

RESEARCH ARTICLE

USING SIX THERMAL AMPLITUDE MODELS FOR ESTIMATING THE DAILY GLOBAL SOLAR RADIATION AS A SOURCE OF CLEAN ENERGY FROM MEASURED TEMPERATURES OVER SAUDI ARABIA

Mohammed Foudil Bourouba

Environmental and Engineering Consultants Company, 7052 Roba Street, Qurtuba District, Riyadh, P.O. Box 13244, Saudi Arabia.

*Corresponding Author Email: mbourouba780@gmail.com

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ABSTRACT

This research presents an analysis of the estimated solar radiation using Maximum and minimum daily temperatures (T_{dmax} and T_{dmin}), and by applying six models. The estimated solar radiation was calibrated by the recently developed CSR model, and extensive digital data sets derived from satellite observations edited in the Atlas Solar Radiation for the Saudi Arabia edited by KACST with the collaboration of Center for renewable energy resources of Colorado. The model performance was analyzed using four statistical models (RMSE, ME, R2, MAE).

KEYWORDS

Maximum daily temperatures, Minimum daily temperature, Mean daily temperature, solar radiation, Models, variations, regions, Saudi Arabia.

1. INTRODUCTION

Solar radiation crosses the atmosphere, reaches the Earth's surface and constitutes a main source of renewable energy. It plays a critical role in many vital human activities by the chemical, physical, and biological processes (Santamouris et al., 1999; Elagib and Mansell, 2000; Ball et al., 2004). Climate data, hydrologic cycle, sensible heat, latent heat, evaporation, ecological life, migration, and other many important processes are directly affected by the changes in solar radiation (Rehman and Mohandes, 2008).

Compared to the traditional energy (fossil fuels) the solar radiation impact on environment are lower and mainly localized in arid and semi-arid regions. Because of all its properties, solar energy systems can be become in the future a suitable alternative of the mitigation of carbon emissions, exclusively in developing countries (Adekoya, 2021; Charfeddine, 2019). From this perspective, it is seen that the solar radiation will become the principal source of sustainable alternative energy that can preserve the environment systems (Adaramola, 2012; Ho, 2022). In this context, the solar energy systems have begun to be widely used on many countries in the world. In the countries with more solar energy potential, the solar radiation was started to become an alternative source of electrical energy. Based on these positive results of the use of solar radiation, many countries increased their solar power plant investment considering their solar energy potentials. However, Africa, Australia, South America, Southern Europe, and Asia (especially India) have a high solar energy potential. In these regions, solar energy has been often used in electricity and heat generation (Almorox et al., 2013). The technology methods of benefiting from solar radiation are mainly solar thermal electricity generation, solar heating systems, and photovoltaic cells (PV systems) (Das and Mandal, 2022; McCormick and Suehrcke, 2018; Khan et al., 2022). Due to the current high energy demand, the increase in the use, the cost of fossil fuels and society's major concern regarding environmental conservation have encouraged research and development of alternative sources of energy (Lima et al., 2019). Solar radiation can become progressively the best alternative of the traditional energy because its low

emission of greenhouse gases (GHG) or even local atmospheric pollutants, and it represents improvements in a country's energy efficiency and imposition of costs on GHG emitters and can also be directly used for environment, water heating and the electricity generation (Besharat et al., 2013). Among all techniques, PV solar systems is the most used technology in generating electrical energy from solar radiation. In this field, China leads the countries with the highest solar PV power capacity of 300 GW in the year 2021 (Gürel et al., 2023).

The main reason of the considerable growth of countries interested in solar energy is to ensure their economic sustainability by reducing dependence on fossil fuels. Other important reason of the growing in solar PV capacities are the energy security issues and the volatility of fossil-fuel prices. From, several studies the solar radiation is a very useful source of renewable energy, followed by wind energy and hydropower, respectively. With the increase in the installation of PV systems all around the world, it becomes important to estimate the solar radiation reaching the earth and the power obtained from these systems 2021 (Gürel et al., 2023).

In arid and semi-arid regions, the high solar radiation rate have various effects on human, agriculture, tourism, and water balance. Consequently, complete and accurate solar radiation data at regions are indispensable. When the solar radiation is unavailable, it is possible to estimate its integral over time-solar global irradiation using empirical methods. The aim of this study was to assess the average daily of Solar radiation based on maximum and minimum air temperature and on extraterrestrial solar using six models, which are (Hargreaves-Samani, 1982; Bristow-Campbell, 1997; Samani, 2000; Allen, 1995; Chen et al., 2006; Annandale et al., 2002) methods.

2. RESEARCH SIGNIFICANCE

It is necessary to measure the solar radiation values in the different regions with the high solar energy potential. Solar radiation is measured using a pyranometer, pyrhelimeter, and solarmeter. However, it is not practically possible to place these measurement devices in all regions due

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to their huge cost, measurement difficulties, and calibration problems (Karaman et al., 2021). Accordingly, many researchers have improved many models to estimate the solar radiation in absence of the actual data. In this study, there are six different approaches for the estimation of solar radiation. While, every empirical used model has its characteristics, challenges, advantages, disadvantages, limitations, and accuracy. The advantages of traditional methods can be listed as not requiring software knowledge, being easily applicable, and yielding results with less input (Hargreaves-Samani, 1982; Bristow-Campbell, 1997; Samani, 2000; Allen, 1995; Annandale et al., 2002; Chen et al., 2006). For the various models, more parameters (measured solar radiation, wind speed, temperature, day length, sunshine duration, pressure, humidity, etc.) were used as inputs to predict solar radiation. The significance of this study is the application of six models to estimate solar radiation using the maximum and minimum daily temperatures available in 17 meteorology stations over Saudi Arabia.

3. MATERIAL AND METHODS

3.1 Study area

The selected weather stations were located over Saudi Arabia between 17° and 31° latitudes North and 35° and 50° Longitudes East as shown in the map of Figure 1. The study area is characterized by a diversity of relief features between coastal plains, inland valleys, and mountain ranges, extending at altitudes ranging from sea level to approximately 3000 meters in the south western region. This region includes the Red Sea Plain (Tihama Plain), which is bordered by the Red Sea to the west and the

Western Highlands to the east, as well as the Western Highlands region (the Hijaz Mountains), which is considered one of the most distinguished natural regions. Saudi Arabia is characterized by a semi-arid environment with high temperature variability, low annual temperatures, no natural perennial flow and limited groundwater reserves (Chowdhury and Zahrani, 2013). The policies on agriculture, industry and water resources are greatly affected by the climatic condition. Summers in the central region are extremely hot and dry, ranging from 27°C to 43°C in the inland areas and 27°C to 33°C in coastal areas. In winter, the temperature ranges between 8 to 20°C in the interior parts while higher temperatures (19°C-29°C) have been recorded in the coastal areas of Red sea. The average annual rainfall in most parts of the country is below 150 mm throughout the year except the southwestern part where the rainfall occurs between 400-600 mm/year.

The data analyzed in this study were recorded at nine meteorology stations since 1985 to 2018. The study incorporates daily maximum and minimum values of temperature in the present analyses. In this study, the daily data of temperature in different regions of Saudi Arabia were obtained for the period of 1985-2018 from the Presidency of Meteorology and Environment of Saudi Arabia (PME, 2018).

The data from the weather stations of Riyadh and Qasim represents the central region; Tabouk, the west north region; Turayf and Ar'ar the north region; Abha the southwest region; Qaysumah, the eastern region; Al Wajh the west coast; and Najran the southern of Saudi Arabia (Table 1). The maximum and minimum daily temperatures for 1985-2018 were used to estimate the daily solar radiation in every selected weather station.

Table 1: Geographic coordinates of the weather selected stations.

Region	Station Code	Station name	Longitude (E)	Latitude (N)	Elevation (m)
Riyadh	40437	Riyadh KKIA	46°43'19"	24°55'31"	613.6
Eastern Province	40373	Qaysumah	46°07'49"	28°19'08"	357.6
Asir	41112	Abha	42°39'39"	18°13'59"	2093.3
Qasim	40405	Prince Naif Airport	43°46'03"	26°18'28"	646.7
Tabouk	40375	Tabouk	36°36'25"	28°22'35"	768.1
	40400	Al Wajh	36°28'37"	26°12'19"	23.7
Northern Borders	40357	Ar'ar	41°08'26"	30°54'08"	548.9
	40356	Turayf	38°44'22"	31°41'16"	852.4
Najran	41118	Najran	44°24'49"	17°36'41"	1212.3

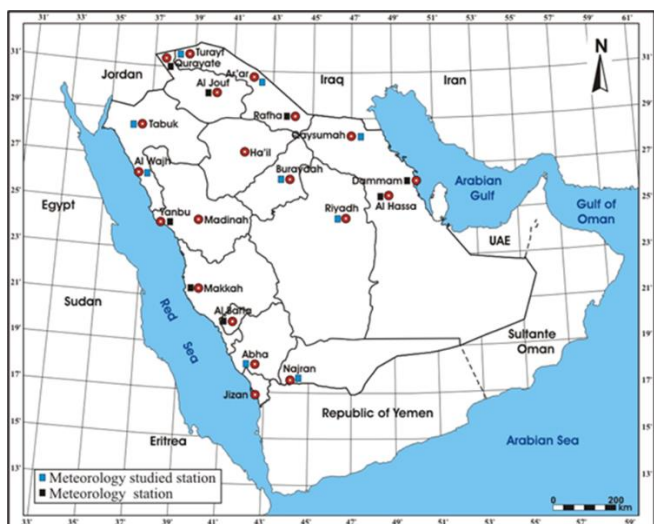


Figure 1: Geographic location of the weather stations.

3.2 Extraterrestrial radiation calculation

Daily total extraterrestrial radiation (H_o) is the main input to estimate incident solar radiation. H_o values were calculated for a specific day of the year based on the location's latitude, by applying the followings:

$$H_o = (1/\pi) I_{sc} E_o [(Cos\lambda Cos\delta Sin\omega_s)] (\pi / 180) Sin\lambda Sin\delta \omega_s$$

Where:

- I_{sc} : solar constant equals 118.108 MJ.m-2.d-1.

E_o : Eccentricity correction factor of the earth's orbit, equals:

$$E_o = 1.00011 + 0.034221 Cos\Gamma + 0.00128 Sin\Gamma + 0.00719 Cos2\Gamma + 0.000077 Sin\Gamma$$

Where:

Γ : the day angle (radians) and n day is the day number (starting 1st January), equals:

$$\Gamma = \frac{2\pi (nday - 1)}{365}$$

λ : the latitude of the site (degrees),

δ : solar declination (degrees) equals:

$$\delta = 180/\pi(0.006918 - 0.3999912 Cos\Gamma - 0.070257 Sin\Gamma - 0.006758 Cos2\Gamma + 0.000907 Sin2\Gamma - 0.002697 Cos3\Gamma + 0.00148 Sin3\Gamma$$

ω_s : Hour angle of the sun (degrees) equals:

$$\omega_s = Cos^{-1} \frac{(-Sin\lambda Sin\delta)}{Cos\lambda Cos\delta}$$

3.3 Models

Model 1- Hargreaves-Samani (1982):

Hargreaves and Samani presented in 1982 the first attempt to evaluate the incident radiation from the difference between the daily maximum and minimum temperatures using the following model:

$$H_c = H_o [K\Gamma (T_{max} - T_{min})^{0.5}]$$

Where:

- H_c : Estimated solar radiation (MJ.m-2.d-1),
- H_o : Extraterrestrial solar radiation (MJ.m-2.d-1),
- T_{max} : Maximum daily temperature (°C),
- T_{min} : Minimum daily temperature (°C),
- $K\Gamma$: Empirical coefficient equals 0.17 for arid and semi-arid regions.

Hargreaves and Samani suggested to use $K\Gamma = 0.16$ for interior regions and $K\Gamma = 0.19$ for coastal regions.

Model 2- Allen (1997):

Allen recommended a correction factor for K_T and suggested a function of elevation as :

$$K_T = A(P/1013)$$

Where:

- P (hPa) : Mean atmospheric pressure of site and $A(oC-0.5 \text{ hPa}-0.5)$,

- A : Empirical coefficient equals 0.17 for interior regions and $K_T = 0.20$ for coastal regions.

The model equation of Allen is :

$$H_c = H_o [A(P/1013)^{0.5} (T_{max} - T_{min})^{0.5}]$$

Model 3- Samani (2000):

Based on the average monthly data for the entire year computed by the first model, Samani developed the following equation with a new modification of the empirical coefficient (K_T) :

$$K_T = A(T_{max} - T_{min})^2 - B(T_{max} - T_{min}) + C$$

Samani proposed the coefficients values of $A = 0.00185$ (oC-2), $B = (-0.04330)$ (oC-12) and $C = 0.4023$ (unitless).

Model 4- Bristow-Campbell (1998):

Bristow and Campbell proposed an exponential model for estimating the daily solar radiation by applying the following equation :

$$H_c = H_o A [1 - \exp(-B \Delta T^c)]$$

Where :

- ΔT : $T_{max} - T_{min}$.

- A : Empirical coefficient equals 0.7,

- C : Empirical coefficient equals 2.4,

- B : Empirical coefficient calculated as follows:

$$B = 0.036 \exp[-0.154 \Delta T^{(c)}]$$

Model 5- Chen et al., (2006):

Chen et al., have modified Hargreaves-Samani model by introducing an empirical coefficient b as given by the following equation:

$$H_c = H_o [(0.28)^b \ln(T_x - T_m)]$$

Model 6- Annandale et al., (2002):

Annandale et al., modified Hargreaves-Samani model by introducing a correlation factor for parameter (A) to account the effects of reduced altitude and atmospheric thickness on global solar radiation (H_c). the proposed model can be expressed by the following equation:

$$H_c = H_o A (1 + 2.7 \times 10^{-5} Z)(T_x - T_m)^{0.5}$$

Where Z is the elevation above sea level in (m).

3.4 Evaluation of model performance

The accuracy and performance of the estimated solar radiation were evaluated and compared using the statistical indicators shown in Table 2.

Table 2: Statistical indicators used for the performance evaluation of solar radiation models (Trajeda et al., 2022)		
Model	Decision Rule	
$PRMSE = \left[\frac{1}{n} \sum_{i=1}^n (Y_i - X_i)^2 \right] * 100$	PRMSE <10	Excellent
	10 = PRMSE <20	Satisfactory
	20 = PRMSE <30	Acceptable
	PRMSE =30	Unsatisfactory
$R^2 = \left[\frac{\sum_{i=1}^n (X_i - Y_i)^2}{\sum_{i=1}^n (X - X')^2} \right]$	0.80=R ² <1	Excellent
	0.65=R ² <0.80	Satisfactory
	0.65=R ² <0.50	Acceptable
	R ² <0.50	Unsatisfactory
$MAE = \left[\frac{1}{n} \sum_{i=1}^n (Y_i - X_i) \right]$	Lower values are preferred	
$RMSE = \left[\frac{1}{n} \sum_{i=1}^n (X_i - Y_i)^2 \right]^{0.5}$	Lower values are preferred	

4. RESULTS AND DISCUSSION

With the growing concerns on clean energy, solar energy systems have begun to be widely used on a large scale in many countries in the world, exclusively in those with more solar energy potential, such as Saudi Arabia. That is because the economy and environmental aspects were developed in the short run. So, many of these countries started to enhance the share of solar systems in their electricity production methods (Gürel et al., 2023).

But, the number of weather stations that measure solar global irradiance (I_g) is scarce, and when it is available, it does not present long-time series. When the solar radiation is unavailable, it is possible to estimate it using empirical methods. However, for a better performance these methods need to be fitted to the local climatic conditions. The aim of this study was to assess the (Hargreaves-Samani, 1982; Allen, 1997; Bristow-Campbell, 1998; Samani, 2000; Annandale, 2002 and Chen, 2004) methods to estimate monthly average daily in the nine meteorology stations. The methods are based on maximum, minimum air temperature and on extraterrestrial solar irradiation between 1985 until 2018. The methods efficiency were evaluated by the statistical indexes: determination coefficient (R^2) of the linear regression between observed and estimated monthly, root mean square error (RMSE), Willmott's index (d) and performance index (c).

4.1 Variability of temperatures data

The quality of temperatures data used in this study was based on the statistical analysis used three-step quality control was used: (1) Central tendency measurements, (2) Normality test and (3) Homogeneity of variance.

Table 3 and Figure 2 resume the monthly averages of the maximum, minimum and mean temperatures. It shows that the hottest month in the year is June in

Table 3: Monthly averages of maximum, minimum and mean daily temperature for 1985-2018

Station	Month	Temperature (°C)			Station	Temperature (°C)			Station	Temperature (°C)		
		T _{mean}	T _{max}	T _{min}		T _{mean}	T _{max}	T _{min}		T _{mean}	T _{max}	T _{min}
Abha	Jan	13.5	19.9	7.9	Riyadh	13.7	20.5	7.2	Qaysumah	11.8	18.4	6.2
	Feb	13.5	19.9	7.9		16.4	23.4	9.5		14.5	21.5	8.1
	Mar	17.1	23.4	11.5		20.8	27.8	13.7		19.4	26.8	12.5
	Apr	19.0	25.7	13.2		26.2	33.3	18.7		25.7	33.3	18.4
	May	21.8	29.0	15.3		32.2	39.5	23.9		32.2	39.8	24.2
	Jun	23.9	31.3	17.1		34.8	42.6	25.6		35.6	43.4	26.9
	Jul	23.6	30.9	17.6		36.0	43.8	26.8		37.2	45.0	28.6
	Aug	23.0	30.7	17.0		35.9	43.7	26.7		37.2	45.3	28.7
	Sep	22.4	29.7	15.3		32.5	40.6	23.2		33.6	42.0	25.1
	Oct	19.0	26.3	12.0		27.3	35.5	18.5		27.9	36.2	20.4
Nov	15.9	23.1	9.3	20.3	27.5	13.2	19.1	26.2	12.9			

Table 3 (Cont): Monthly averages of maximum, minimum and mean daily temperature for 1985-2018

Station	Month	Temperature (°C)			Station	Temperature (°C)			Station	Temperature (°C)		
		T _{mean}	T _{max}	T _{min}		T _{mean}	T _{max}	T _{min}		T _{mean}	T _{max}	T _{min}
Al Wajh	Dec	14.1	21.1	7.5	Buraydah	15.2	22.1	8.6	Tabouk	13.4	20.1	7.7
	Jan	19.0	24.4	13.5		13.0	19.8	6.6		11.1	18.3	4.4
	Feb	19.9	25.2	14.4		15.6	22.9	8.5		13.5	20.9	6.3
	Mar	22.0	27.3	16.6		20.0	27.3	12.6		17.6	25.2	10.0
	Apr	24.9	29.9	19.7		25.4	33.0	17.8		22.7	30.5	14.7
	May	27.4	32.1	22.5		31.3	39.0	23.1		26.9	34.7	19.0
	Jun	28.7	33.2	23.8		34.4	42.5	25.2		30.2	37.9	22.0
	Jul	30.0	34.3	25.3		35.6	43.6	26.2		31.7	39.2	24.0
	Aug	30.4	34.6	25.9		35.9	44.0	26.7		31.8	39.5	24.2
	Sep	29.1	33.5	24.4		32.8	41.3	23.7		29.1	37.1	21.3
	Oct	24.6	22.4	29.0		27.4	35.9	18.9		24.2	32.1	16.7
	Nov	17.7	19.1	24.3		19.9	27.2	13.1		17.5	25.0	10.7
Dec	20.8	26.4	15.4	14.7	21.7	8.3	12.4	19.8	5.8			
Turayf	Jan	7.3	13.3	1.8	Ar'ar	9.1	15.9	3.5	Najran	17.6	25.7	9.0
	Feb	9.3	15.6	3.2		11.6	18.5	5.3		20.6	28.7	11.9
	Mar	13.4	20.1	6.7		16.4	23.5	9.3		24.0	31.7	15.8
	Apr	18.8	25.8	11.4		22.3	29.8	14.9		26.6	34.0	18.8
	May	23.8	30.9	16.0		27.9	35.4	20.2		30.1	37.2	21.5
	Jun	27.6	35.0	19.1		32.1	39.8	23.7		31.9	39.1	22.8
	Jul	29.6	37.2	21.1		34.4	42.1	26.0		33.2	39.6	25.4
	Aug	29.6	37.3	21.2		34.6	42.4	26.1		32.7	39.4	24.7
	Sep	26.8	34.6	18.6		30.7	38.9	22.5		29.7	37.0	20.8
	Oct	21.4	28.8	14.2		24.4	32.4	17.2		24.6	32.3	15.6
	Nov	13.7	20.4	7.6		16.0	23.1	9.9		20.7	28.4	12.3
	Dec	8.8	15.1	3.2		10.6	17.4	5.0		17.9	26.0	9.5

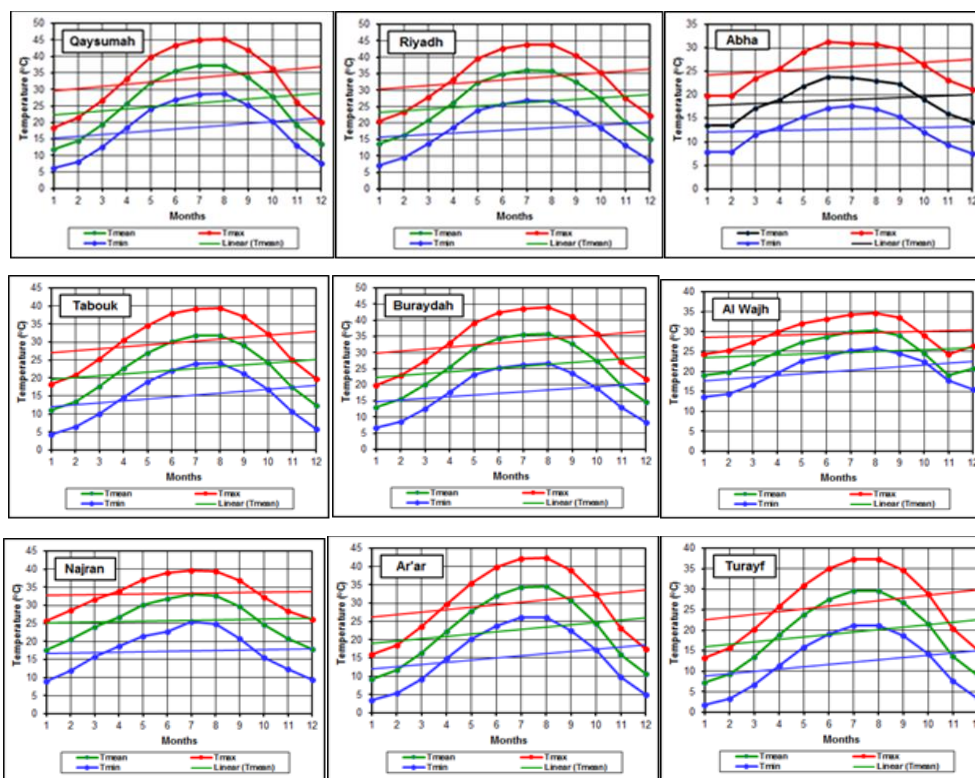


Figure 2: Monthly averages of Daily maximum, minimum and mean temperatures for 1985-2018

Abha with a mean of maximum daily value of 31.3 °C, July in Riyadh and Najran with 43.8 oC and 39.6 oC, respectively; August in Al Wajh, Buraydah, Tabouk, Qaysumah, Ar'ar and Turayf, with 34.6 oC, 44.0 oC, 39.5

oC, 45.3 oC, 42.4 oC and 37.3 oC, respectively. Contrary, January is the coldest month with a mean of minimum daily temperatures in the total of selected stations ranged between 7.3 oC and 19.0 oC, in Turayf and Al

Wajh, respectively.

The extreme values of maximum daily temperatures were ranged from 35.5 oC (August 6, 2017) in Abha and 49.0 oC (August 5, 1998 and July 13,

2010) in Buraydah and Ar'ar, respectively (Table 4). In addition, the Kolmogorov-Smirnov of Normality test showed that the distribution of daily temperatures data (Maximum, Minimum and Mean) differs from the normal distribution in all stations at the significance level 0.000.

Table 4: Extreme maximum and minimum daily temperatures during 1985-2018.

	Maximum Daily Temperature (°C)	Date	Minimum Daily Temperature (°C)	Date
Abha	35.5	6/8/2017	0.0	13/1/1992
Riyadh	48.2	7/8/1998	-5.4	17/1/2008
Al Wajh	48.0	31/5/2017	-8.0	5/1/1989
Qaysumah	51.0	19/8/1998	-4.2	17/1/2008
Tabouk	46.4	27/7/2000	-4.0	17/1/2008
Turayf	45.5	23/7/1998	-8.0	26/1/1992
Buraydah	49.0	5/8/1998	-5.0	17/1/2008
Ar'ar	49.0	13/7/2010	-6.3	16/1/2008
Najran	44.0	2/7/2006	-0.5	4/1/1986

4.2 Analysis of Temperatures trends

The semi-averages method was applied for determining the daily maximum (Tx) and minimum (Tm) temperatures trends using T-student test and Standard Error (SE). So, the temperatures data was divided in two equal periods of 17 years, with (1985-2001) for the first period (2002-2018) for the second period. For each period, the arithmetic mean (X'1, X'2), the standard deviation (σ1, σ2) and variance (σ21, σ22) were computed. So, the trend is significant at the level 0.05 and degree of freedom [d.f = (n1+n2) - 2], if :a- The computed T-student value is greater the critical T value b- The absolute difference |X'1 - X'2| > 2 SE or 3 SE, at the significance level 0.05 and degree of freedom (Gregory, 1970 ; Oliver, 1981).

Using the data of daily maximum (Tx) and minimum (Tm) values of temperature, the critical value of T-student at the significance level 0.05 and the freedom degrees of 32, is 1.96. The table 5 summarized the results. From this table, the overall semi-averages (X'2) of daily maximum temperatures recorded during the second period (2002-2018) are greater than the similar averages (X'1) of the first period (1985-2001) over different months in Abha, Qaysumah, Al Wajh, Buraydah, Ar'ar and Najran. The same trends characterized the semi-averages of maximum daily temperatures over 10 months from January to October in Riyadh, total of the months in Tabouk, except September and November and September in Turayf.

The positive differences between both semi-averages (X'2-X'1) in each station, expressed the increased trends of the daily maximum temperatures. Consequently, the differences (X'2-X'1) are smaller the (2 SE) over different months in the selected stations, except February and May in Abha and May to October in Najran. So, the overall increased trends of the daily maximum temperatures are not significant in the total of studied, except the mentioned months in both Abha and Najran.

In the other hand, the table 6 summarized the Semi-averages of the minimum daily temperatures, the Standard Error and the T-student values. From this table, the overall semi-averages (X'2) of daily minimum temperatures recorded during the second period (2002-2018) are greater than the similar averages (X'1) of the first period (1985-2001) over different months in Abha, Al Wajh, Tabouk and Turayf.

The same trends characterized the semi-averages of minimum daily temperatures over 12 months in Riyadh, Qaysumah, Buraydah and Ar'ar, except December and Najran, except February. The positive differences between both semi-averages (X'2-X'1) are smaller the (2 SE) over different months in Al Wajh, Buraydahm Turayf, Ar'ar and Najran. In the rest of selected stations, the differences are also positive and smaller than the (2 SE), over different months, except April to September and November in Abha; From May to September in Riyadh; june in Qaysumah; July and August in Tabouk.

Table 5: Maximum daily temperatures trends using T-student test.

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	
Abha	X'1	19.4	20.4	22.4	24.7	28.2	30.7	30.4	30.3	29.3	25.8	22.9	20.6
	Sd1	2.7	2.8	2.7	2.8	2.3	1.3	1.7	1.8	1.3	1.7	1.7	2.1
	X'2	20.3	22.5	24.3	26.1	29.4	31.7	31.3	31.1	30.1	26.7	23.3	21.3
	Sd2	2.6	2.5	2.2	2.5	2.1	1.5	1.8	1.7	1.4	1.5	1.9	2.1
	SE	0.9	0.9	0.8	0.9	0.8	0.5	0.6	0.6	0.5	0.5	0.6	0.7
	T test	0.988	2.287	2.366	1.552	1.558	2.035	1.520	1.346	1.565	1.690	0.740	0.932
Riyadh	X'1	20.00	22.70	26.81	32.98	39.21	42.36	43.43	43.49	40.41	35.29	27.90	22.32
	Sd1	4.3	4.6	4.3	4.0	2.8	1.7	1.4	1.2	1.9	2.3	4.5	4.0
	X'2	20.9	24.1	28.8	33.7	39.8	42.8	44.2	44.0	40.8	35.6	27.2	21.9
	Sd2	4.25	4.59	4.26	4.04	2.76	1.74	1.39	1.21	1.93	2.31	4.49	3.99
	SE	1.47	1.51	1.49	1.41	0.99	0.61	0.52	0.50	0.68	0.90	1.44	1.47
	T test	10.710	12.007	15.172	20.596	36.778	66.964	80.117	85.297	56.529	36.564	16.232	12.457
Qaysuah	X'1	17.8	20.6	25.2	32.8	39.3	42.9	44.3	44.7	41.6	35.5	26.2	19.9
	Sd1	4.0	4.0	4.4	4.5	3.6	2.4	2.2	2.4	2.3	3.5	4.9	4.4
	X'2	19.0	22.5	28.3	33.8	40.3	43.9	45.6	45.8	42.4	36.9	26.2	20.3
	Sd2	4.1	4.6	4.7	4.4	3.3	2.3	2.0	1.8	2.4	3.2	4.8	4.3
	SE	1.4	1.5	1.6	1.5	1.2	0.8	0.7	0.7	0.8	1.2	1.7	1.5
	T test	2.895	2.958	3.087	3.659	5.239	7.971	9.161	9.151	7.931	5.098	2.981	2.852

Table 5 (Cont): Maximum daily temperatures trends using T-student test.													
Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	
Al Wajh	X ₁	23.8	24.3	26.5	29.7	31.8	32.7	33.8	34.2	33.1	31.9	29.4	26.0
	Sd ₁	4.4	3.1	2.6	3.3	2.9	2.8	1.6	1.4	1.9	2.0	2.3	3.5
	X ₂	25.1	26.1	28.2	30.2	32.4	33.8	34.9	35.0	33.9	32.7	30.6	26.9
	Sd ₂	2.7	2.8	3.0	2.9	3.0	2.8	1.8	1.4	1.9	2.0	2.6	3.5
	SE	6.1	5.3	6.7	7.4	8.4	8.0	8.5	8.3	7.9	7.5	7.5	6.6
	T test	0.216	0.347	0.216	0.347	0.252	0.071	0.078	0.139	0.134	0.106	0.092	0.110
Buraydah	X ₁	18.7	21.4	25.5	32.0	38.2	41.9	42.9	43.2	40.5	35.1	26.8	21.2
	Sd ₁	4.5	4.4	4.5	4.4	3.5	2.2	2.0	2.2	2.4	3.2	4.5	4.7
	X ₂	20.7	24.5	29.2	33.9	39.9	43.1	44.4	44.9	42.1	36.7	27.5	22.1
	Sd ₂	4.3	4.8	4.5	4.1	3.0	1.9	1.7	1.5	2.2	2.7	4.8	4.2
	SE	4.7	5.3	6.3	7.8	9.3	10.2	10.4	10.5	9.8	8.5	6.6	5.2
	T test	0.431	0.587	0.590	0.249	0.182	0.115	0.148	0.164	0.153	0.187	0.105	0.171
Tabouk	X ₁	18.1	20.0	24.2	30.3	34.6	37.8	38.9	39.2	37.1	31.9	25.1	19.7
	Sd ₁	3.8	4.2	4.0	4.2	3.5	2.3	2.0	2.2	2.2	3.5	3.7	3.8
	X ₂	18.5	21.8	26.2	30.6	34.8	38.0	39.4	39.7	37.1	32.4	25.0	20.0
	Sd ₂	4.1	4.3	4.5	4.0	3.3	2.3	2.1	2.1	2.4	3.4	3.9	3.7
	SE	1.3	1.5	1.5	1.4	1.2	0.8	0.7	0.7	0.8	1.2	1.3	1.3
	T test	0.338	1.247	1.366	0.223	0.187	0.286	0.746	0.757	0.021	0.415	0.035	0.177
Turayf	X ₁	13.3	15.2	19.3	25.6	30.8	34.6	36.6	36.4	34.6	28.4	20.1	14.8
	Sd ₁	3.5	4.3	4.3	4.8	4.2	2.9	2.7	2.7	2.8	3.7	4.2	4.1
	X ₂	13.2	16.1	20.9	25.7	31.3	35.4	37.6	37.9	34.4	28.8	20.6	15.5
	Sd ₂	3.9	4.6	5.0	4.9	4.1	3.1	3.1	3.0	3.2	4.1	4.2	3.9
	SE	1.3	1.5	1.6	1.7	1.4	1.0	1.0	1.0	1.0	1.3	1.4	1.4
	T test	0.109	0.588	1.000	0.101	0.382	0.726	1.030	1.493	56.729	0.297	0.336	0.550
Ar'ar	X ₁	15.3	17.5	22.1	29.3	34.9	38.9	41.3	41.6	38.3	31.5	22.8	17.0
	Sd ₁	3.8	4.0	4.3	4.4	3.9	2.7	2.3	2.6	2.7	3.8	4.4	4.1
	X ₂	16.4	19.6	25.0	30.2	35.8	40.6	42.9	43.1	39.5	33.2	23.4	17.8
	Sd ₂	3.8	4.1	4.6	4.5	3.8	3.1	2.8	2.9	3.3	4.2	4.5	4.1
	SE	16.7	23.4	37.8	54.9	76.4	97.2	108.7	109.8	92.3	65.6	33.2	19.7
	T test	0.757	0.664	0.546	0.469	0.418	0.390	0.374	0.369	0.399	0.448	0.571	0.698
Najran	X ₁	25.1	28.1	30.7	33.2	36.5	38.4	38.8	38.7	36.3	31.6	27.7	25.8
	Sd ₁	4.3	4.3	3.9	3.3	2.2	1.5	1.3	1.3	1.7	2.0	2.5	3.7
	X ₂	26.4	29.4	32.6	34.7	37.9	39.8	40.4	40.1	37.7	33.0	29.2	26.3
	Sd ₂	4.4	4.5	3.5	3.2	1.7	1.2	1.1	1.3	1.7	1.7	2.4	3.3
	SE	1.5	1.5	1.3	1.1	0.7	0.5	0.4	0.4	0.6	0.6	0.8	1.2
	T test	0.895	0.895	1.511	1.308	2.125	3.066	3.904	3.032	2.362	2.195	1.759	0.403

Table 6: Minimum daily temperatures trends using T-student test.													
Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	
Abha	X ₁	7.4	9.3	11.0	12.3	14.4	16.1	16.8	16.4	14.6	11.4	8.5	7.3
	Sd ₁	2.4	2.1	2.1	1.7	1.6	1.5	1.6	1.4	1.5	1.8	2.0	2.3
	X ₂	8.4	9.8	12.0	13.8	15.9	17.9	18.4	17.6	16.0	12.5	10.1	7.8
	Sd ₂	2.4	2.1	2.1	1.7	1.8	1.6	1.7	1.4	1.7	1.7	1.8	2.3
	SE	0.8	0.7	0.7	0.6	0.6	0.5	0.6	0.5	0.6	0.6	0.7	0.8
	T test	1.206	0.587	1.353	2.559	2.544	3.481	2.829	2.509	2.450	1.722	2.542	0.681
Riyadh	X ₁	6.58	8.72	12.78	17.85	22.96	24.62	25.86	25.91	22.39	18.02	12.81	8.64
	Sd ₁	3.35	3.56	3.49	3.21	2.43	1.83	2.08	2.22	2.33	2.69	3.04	3.63
	X ₂	7.75	10.21	14.52	19.58	24.72	26.62	27.81	27.48	24.03	19.06	13.61	8.60
	Sd ₂	3.57	3.91	3.49	3.11	2.58	1.98	1.96	1.91	2.35	2.30	3.10	3.45
	SE	1.19	1.28	1.20	1.08	0.86	0.65	0.69	0.71	0.80	0.86	1.05	1.21
	T test	2.541	3.753	7.771	13.610	23.697	34.633	34.440	33.796	24.942	18.293	9.225	4.273

Table 6 (Cont): Minimum daily temperatures trends using T-student test.

Station		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	
Qaysnah	X'1	6.1	7.6	11.6	18.2	23.8	26.2	28.0	28.3	24.7	19.9	13.1	8.0	
	Sd1	3.2	3.4	3.5	3.6	2.9	2.0	2.0	2.3	2.4	2.9	3.6	3.3	
	X'2	6.2	8.7	13.3	18.6	24.5	27.7	29.2	29.1	25.6	20.8	12.8	7.4	
	Sd2	3.4	3.7	3.4	3.4	2.9	2.0	1.8	1.9	2.3	2.7	3.8	3.5	
	SE	1.1	1.2	1.2	1.2	1.0	0.7	0.7	0.7	0.7	0.8	1.0	1.3	1.2
	T test	1.955	2.089	2.724	3.438	4.846	7.353	7.812	7.217	6.141	4.577	2.724	2.220	
Al Wajh	X'1	12.9	13.5	15.8	19.4	22.3	23.3	24.8	25.4	24.0	21.9	18.8	15.3	
	Sd1	4.3	3.2	2.7	3.0	2.6	1.8	1.4	1.5	1.8	2.0	2.0	3.0	
	X'2	14.2	15.3	17.4	20.1	22.8	24.4	25.9	26.5	24.8	22.9	19.4	15.6	
	Sd2	2.5	2.5	2.8	2.7	2.4	2.0	1.5	1.7	1.7	1.8	2.4	3.4	
	SE	3.1	3.0	4.5	5.6	6.1	6.1	6.6	6.1	6.3	6.3	4.4	3.7	
	T test	0.415	0.588	0.415	0.588	0.349	0.130	0.067	0.178	0.169	0.185	0.126	0.209	
Buraydah	X'1	6.3	7.6	11.6	17.1	22.4	24.5	25.5	26.1	23.1	18.5	13.0	8.3	
	Sd1	3.5	3.5	3.5	3.2	2.9	1.9	2.3	2.4	2.7	2.9	3.2	3.4	
	X'2	6.8	9.3	13.6	18.6	23.8	26.0	26.9	27.3	24.2	19.3	13.2	8.2	
	Sd2	3.8	4.0	3.6	3.2	3.1	2.3	2.3	2.3	2.8	2.5	3.4	3.7	
	SE	1.8	2.1	2.9	4.2	5.5	6.0	6.2	6.3	5.6	4.5	3.3	2.2	
	T test	0.290	0.808	0.684	0.345	0.265	0.252	0.224	0.189	0.201	0.171	0.063	0.051	
Tabouk	X'1	4.2	5.5	9.2	14.3	18.5	21.3	23.3	23.4	20.6	16.1	10.5	5.8	
	Sd1	3.0	3.2	3.3	3.5	3.0	1.9	1.8	1.9	2.0	2.6	2.9	3.2	
	X'2	4.5	7.1	10.8	15.1	19.4	22.7	24.8	25.0	21.9	17.3	10.9	5.9	
	Sd2	3.2	3.4	3.4	3.2	2.7	2.0	1.8	1.8	2.1	2.5	3.3	3.3	
	SE	1.1	1.1	1.2	1.2	1.0	0.7	0.6	0.6	0.7	0.9	1.1	1.1	
	T test	0.260	1.423	1.391	0.697	0.962	2.101	2.457	2.475	1.908	1.334	0.413	0.093	
Turayf	X'1	1.7	2.6	5.8	11.0	15.5	18.4	20.2	20.1	18.1	13.7	7.4	3.1	
	Sd1	3.2	3.0	3.4	3.8	3.6	2.3	2.5	2.5	2.5	2.8	3.7	3.1	
	X'2	1.9	3.9	7.5	11.5	16.4	19.5	21.6	21.7	18.9	14.3	7.7	3.4	
	Sd2	3.1	3.3	3.4	3.8	3.2	2.4	2.5	2.5	2.6	3.1	3.6	3.2	
	SE	1.1	1.1	1.2	1.3	1.2	0.8	0.8	0.9	0.9	1.0	1.2	1.1	
	T test	0.186	1.167	1.399	0.379	0.703	1.301	1.640	1.836	0.914	0.587	0.235	0.272	
Ar'ar	X'1	3.3	4.5	8.2	14.5	19.7	22.9	25.3	25.5	21.9	16.5	9.7	5.1	
	Sd1	3.0	3.0	3.3	3.5	3.2	1.8	1.9	2.2	2.2	2.7	3.4	3.0	
	X'2	3.8	6.1	10.4	15.3	20.6	24.4	26.7	26.6	23.0	17.8	10.1	5.0	
	Sd2	3.2	3.5	3.5	3.6	3.1	2.4	2.4	2.4	2.7	3.1	4.0	3.4	
	SE	1.4	2.7	7.0	14.5	25.6	35.2	42.0	42.0	31.4	19.1	6.7	2.0	
	T test	0.543	1.128	1.009	0.811	0.680	0.640	0.589	0.583	0.663	0.790	0.994	0.981	
Najran	X'1	8.7	11.9	15.6	18.4	21.1	22.1	24.8	24.4	20.4	15.3	11.5	9.4	
	Sd1	3.0	3.3	3.2	2.4	2.3	2.2	2.2	2.2	2.6	2.6	3.1	3.1	
	X'2	9.4	11.9	16.0	19.1	21.9	23.4	26.0	25.1	21.2	15.9	13.0	9.6	
	Sd2	3.1	3.4	3.4	2.4	2.0	2.0	2.2	2.2	2.5	2.3	2.3	2.9	
	SE	1.0	1.1	1.1	0.8	0.7	0.7	0.8	0.7	0.9	0.8	0.9	1.0	
	T test	0.636	0.002	0.340	0.820	1.012	1.932	1.522	0.875	0.967	0.682	1.577	0.154	

4.3 Analysis of Solar radiation variability

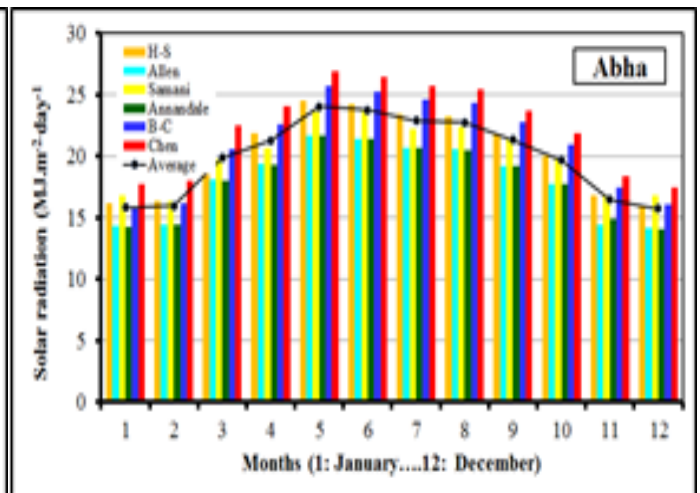
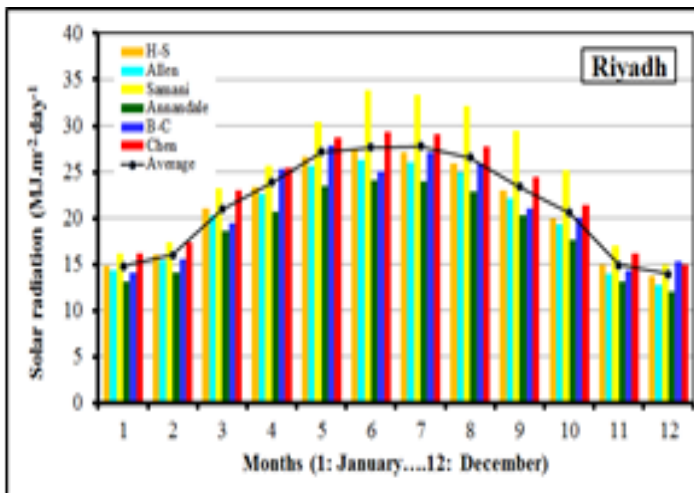
The long-term daily solar radiation were calculated using the six models. The table 7 and Figure 3 summarized the results. The highest value of mean solar radiation were ranged from 20.2 (May) MJm-2day-1 in Al Wajh to 27.7 (June) MJm-2day-1 in Buraydah for Hargreaves-Samani model, from 20.1 (May) MJm-2day-1 in Al Wajh to 26.6 (June) MJm-2day-1 in Qaysumah for Allen model, from 19.8 MJm-2day-1 (May) in Al Wajh to 35.2 (June) MJm-2day-1 in Buraydah for Samani model, from 17.8 (May) MJm-2day-1 in Al Wajh to 24.5 (June) MJm-2day-1 in Buraydah for Annandale model, from 22.0 (May) MJm-2day-1 in Al Wajh to 27.8 (June) MJm-2day-1 in both Qaysumah and Tabouk for Bristow-Campbell model and from 22.5 (May) MJm-2day-1 in

Al Wajh to 29.7 (June) MJm-2day-1 in Buraydah for Chen model.

The highest value of mean solar radiation were ranged from 20.2 (May) MJm-2day-1 in Al Wajh to 27.7 (June) MJm-2day-1 in Buraydah for Hargreaves-Samani model, from 20.1 (May) MJm-2day-1 in Al Wajh to 26.6 (June) MJm-2day-1 in Qaysumah for Allen model, from 19.8 MJm-2day-1 (May) in Al Wajh to 35.2 (June) MJm-2day-1 in Buraydah for Samani model, from 17.8 (May) MJm-2day-1 in Al Wajh to 24.5 (June) MJm-2day-1 in Buraydah for Annandale model, from 22.0 (May) MJm-2day-1 in Al Wajh to 27.8 (June) MJm-2day-1 in both Qaysumah and Tabouk for Bristow-Campbell model and from 22.5 (May) MJm-2day-1 in Al Wajh to 29.7 (June) MJm-2day-1 in Buraydah for Chen model.

Table 7: Monthly averages of estimated solar radiation (MJ/m²/day) during 1985-2018.

Model	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
	Abha											
H-S	16.2	16.3	20.4	21.9	24.5	24.2	23.4	23.2	21.7	20.1	16.8	16.0
Allen	14.3	14.5	18.1	19.4	21.7	21.4	20.7	20.6	19.2	17.8	14.4	14.2
Sam	16.9	16.4	19.8	20.7	23.6	23.8	22.2	22.4	21.4	19.8	16.8	16.8
Ann.	14.3	14.4	18.0	19.3	21.6	21.4	20.7	20.5	19.2	17.7	14.9	14.1
BC	15.8	16.1	20.6	22.6	25.7	25.3	24.6	24.3	22.8	20.9	17.4	16.1
Chen	17.7	18.0	22.5	24.1	26.9	26.5	25.7	25.5	23.7	21.9	18.4	17.5
Riyadh												
H-S	14.8	16.0	21.1	23.4	26.6	27.3	27.1	25.9	23.0	20.0	14.9	13.7
Allen	14.3	15.5	20.4	22.6	25.7	26.3	26.0	24.9	22.1	19.3	13.9	12.8
Sam	16.2	17.4	23.3	25.7	30.5	33.9	33.3	32.1	29.5	25.1	17.0	15.0
Ann.	13.1	14.1	18.6	20.7	23.5	24.1	23.9	22.9	20.3	17.7	13.2	12.1
BC	14.1	15.6	19.5	25.3	27.8	25.0	27.2	25.9	21.1	20.1	14.4	15.4
Chen	16.2	17.5	23.0	25.4	28.8	29.3	29.1	27.8	24.5	21.4	16.2	14.9
Qaysumah												
H-S	13.1	14.8	20.5	23.4	26.8	27.3	26.9	25.5	22.0	18.4	13.4	12.0
Allen	12.8	14.6	20.1	22.9	26.2	26.6	26.2	24.9	21.5	18.0	12.6	11.4
Sam	13.3	15.6	22.6	26.1	30.3	32.0	31.0	29.9	26.6	21.1	14.1	12.3
Ann.	11.5	13.1	18.1	20.7	23.6	24.1	23.8	22.5	19.5	16.3	11.8	10.6
BC	12.4	16.7	22.4	25.1	24.1	27.8	24.8	23.5	22.1	16.7	15.1	11.9
Chen	14.4	16.2	22.3	25.4	29.0	29.3	29.0	27.4	23.6	19.9	14.6	13.1
Al Wajh												
H-S	12.7	13.5	17.6	18.9	20.2	19.8	19.8	18.4	16.4	14.9	12.6	11.8
Allen	12.7	13.4	17.6	18.8	20.1	19.7	19.7	18.3	16.3	14.9	12.6	11.8
Sam	11.9	12.7	16.7	18.1	19.8	19.6	19.4	18.3	16.1	14.1	11.7	11.1
Ann.	11.2	11.9	15.5	16.7	17.8	17.5	17.5	16.3	14.4	13.2	11.1	10.4
BC	13.4	16.8	18.3	24.2	22.0	26.5	21.7	20.8	22.3	16.3	15.7	12.5
Chen	14.1	14.9	19.5	21.0	22.5	22.1	22.1	20.6	18.3	16.7	14.0	13.1
Buraydah												
H-S	14.3	16.0	21.2	23.8	26.9	27.7	27.7	26.2	22.9	19.6	14.4	13.2
Allen	13.8	15.4	20.4	22.9	25.9	26.6	26.5	25.1	22.0	18.9	13.4	12.3
Sam	15.4	18.1	24.5	27.2	31.8	35.2	35.6	33.6	30.5	25.2	16.2	14.3
Ann.	12.6	14.1	18.7	21.0	23.8	24.5	24.4	23.1	20.2	17.3	12.7	11.6
BC	13.6	17.4	19.7	25.3	24.2	27.6	25.4	24.0	22.5	17.7	15.8	12.6
Chen	15.6	17.3	23.0	25.7	29.0	29.7	29.5	27.9	24.4	21.0	15.6	14.3



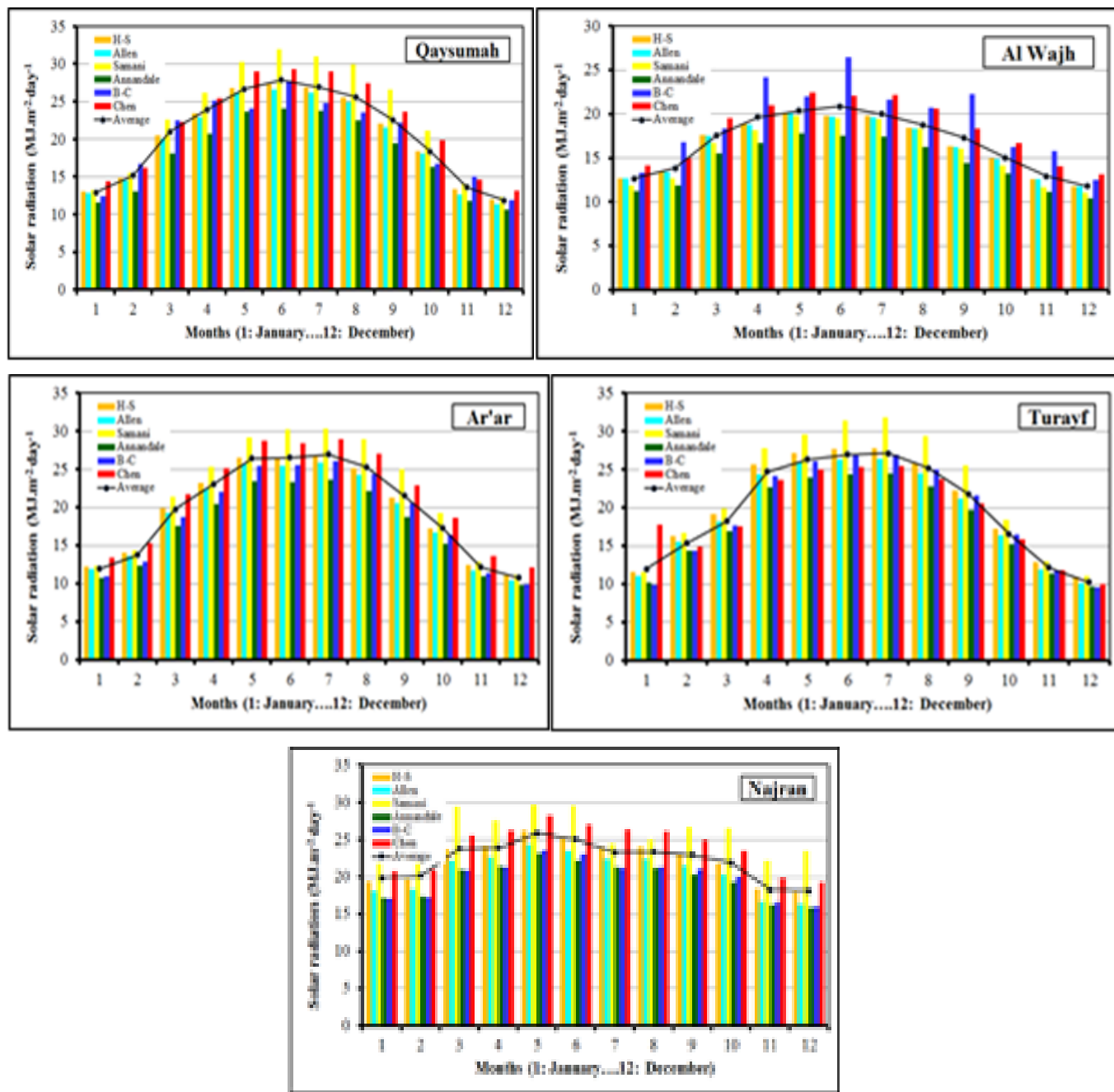


Figure 3: Estimated monthly solar radiation

5. EVALUATION OF MODEL PERFORMANCE

The accuracy and performance of the empirical models for Solar radiation estimation were evaluated and compared using the statistical indicators shown in Table 2. The table 8 summarized the model performance obtained using four statistical goodness of fit tests.

On average, the estimated global solar radiation is smaller than the observed with 0.3 to 29.7% for Hargreaves-Samani model, 4.7% to 30.1% for Allen model, 13.7 to 47.0% for Annandale model, 3.4 to 20.1% for Bristow-Campbell model (Table 8). The averages of estimated solar radiation of Samani model in Abha, Al Wajh, Ar'ar and of Chen model in Al Wajh, Ar'ar and Turayf are also smaller than the observed values with 9.5%, 34.6%, 0.3% and 16.4%, 2.2% and 12.9%, respectively. While, the estimated global solar radiation in Buraydah, Najran Qaysumah, Riyadh, Tabouk, and Turayf is only 1.4 to 17.2% greater than the observed values. The estimated solar radiation obtained by Chen model is 0.2 to 6.8%

greater than the observed in Abha, Buraydah, Najran, Qaysumah, Riyadh and Tabouk.

Based on the different statistical indicators Bristow-Campbell estimations perform the best among the studied empirical models in Abha (R2 : 0.90), Turayf (MAE : 0.29), Al Wajh (RMSE : 2.6), Riyadh (MAE : 0.05) and Buraydah (RMSE : 1.60). The Hargreaves-Samani estimations daily solar radiation were the best in Riyadh (PRMSE : 19.9; RMSE : 1.22), Buraydah (MAE : 0.13; PRMSE : 18.5), Tabouk (MAE : 0.62) and Najran (MAE : 0.61). The best daily estimations of solar radiation were obtained by Samani model in Turayf (PRMSE : 16.2; RMSE : 1.04) and Ar'ar (PRMSE : 19.3; MAE : 0.38, RMSE : 1.21). The best estimations given by Annandale model were recorded in Al Wajh and Najran with R2 : 0.76 and R2 : 0.70, respectively. Chen model shows the best estimations in five stations with (MAE : 1.84, RMSE : 2.25) in Abha; (PRMSE : 18.9, MAE : 0.12 and RMSE : 1.21) in Qaysumah, (MAE : 0.23) in Al Wajh; (PRMSE : 18.7, RMSE : 1.20) in Tabouk and (PRMSE : 20.5 and RMSE : 1.42) in Najran.

Table 8: Results of Models Performance used in estimating the solar radiation.

Abha	R ²	PRMSE	MAE	RMSE	Tabouk	R ²	PRMSE	MAE	RMSE
H-S	0.75	43.1	2.03	2.54	H-S	0.12	36.3	0.62	2.14
Allen	0.87	83.3	3.93	4.33	Allen	0.21	53.4	2.63	2.99
Samani	0.74	46.4	1.98	2.69	Samani	0.06	22.9	0.32	1.48

Table 8 (Cont): Results of Models Performance used in estimating the solar radiation.

Abha	R ²	PRMSE	MAE	RMSE	Tabouk	R ²	PRMSE	MAE	RMSE
Annandale	0.87	83.6	3.05	4.34	Annandale	0.38	84.7	4.05	4.40
B-C	0.90	41.5	2.16	2.52	B-C	0.14	39.6	1.99	2.30
Chen	0.80	34.8	1.84	2.25	Chen	0.04	18.7	1.07	1.20
Riyadh	R ²	PRMSE	MAE	RMSE	Turayf	R ²	PRMSE	MAE	RMSE
H-S	0.05	19.9	0.32	1.22	H-S	0.07	32.1	0.44	1.89
Allen	0.10	29.8	1.33	1.75	Allen	0.14	50.9	2.47	2.84
Samani	0.38	52.9	3.44	3.80	Samani	0.02	16.2	0.84	1.04
Annandale	0.20	60.6	2.98	3.27	Annandale	0.28	81.3	3.83	4.22
B-C	0.15	34.6	0.05	2.09	B-C	0.14	50.4	0.29	2.80
Chen	0.09	25.1	0.43	1.66	Chen	0.26	68.4	3.44	3.81
Qaysumah	R ²	PRMSE	MAE	RMSE	Ar'ar	R ²	PRMSE	MAE	RMSE
H-S	0.12	36.2	0.62	2.13	H-S	0.13	47.5	0.74	2.70
Allen	0.21	53.3	2.63	2.99	Allen	0.19	60.9	2.81	3.34
Samani	0.06	22.9	0.33	1.48	Samani	0.03	19.3	0.38	1.21
Annandale	0.38	84.9	4.05	4.41	Annandale	0.35	98.6	4.43	4.94
B-C	0.13	39.5	1.99	2.29	B-C	0.20	64.6	3.11	3.49
Chen	0.04	18.9	0.12	1.21	Chen	0.05	25.3	1.31	1.56
Al Wajh	R ²	PRMSE	MAE	RMSE	Najran	R ²	PRMSE	MAE	RMSE
H-S	0.63	112.6	1.86	5.33	H-S	0.35	33.5	0.61	2.16
Allen	0.63	114.4	4.92	5.39	Allen	0.60	59.3	3.22	3.54
Samani	0.65	127.5	4.19	5.81	Samani	0.87	51.5	2.98	3.95
Annandale	0.76	172.6	6.79	7.20	Annandale	0.70	78.8	4.22	4.48
B-C	0.26	46.9	2.12	2.60	B-C	0.68	74.0	4.01	4.25
Chen	0.41	67.7	0.23	3.57	Chen	0.19	20.5	1.16	1.42
Buraydh	R ²	PRMSE	MAE	RMSE					
H-S	0.04	18.5	0.13	1.13					
Allen	0.07	25.4	0.96	1.49					
Samani	0.49	67.8	4.43	5.01					
Annandale	0.22	54.0	2.56	2.91					
B-C	0.08	27.1	1.36	1.60					
Chen	0.11	29.6	0.38	1.94					

6. CONCLUSION

From the selected stations and the used data, the overall semi-averages ($X'2$) of daily maximum temperatures recorded during the second period (2002-2018) are greater than the similar averages ($X'1$) of the first period (1985-2001) over different months in Abha, Qaysumah, Al Wajh, Buraydah, Ar'ar and Najran and over 10 months from January to October in Riyadh, total of the months in Tabouk, except September and November and September in Turayf. The differences ($X'2-X'1$) are smaller the (2 SE) over different months in the selected stations, except February and May in Abha and May to October in Najran. So, the overall increased trends of the daily maximum temperatures are not significant in the total of studied, except the mentioned months in both Abha and Najran.

In the other hand, the overall semi-averages ($X'2$) of daily minimum temperatures of the second period (2002-2018) are greater than the similar averages ($X'1$) of the first period (1985-2001) over different months in Abha, Al Wajh, Tabouk and Turayf and over 12 months in Riyadh, Qaysumah, Buraydah and Ar'ar, except December and Najran, except February. The positive differences between both semi-averages ($X'2-X'1$) are smaller the (2 SE) over different months in Al Wajh, Buraydah Turayf, Ar'ar and Najran. In the rest of selected stations, the differences are also positive and smaller than the (2 SE), over different months, except April to September and November in Abha; From May to September in Riyadh; June in Qaysumah; July and August in Tabouk. Consequently, the overall increased trends of the daily minimum temperatures are not significant in the total of studied, except the mentioned months.

The highest value of mean solar radiation were obtained in May and June, with 20.2 to 27.7 MJm-2day-1 in Al Wajh and Buraydah for Hargreaves-

Samani model, from 20.1 to 26.6 (June) MJm-2day-1 in Al Wajh Qaysumah for Allen model, from 19.8 to 35.2 MJm-2day-1 in Al Wajh and Buraydah for Samani model, from 17.8 to 24.5 MJm-2day-1 in Al Wajh and Buraydah for Annandale model, from 22.0 to 27.8 MJm-2day-1 in both Qaysumah and Tabouk for Bristow-Campbell model and from 22.5 to 29.7 MJm-2day-1 in Al Wajh and Buraydah for Chen model. Based on the different statistical indicators Bristow-Campbell estimations perform the best among the studied empirical models in Abha, Turayf, Al Wajh, Riyadh and Buraydah.

The Hargreaves-Samani estimations daily solar radiation were the best in Riyadh, Buraydah, Tabouk and Najran. The best daily estimations of solar radiation were obtained by Samani model in Turayf and Ar'ar. The best estimations given by Annandale model were recorded in Al Wajh and Najran. Chen model shows the best estimations in Abha; Qaysumah, Al Wajh, Tabouk and Najran.

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