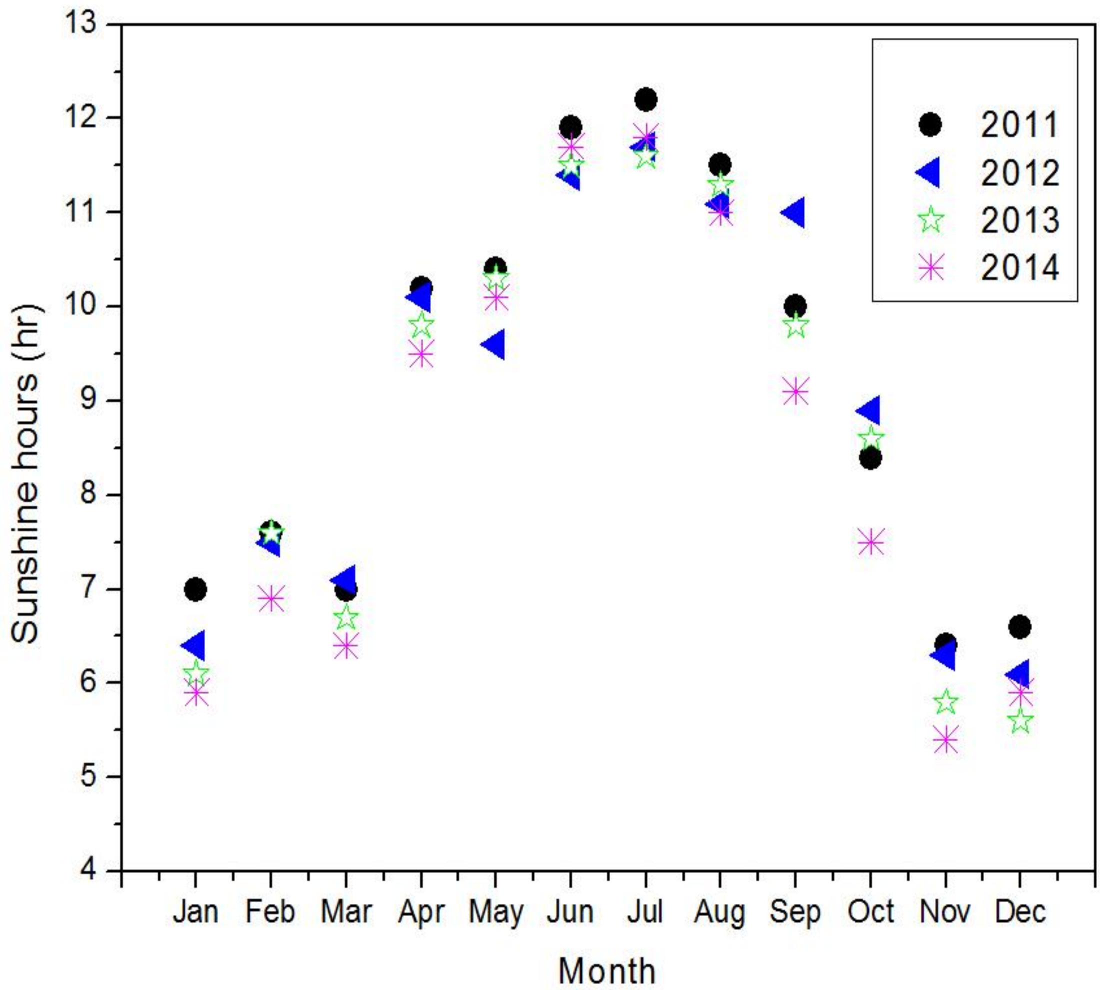


Figure 3.2. The monthly average values of sunshine duration (hr) for each year in the period of study.

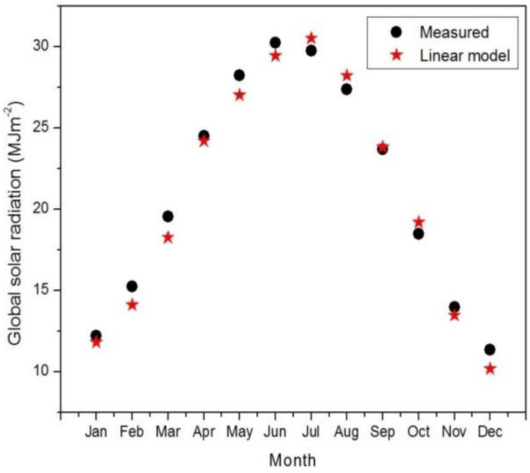
The average numbers of hours of sunshine duration were obtained from daily measurements covering a period of study. From table 3.1, the overall average clear index (S/S_0) was computed and substituted into equation 2.6 and 2.7 to obtain the values of the regression coefficients *a* and *b*. The values of *a* and *b* were substituted into the equations in table 2.1 which gives the estimated values of global solar radiation for each model as shown in Table 3.2.

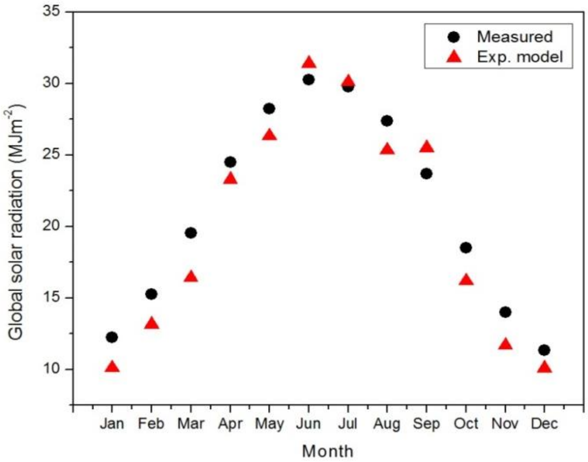
Table3. 2:Comparison between measured and estimated monthly global solar radiation (MJ/m^2)

Month	**Measured** (MJ/m^2day)	**Models**			
		Linear (MJ/m^2day)	**Exponential**(MJ/m^2day)	**Logarithmic** (MJ/m^2day)	**Quadratic** (MJ/m^2day)
JAN	12.22	11.82	10.12	10.19	11.13
FEB	15.25	14.11	13.14	13.21	15.23
MAR	19.54	18.26	16.4	17.29	19.12
APR	24.49	24.18	23.29	23.21	25.11
MAY	28.22	27.01	26.34	26.13	28.34
JUN	30.24	29.44	31.39	31.32	30.48
JUL	29.76	30.52	30.11	28.96	29.25
AUG	27.35	28.23	25.33	29.04	28.13
SEP	23.68	23.82	25.49	25.22	22.37
OCT	18.49	19.2	16.19	16.19	17.3
NOV	13.99	13.48	11.69	14.82	12.77
DEC	11.34	10.19	10.09	13.2	12.17

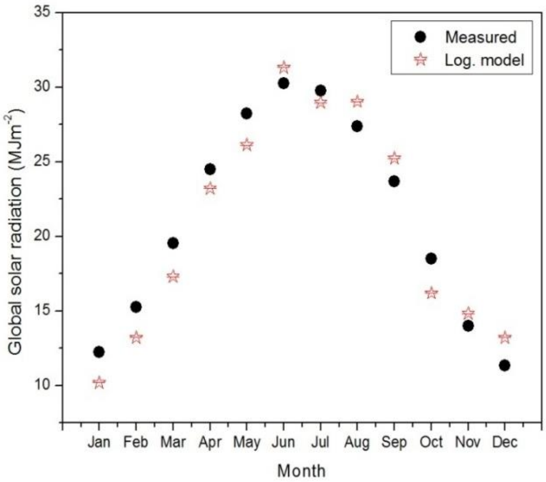
The results of the models that estimate the global solar radiation from sunshine duration on the monthly basis are presented in table 3.2. The analysis of the measured and calculated values of global solar radiation shows that the maximum value is observed in June for the exponential, logarithmic and quadratic models while the linear model presents the maximum value in July month. All models present the minimum values in winter months, the linear and exponential models obtained the minimum value in December while the logarithmic and quadratic models obtained that value in January. The four models present an overestimation of global solar radiation values in summer months (June-August) except the linear model presents an underestimation for all months. However, the logarithmic and quadratic models overestimate the values in December.

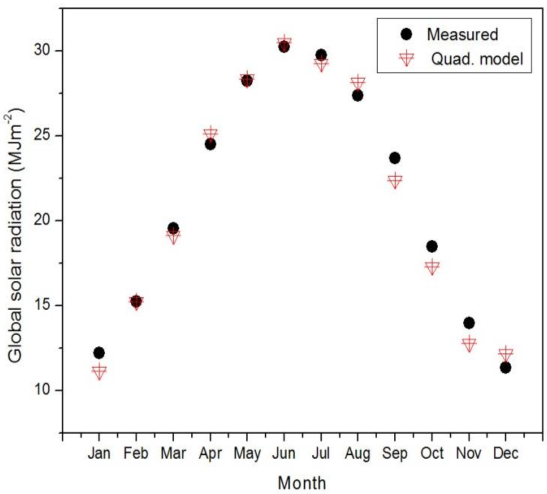
Figure 3.3 present a comparison of the measured and the estimated values of global solar radiation for each model. As mentioned before, the estimated values obtained by the models are close to the actual measured value of global solar radiation as appears in figure 3.3 and table 3.2.





(a) (b)





(b) (d)

Figure 3.3Comparison between the measured and the calculated values of the monthly average global solar radiation using the four different regression models.

The over estimation and under estimation of the global solar radiation values obtained by the models used appear clearly in the figure above, the linear model appears to be better than the others. In order to compare all the estimated values obtained by the models with the measure global solar radiation, figure 3.4 presents this comparison; the linear model provides better estimates in winter months while the quadratic model providers better estimates in summer months.

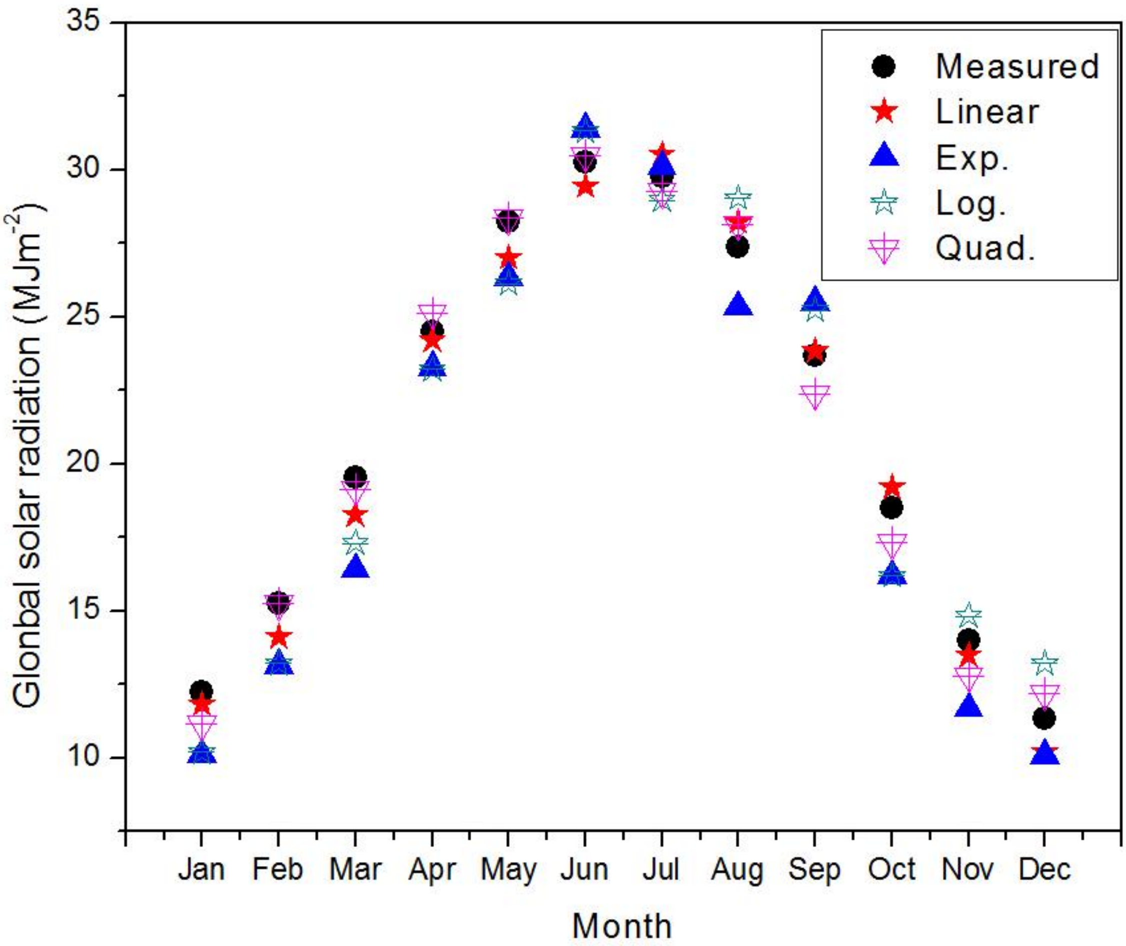


Figure 3.4. The estimated global solar radiation by four models versus the observed values.

In order to validate the estimated values of global solar radiation, the coefficient of determination

R^2, RMSE and MAPE were used. Table 3.3 provides the values of RMSE and MAPE for all models.

All used regression models showed a good degree of accuracy as global solar radiation estimators. The residual analysis showed that the residuals for the developed models are scattered randomly around zero, which indicates a good fit. Approximately All developed regression models produced permissible values of coefficient of determination. It is preferred to have the statistics like MAPE, and RMSE as small as possible.

Table 3.3. RMSE and MAPE values for all models.

Month	**RMSE (** MJ / m^2)				**MAPE (**MJ / m^2)			
	Linear	**Exponential**	**Logarithmic**	**Quadratic**	**Linear**	**Exponential**	**Logarithmic**	**Quadratic**
JAN	0.74	0.75	0.76	0.71	0.25	0.91	1.33	0.52
FEB	0.80	0.81	0.85	0.84	0.82	0.74	0.99	0.73
MAR	0.81	0.82	0.83	0.85	1.56	2.12	1.97	2.05
APR	0.70	0.72	0.68	0.70	1.66	1.76	1.44	1.56
MAY	0.91	0.92	0.91	0.92	0.77	0.94	1.73	0.70
JUN	1.02	0.98	1.12	1.01	1.03	0.97	0.69	0.99
JUL	1.03	1.12	1.10	1.10	1.60	1.12	0.98	1.11
AUG	0.95	0.96	0.90	0.94	1.33	1.45	1.11	1.17
SEP	0.77	0.78	0.81	0.77	1.11	1.08	1.15	1.00
OCT	0.79	0.81	0.82	0.80	0.96	0.91	1.09	1.15
NOV	0.64	0.68	0.67	0.69	1.27	1.08	1.29	1.20
DEC	0.54	0.58	0.61	0.57	1.25	1.41	1.29	1.13

To clarify the statistical results, RMSE and MAPE are graphed in figures 3.5 and 3.6 respectively for each model as seen below. The higher values of RMSE as seen in figure 3.5 were observed in summer months due to the over estimation of the estimated values while a lower values observed in winter months. In general, the linear model provides lower errors than the other models.

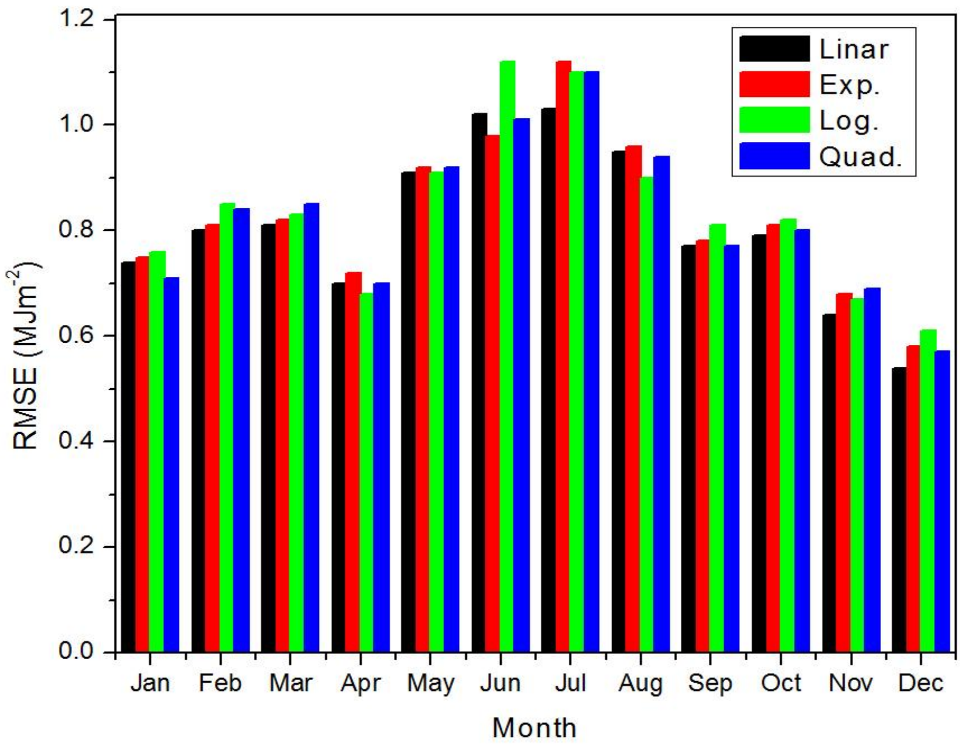


Figure 3.5. RMSE values for all models.

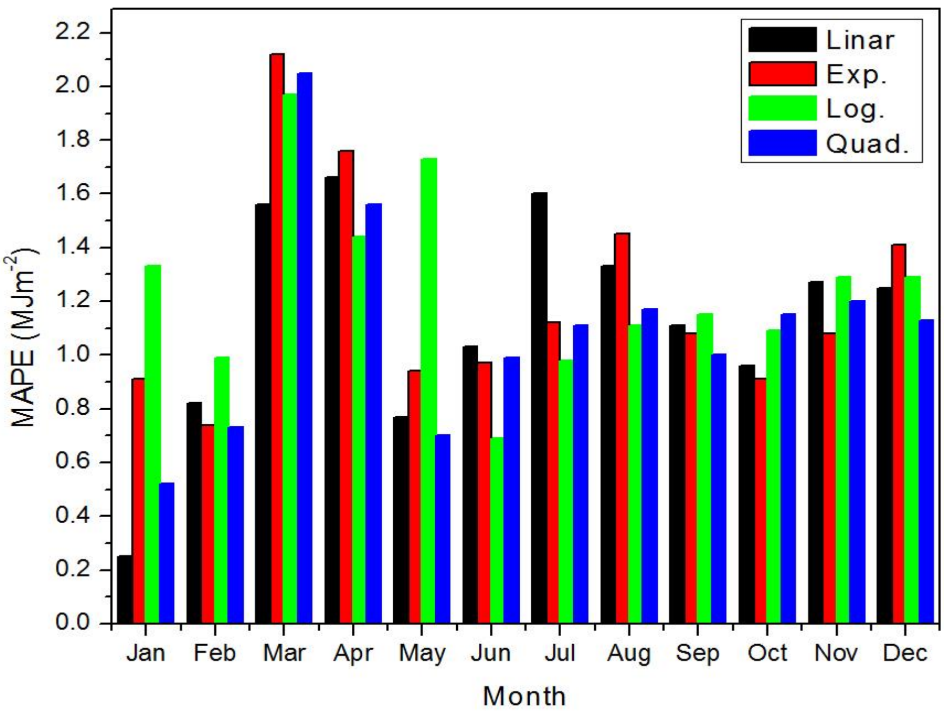


Figure 3.6. MAPE values for all models.

The higher values were observed in spring months for all models while the lower values were obtained in summer and winter months. The higher values of MAPE for the linear model due to its under estimation of the maximum values of global solar radiation. Overall, the quadratic model better than the other models from MAPE basis.The coefficient of determination and the regression coefficients are reported in table 3.4. The linear and quadratic models provide very close values 0.988 and 0.987 respectively, this results agree with values obtained by RMSE.

Table 3.4. Coefficient of determination and regression models coefficients.

Model Type	R^2	a	b	c
Linear	0.988	0.4612	0.3442	
Exponential	0.965	0.4836	0.4722	
Logarithmic	0.932	0.7462	0.1953	
Quadratic	0.987	0.4782	0.2457	0.0521

The lowest value of the coefficient of determination was found to be 93.2% and the highest values of MAPE and RMSE for the logarithmic model. The liner model offered the best estimate with the coefficient of determination value 98.8%. The logarithmic and exponential regression equations gave good and almost similar results.For the linear model, the quality of the estimate is a slightly worse for the months of the Jun and July when the RMSE is between 1.02 and 1.03.For the quadratic model,the quality of estimation is also improved in the months of November and December with an RMSE of 0.69 and 0.57, respectively.The regression based on the logarithmic and exponential models, the quality of the estimate is a slightly worse for the months of the Jun and July when the RMSE is between 1.12 and 1.10, respectively for logarithmic model, and between 0.98 and 1.12, respectively for exponential model.The estimated values obtained from the linear model were correlated with the measured values, giving a correlation coefficient R^2 of 0.988, as shown in figure 3.7. The corresponding MAPE average was 1.134 MJ / m^2 and the RMSE average was 0.808 MJ / m^2.

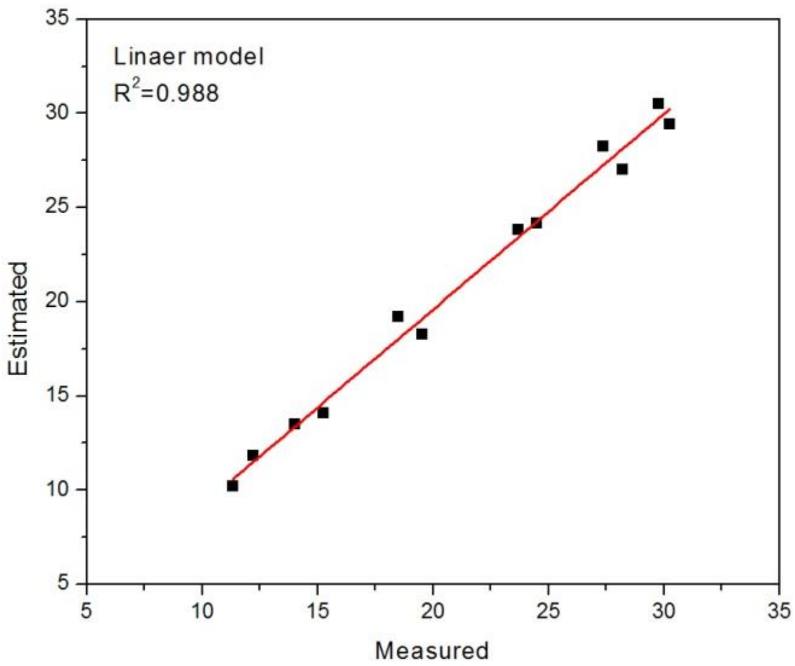


Figure 3.7. Correlation between measured and calculated global solar radiation values using linear model.

The estimated values obtained from the exponential model were correlated with the measured values, giving a correlation coefficient R^2 of 0.965, as shown in figure 3.8. The corresponding MAPE average was 1.2075 MJ / m^2 and the RMSE average was 0.827 MJ / m^2.

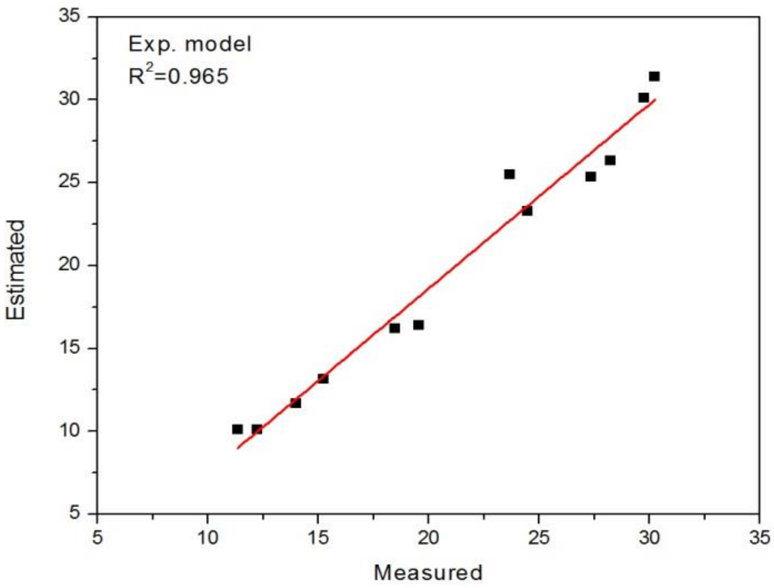


Figure 3.8 Correlation between measured and calculated global solar radiation values using exponential model.

The estimated values obtained from the logarithmic model were correlated with the measured values, giving a correlation coefficient R^2 of 0.932, as shown in figure 3.9. The corresponding MAPE average was 1.255 MJ / m^2 and the RMSE average was 0.838 MJ / m^2.

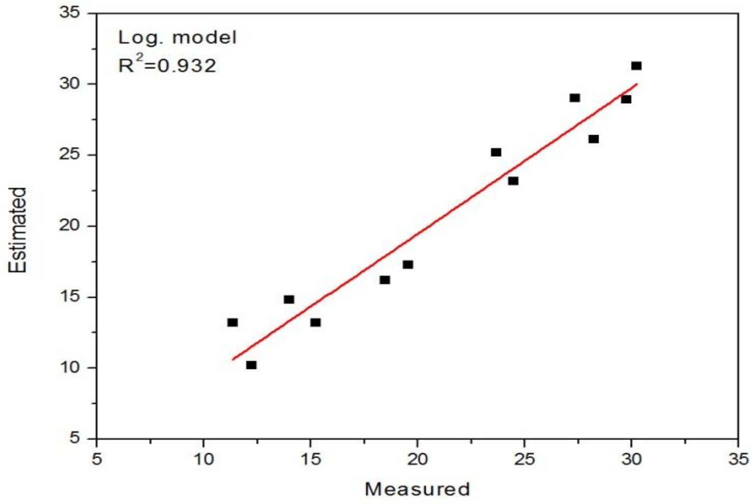


Figure 3.9. Correlation between measured and calculated global solar radiation values using logarithmic model.

The estimated values obtained from the quadratic model were correlated with the measured values, giving a correlation coefficient R^2 of 0.987 , as shown in figure 3.10. The corresponding MAPE average was 1.109 MJ / m^2 and the RMSE average was 0.825 MJ / m^2.

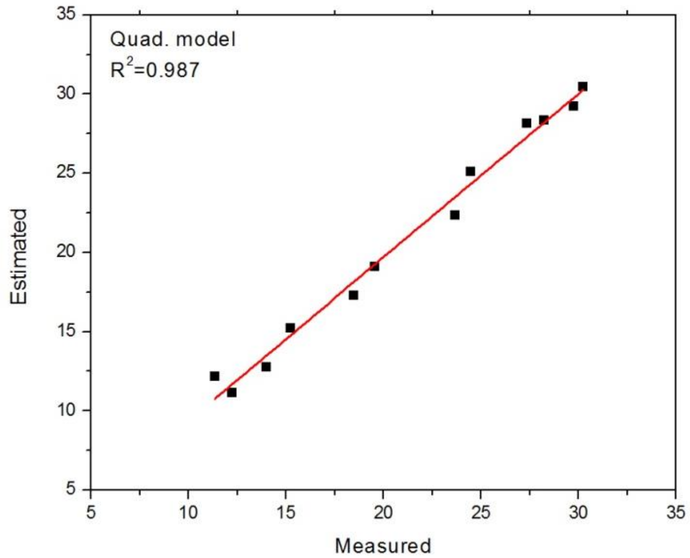


Figure 3.10. Correlation between measured and calculated global solar radiation values using quadratic model.

To Summaries, Angstrom model and the modified versions of this model were used to estimate the global solar radiation in Hebron city, Palestine. It was found that the linear and quadratic models provide better estimates than the exponential and logarithmic models. Overall, the assessment criteria showed that the linear model estimated the winter values of global solar radiation with a good accuracy while the quadratic model provides better estimates in summer values of global solar radiation.

Chapter Four

Conclusions & Future work

CHAPTER FOUR

CONCLUSIONS & FUTURE WORK

4.1 Conclusions and Future work

All human cultures require the production and use of energy that is, resources with the capacity to produce work or power. Energy is used for transportation, heating, cooling, cooking, lighting, and industrial production. In fact, energy is the lifeblood of economies around the world and global economic growth depends on adequate, reliable and affordable supplies of energy. The global radiation is an important parameter necessary for most ecological models and an input for different solar systems. It is the ultimate energy for all ecosystems. Obviously, measured data is the best form of this knowledge. Unfortunately, there are very few meteorological stations that measure global solar radiation, especially in developing countries. For such stations where no measured data are available, the common practice is to estimate global solar radiation from other measured meteorological parameters like relative sunshine duration.In the absence and scarcity of trustworthy solar radiation data, the need for an empirical model to predict and estimate global solar radiation seems inevitable. These models use climatological parameters of the location under study. Among all such parameters, sunshine hours are the most widely and commonly used. The models employing this common and important parameter are called sunshine-based models.The need for radiation data covering entire areas led to the development of radiation models that allow the calculation of radiation parameters within certain margins of error. These models grew particularly important in connection with the use of solar energy. The study resulted in the development of respective Angstrom regression models for Hebron city in Palestine. By conducting the study, it was found that the measured values of global solar radiation varies from 11.34 MJ/m^2 in December to 30.24 MJ/m^2 in June. The maximum values of actual sunshine duration obtained in summer months (July, 11.82 hr) while the minimum values in winter months (December, 5.94hr).The linear regression model showed better estimates in winter months with an underestimation of the global solar radiation values while the quadratic model provide better estimation in summer months than the other models.

The lowest value of the coefficient of determination was found to be 93.2% and the highest values of MAPE and RMSE for the logarithmic model. The liner and quadratic models offered the best estimate with the coefficient of determination value 98.8%, 98.7% respectively. The logarithmic and exponential regression equations gave good and almost similar MAPE and RMSE results.

In Future, correlation models can be used in order to estimate global solar radiation; these models use other meteorological parameters such as air temperature (minimum, maximum), relative humidity and precipitation. Also, it is better to use a long data period of solar radiation that provides accurate results.

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استخدام مدة سطوع الشمس لتقدير الإشعاع الشمسي العالمي في مدينة الخليل، فلسطين

إعداد: مؤمنة سليمان حسن دوابشة

إشراف: الدكتور حسين السمامرة

ملخص:

إن المعرفة الدقيقة لتوزيع الإشعاع الشمسي في منطقة جغرافية يشكل أهمية حيوية لتطوير العديد من أنظمة الطاقة الشمسية .هدفت هذه الدراسة إلى تحليل الإشعاع الشمسي الكلي الساقط على السطوح الأفقية إضافة إلى فترة السطوع الشمسي في الفترة الزمنية 2011 – 2014 في مدينة الخليل، فلسطين. وقد تم استخدام نموذج آنغستروم بالإضافة إلى النماذج المعدلة منه وذلك من أجل تقدير الإشعاع الشمسي في منطقة الدراسة.وقد تم استخدام أربعة نماذج (خطي، أسي، لوغاريتمي، اقتران من درجة ثانية))) والتي تعتمد على مدة السطوع الشمسي وذلك من أجل تقدير الإشعاع الشمسي في منطقة الدراسة . ويشكل عام ، استطاعت النماذج الأربعة تقدير الإشعاع الشمسي حسب معامل أداء 98.8% للنموذج الخطي، 93.2% للنموذج الأسي، 96.5 للنموذج أللوغاريتمي، 98.7% للاقتران من الدرجة الثانية. حيث كان النموذج الخطي أفضل النماذج لتقدير الإشعاع الشمسي في أشهر الشتاء في حين أن نموذج الاقتران من الدرجة الثانية كان مناسبا في أشهر الصيف. وقد تلاءمت النتائج بشكل .من أجل اختبار أداء الدالة الإحصائية للنماذج، تم استخدام (MAPE) و (RMSE) حيث أظهرت النتائج وبغض النظر عن الفروقات بين هذه النماذج أن تقدير الإشعاع الشمسي كان إلى حد ما دقيقا بالنسبة للقراءات العملية.وقد بينت نتائج معامل الأداء متوافقاً مع معامل الوضوح.