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RESEARCH ARTICLE

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

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ABSTRACT

This research presents an analysis of the estimated solar radiation using Maximum and minimum daily temperatures (Tdmax and Tdmin), and by applying three 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, R^2, MAE). This study seeks to analyze the variability and determine the best model of estimating the daily solar radiation using the temperature data over 1985-2018. This study relied on daily dataset of extreme temperatures collected during 34 years (1985-2018) in (Abha 41112), (Makkah 41030), (Tabouk 40375), (Yanbu 40439), (Qaysumah 40373), (Dammam 40417), (Al Jouf 40361), (Qasim 40405) and (Najran, 41118) meteorology stations supervised by the National Center of Meteorology (NCM). The methodology of this study deals with the analysis of the statistic distribution of dataset of the selected (T_x), Minimum daily (T_m) and Daily average (T') during the period 1985-2018 by applying the Kolmogorov-Smirnov test. The statistical significance of the Trends variance of daily temperatures was analyzed using the Semi-averages method and T-student test. The results of the statistical analysis were also represented on thematic graphs. This study revealed the spatial variations of the daily temperatures and their trends among the selected meteorology stations. The funding show many effective differences in spatial distribution of the daily temperatures. In the context of Trends analysis, the T-student test revealed the clearly differences between the semi-averages during the two periods of 1985-2001 (X'_1) and 2002-2018 (X'_2). In general, the differences (X'_2–X'_1) of temperatures (Minimum and Maximum) are smaller than the (2 SE) over different months in the selected stations. The mean of daily temperature had an increased not significantly trends in the studied stations. This study was able to represent the variation of the spatial distribution of daily temperatures using the statistical tests for determining the significance of the trends during the period 1985-2018. The integrated employment of the methods can give more accurate results in inferring climate change indicators over Saudi Arabia regions.

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 (Hargreaves-Samani, 1982; Allen, 1997; Bristow-Campbell, 1998). Because of all its properties, solar energy systems can be became 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

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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 became 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 three models, which are (Hargreaves-Samani, 1982; Bristow-Campbell, 1997).

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, pyrheliometer, and solarmeter. However, it is not practically possible to place these measurement devices in all regions due 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 three models to estimate solar radiation using the maximum and minimum daily temperatures available in 9 meteorology stations over Saudi Arabia.

3. Material and Methods

3.1 Study area

The selected weather stations were located over Saudi Arabia between 17º and 31º30' latitudes North and 35º and 50º 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 27ºC to 43ºC in the inland areas and 27ºC to 33ºC in coastal areas. In winter, the temperature ranges between 8 to 20 ºC in the interior parts while higher temperatures (19ºC-29ºC) have been recorded in the coastal areas of Red sea. The average annual rainfall in most parts of the country is bellow 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 values of temperature collected from the Presidency of Meteorology and Environment of Saudi Arabia (PME, 2018). The data from the weather station of Buraydah and Riyadh represent the Central region; Tabouk, the West Northern region; Ar'ar, and Turayf the Northern region; Abha the Southwestern region; Qaysumah, the Eastern region; Al Wajh the Western coast; and Najran the Southern of Saudi Arabia (Table 1).

Table 1: Geographic coordinates of the weather selected stations.

Region	Station Code	Station name	Longitude (E)	Latitude (N)	Elevation (m)
Asir highlands	41112	Abha	42º39'39"	18º13'59"	2093.3
Central region	40437	Riyadh	46º43'19"	24º55'31"	613.6
Eastern region	40373	Qaysumah	46º07'49"	28º19'08"	357.6
Western coastal	40400	Al Wajh	36º28'37"	26º12'19"	23.7
Central region	40405	Prince Naif Airport	43º46'03"	26º18'28"	646.7
West northern region	40375	Tabouk	36º36'25"	28º22'35"	768.1
Northern region	40356	Turayf	38º44'22"	31º41'16"	852.4
Northern region	40357	Ar'ar	41º08'26"	30º54'08"	548.9
Southern region	41128	Najran	44º24'49"	17º36'41"	1212.3

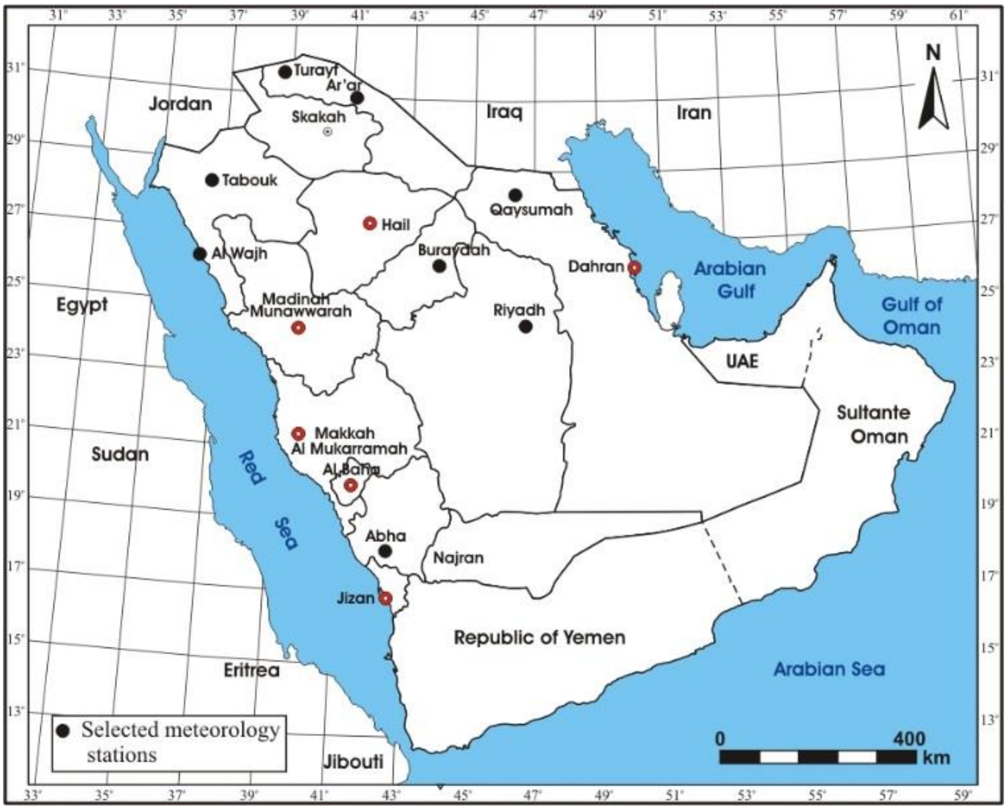


Figure 1: Geographic location of the weather stations.

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 :

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

Where:

lsc : solar constant equals 118.108 MJ.m-2.d-1.

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

$Eo = 1.00011 + 0.034221\ \text{Cos}\Gamma + 0.00128\ \text{Sin}\Gamma + 0.00719\ \text{Cos}2\Gamma + 0.000077\ \text{Sin}\Gamma$

Where:

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

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

λ: the latitude of the site (degrees),

δ: solar declination (degrees) equals :

$\delta = 180/\pi)(0.006918 - 0.3999912\ \text{Cos}\Gamma - 0.070257\ \text{Sin}\Gamma - 0.006758\ \text{Cos}2\Gamma + 0.000907\ \text{Sin}2\Gamma - 0.002697\ \text{Cos}3\Gamma + 0.00148\ \text{Sin}3\Gamma$

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

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

3.3 Models

3.3.1 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 (^oC),

T_{min} : Minimum daily temperature (^oC),

KΓ : Empirical coefficient equals 0.17 for arid and semi-arid regions. Hargreaves and Samani suggested to use KΓ = 0.16 for interior regions and KΓ = 0.19 for coastal regions.

3.3.2 Model 2- Allen (1997)

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

$K\Gamma = A(P/1013)$

Where:

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

A : Empirical coefficient equals 0.17 for interior regions and KΓ = 0.20 for coastal regions.

The model equation of Allen is :

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

3.3.3 Model 3- 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 :

$\Delta T : T_{max} - T_{min.}$

A : Empirical coefficient equals 0.7,

C : Empirical coefficient equals 2.4,

B : Empirical coefficient calculated as follows:

$B = 0.036 \exp[-0.154\ \mathbf{\Delta T_{(i)}}]$.

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 empirical models (Tadeda et al., 2022)

Model formula	Decision Rule	
$PRMSE = \left[\frac{1}{X_I}\sum_{i=1}^{n}(Y_i - X_I)^2\right] x\ 100$	PRMSE < 10	Excellent
	10 = PRMSE < 20	Satisfactory
	20 = PRMSE < 30	Acceptable
	PRMSE = 30	Unsatisfactory
$R^2 = \frac{\sum_{i=1}^{n}(X_i - Y_i)^2}{\sum_{i=1}^{n}(X_i - X')^2}$	$0.80 = R^2 < 1$	Excellent
	$0.65 = R^2 < 0.80$	Satisfactory
	$0.50 = R^2 < 0.65$	Acceptable
	$R^2 < 0.50$	Unsatisfactory
$MAE = \left[\frac{1}{n}\sum_{i:1}^{n}\lvert(Y_i - X_I)\rvert\right]$	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 (Ig) 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 methods to estimate monthly average daily in the nine meteorology stations (Hargreaves-Samani, 1982; Allen, 1997; Bristow-Campbell, 1998). 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 Abha with a mean of maximum daily value of 31.3 °C, July in Riyadh and Najran with 43.8 °C and 39.6 °C, respectively; August in Al Wajh, Buraydah, Tabouk, Qaysumah, Ar'ar and Turayf, with 34.6 °C, 44.0 °C, 39.5 °C, 45.3 °C, 42.4 °C and 37.3 °C, respectively. Contrary, January is the coldest month with a mean of minimum daily temperatures in the total of selected stations ranged between 7.3 °C and 19.0 °C, in Turayf and Al Wajh, respectively. Consequently, the difference between the mean maximum and minimum shows a thermal amplitude varying from 31.3 °C and 45.3 °C in Abha and Qaysumah, respectively. The extreme values of maximum daily temperatures were ranged from 35.5 °C (Augut 6, 2017) in Abha and 49.0 °C (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 3: Monthly averages of maximum, minimum and mean daily temperature for 1985-2018

Station	Month	Temperature (°C)				Temperature (°C)				Temperature (°C)		
		T_{mean}	T_{max}	T_{min}	Station	T_{mean}	T_{max}	T_{min}	Station	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
	Dec	14.1	21.1	7.5		15.2	22.1	8.6		13.4	20.1	7.7
Al Wajh	Jan	19.0	24.4	13.5	Buraydah	13.0	19.8	6.6	Tabouk	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

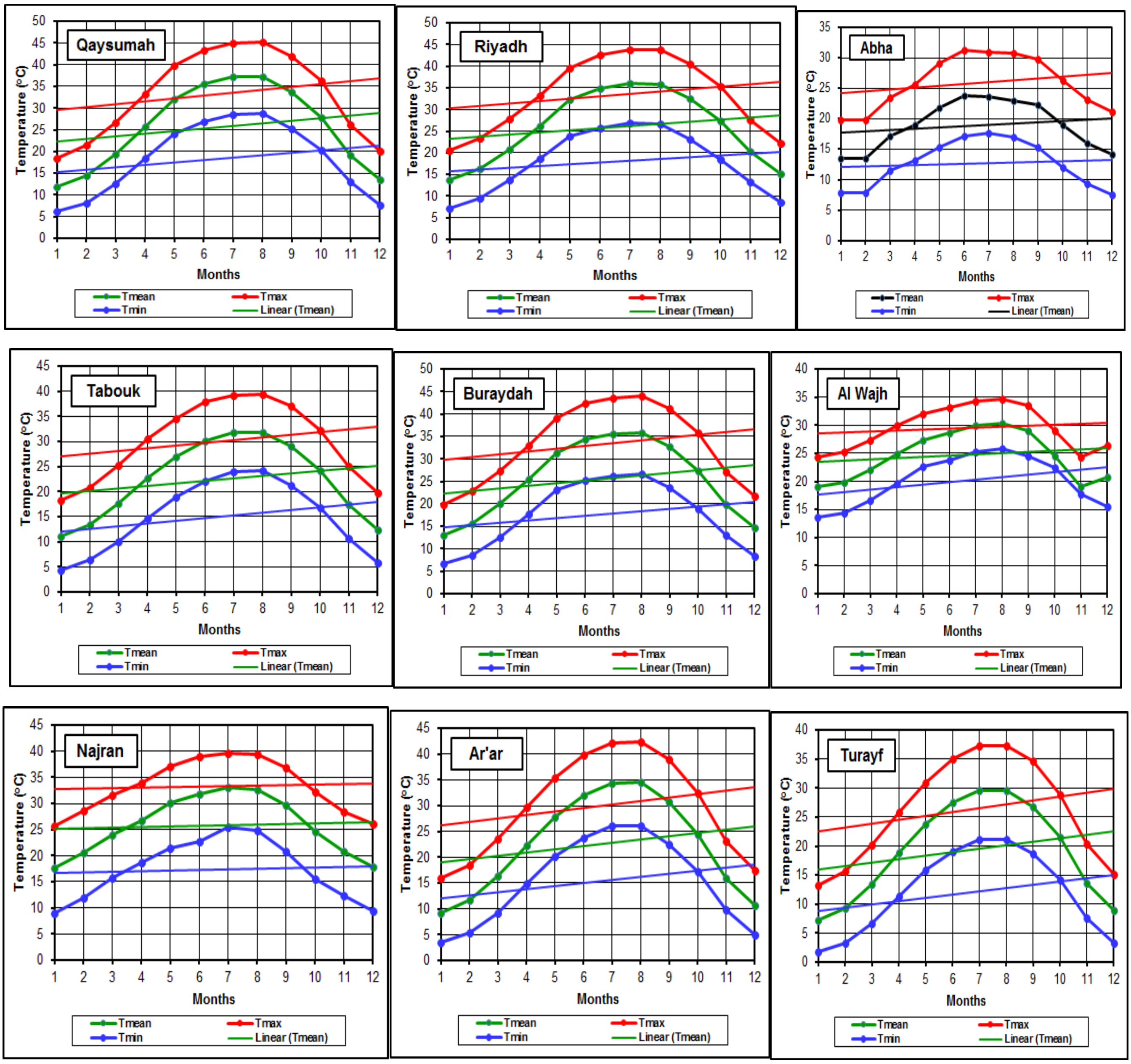


Figure 2: Monthly averages of Daily maximum, minimum and mean temperatures for 1985-2018

Table 4: Extreme maximum and minimum daily temperatures during 1982-2018.

	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

4.3 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 (σ_1, σ_2) and variance (σ^2_1, σ^2_2) 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 IX'1 – X'2I > 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 (T_x) and minimum (T_m) 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
	Sd_1	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
	Sd_2	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
	Sd_1	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
	Sd_2	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
	Sd_1	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
	Sd_2	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**
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**

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

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
	Sd₁	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
	Sd₂	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
	Sd₁	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
	Sd₂	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
	Sd₁	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
	Sd₂	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
	Sd₁	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
	Sd₂	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
	Sd₁	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
	Sd₂	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
	Sd₁	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
	Sd₂	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
	Sd₁	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
	Sd₂	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**
Qaysuah	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	0.8	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	4.8	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**

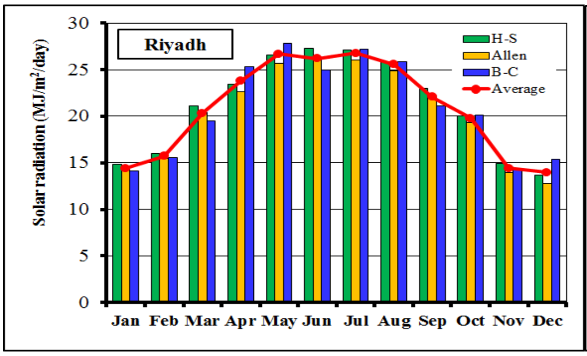
4.4 Analysis of Solar radiation variability

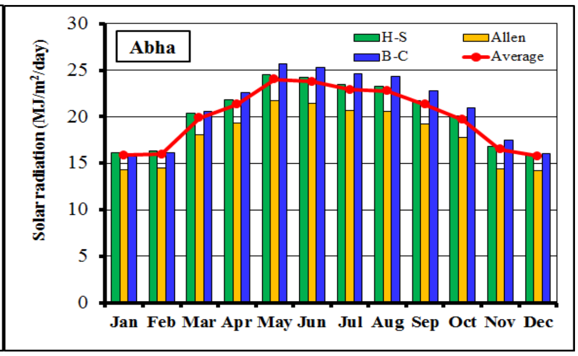
The long-term daily of solar radiation were calculated using the three models. The table 7 and Figure 3 summarized the results.

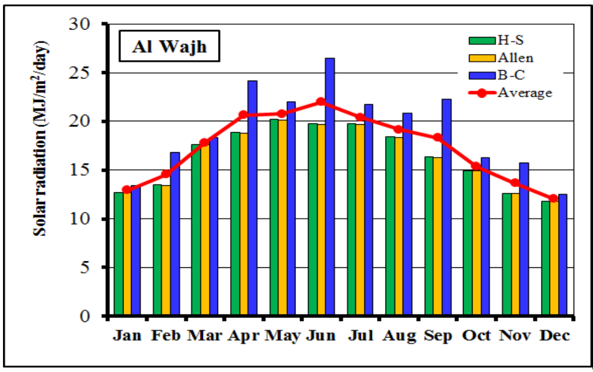
Table 7: Monthly averages of estimated solar radiation (MJ/m²/day) during 1985-2018

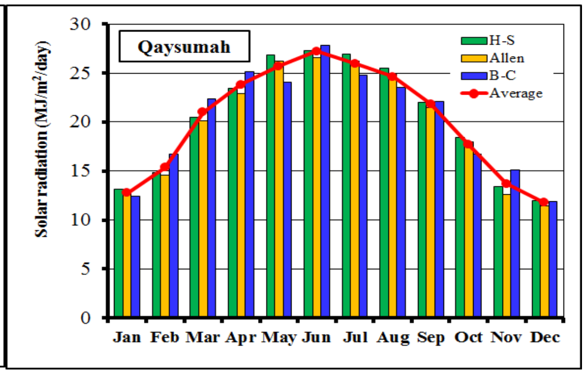
Model	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
	Abha											
H-S	16.2	16.3	20.4	21.9	24.5	24.2	23.4	23.2	21.7	20.1	16.8	16.0
Allen	14.3	14.5	18.1	19.4	21.7	21.4	20.7	20.6	19.2	17.8	14.4	14.2
BC	15.8	16.1	20.6	22.6	25.7	25.3	24.6	24.3	22.8	20.9	17.4	16.1
Riyadh												
H-S	14.8	16.0	21.1	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
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
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
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
Al Wajh												

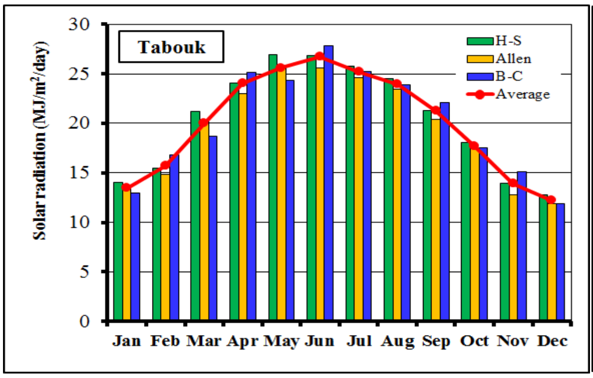
H-S	12.7	13.5	17.6	18.9	20.2	19.8	19.8	18.4	16.4	14.9	12.6	11.8
Allen	12.7	13.4	17.6	18.8	20.1	19.7	19.7	18.3	16.3	14.9	12.6	11.8
BC	13.4	16.8	18.3	24.2	22.0	26.5	21.7	20.8	22.3	16.3	15.7	12.5
Buraydah												
H-S	14.3	16.0	21.2	23.8	26.9	27.7	27.7	26.2	22.9	19.6	14.4	13.2
Allen	13.8	15.4	20.4	22.9	25.9	26.6	26.5	25.1	22.0	18.9	13.4	12.3
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
Tabouk												
H-S	14.0	15.5	21.2	24.1	26.9	26.8	25.8	24.5	21.3	18.1	13.9	12.8
Allen	13.4	14.8	20.2	23.0	25.7	25.6	24.6	23.4	20.4	17.4	12.8	11.9
BC	13.0	16.8	18.7	25.1	24.3	27.8	25.2	23.9	22.1	17.5	15.1	11.9
Turayf												
H-S	11.6	16.3	19.1	25.7	27.2	27.6	27.8	25.8	22.3	17.2	12.9	10.9
Allen	11.0	15.5	18.2	24.4	25.9	26.3	26.4	24.5	21.2	16.4	11.9	10.1
BC	9.9	14.4	17.7	24.2	26.1	26.8	27.0	25.0	21.6	16.5	11.8	9.6
Ar'ar												
H-S	12.2	14.0	19.9	23.2	26.5	26.4	26.8	25.1	21.3	17.2	12.5	11.1
Allen	11.9	13.6	19.3	22.4	25.6	25.5	25.9	24.3	20.6	16.7	11.7	10.4
BC	10.9	12.9	18.7	22.0	25.4	25.5	26.1	24.4	20.6	16.4	11.4	9.9
Najran												
H-S	19.4	19.7	23.7	24.2	26.1	25.2	24.1	24.0	23.1	21.8	18.4	18.0
Allen	18.1	18.4	22.1	22.6	24.3	23.4	22.4	22.3	21.5	20.4	16.6	16.3
BC	17.0	17.3	20.9	21.3	23.5	23.0	21.1	21.3	21.1	19.9	16.5	16.0

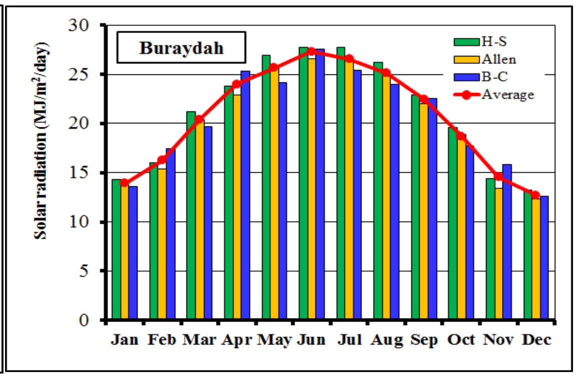












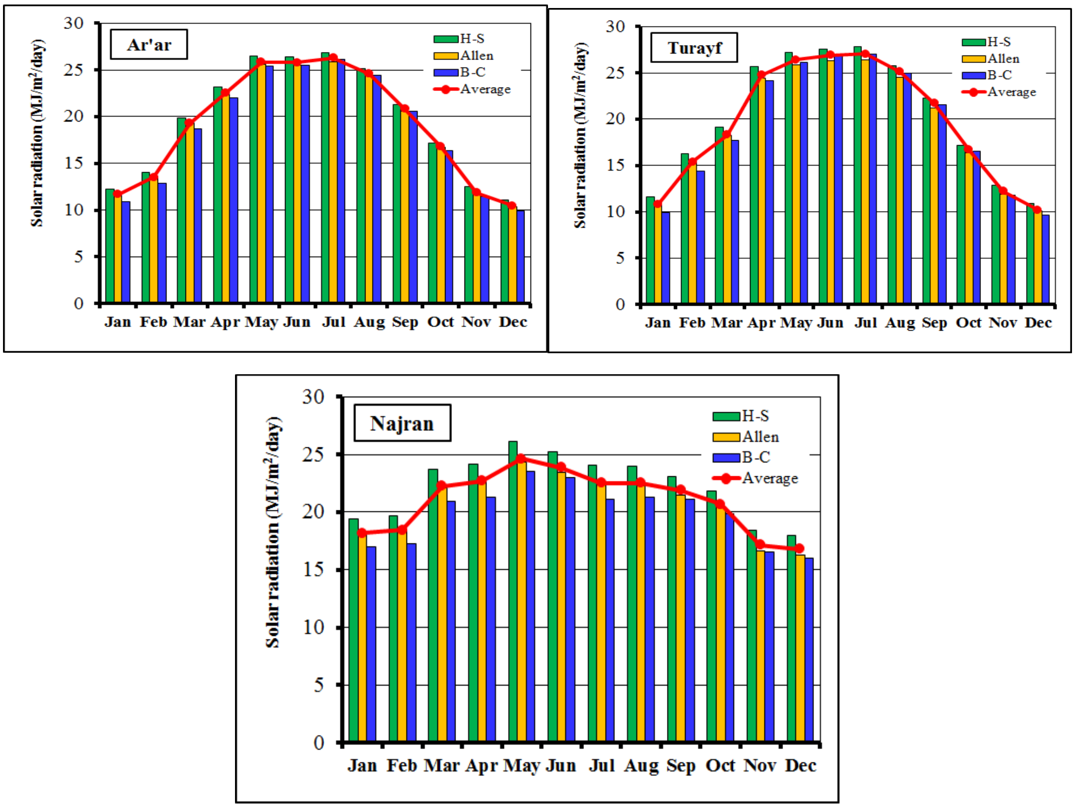


Figure 3: Estimated monthly solar radiation.

The lowest value of mean solar radiation was found in December from 10.9 $MJm^{-2}day^{-1}$ in Turayf to 18.0 $MJm^{-2}day^{-1}$ in Najran for Hargreaves-Samani model, from 10.1 $MJm^{-2}day^{-1}$ in Turayf to 16.3 $MJm^{-2}day^{-1}$ in Najran for Allen model, from 9.6 $MJm^{-2}day^{-1}$ in Turayf to 16.1 $MJm^{-2}day^{-1}$ in Abha for Bristow-Campbell model. The highest value of mean solar radiation were ranged from 20.2 (May) $MJm^{-2}day^{-1}$ in Al Wajh to 27.7 (June) $MJm^{-2}day^{-1}$ in Buraydah for Hargreaves-Samani model, from 20.1 (May) $MJm^{-2}day^{-1}$ in Al Wajh to 26.6 (June) $MJm^{-2}day^{-1}$ in Qaysumah for Allen model, from 22.0 (May) $MJm^{-2}day^{-1}$ in Al Wajh to 27.8 (June) $MJm^{-2}day^{-1}$ in both Qaysumah and Tabouk for Bristow-Campbell model.

4.5 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, and 3.4 to 20.1% for Bristow-Campbell model (Table 8).

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
B-C	0.90	41.5	2.16	2.52	B-C	0.14	39.6	1.99	2.30
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
B-C	0.15	34.6	0.05	2.09	B-C	0.14	50.4	0.29	2.80
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
B-C	0.13	39.5	1.99	2.29	B-C	0.20	64.6	3.11	3.49
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
B-C	0.26	46.9	2.12	2.60	B-C	0.68	74.0	4.01	4.25
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					
B-C	0.08	27.1	1.36	1.60					

Based on the different statistical indicators Bristow-Campbell estimations perform the best among the studied empirical models in Abha (R^2 : 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). In turns out that the Allen model is less efficient than the Hargreaves-Samani and Bristow-Campbell models in estimating the solar radiation in selected stations.

5. 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, 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. 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 $MJm^{-2}day^{-1}$ in Al Wajh and Buraydah for Hargreaves-Samani model, from 20.1 to 26.6 (June) $MJm^{-2}day^{-1}$ in Al Wajh Qaysumah for Allen model, from 22.0 to 27.8 $MJm^{-2}day^{-1}$ in both Qaysumah and Tabouk for Bristow-Campbell 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 Qaysumah, Ar'ar, Tabouk and Najran.

References

Adaramola, M.S., 2012. Estimating global solar radiation using common meteorological data in Akure, Nigeria, Renewable Energy, (47), Pp. 38-44.

Adekoya, O.B., Olabode, J.K., and Rafi, S.K., 2021. Renewable energy, consumption, carbon emissions and human development: empirical comparison of trajectories of world regions, Renew Energy, (179), Pp. 1836-1848.

Allen, R.G., 1995. Evaluation of procedures for estimating mean monthly solar radiation from air temperature, Report prepared for FAO, Rome, Italy.

Almorox, J., Hontoria, C., and Benito, M., 2011. Models for obtaining daily global solar radiation with measured air temperature data in Madrid (Spain), Appl. Energy, (88), Pp. 1703-1709.

Annandale, J., Jovanovic, N., Benade, N., and Allen, R., 2002. Software for missing data error analysis of Penman-Monteith reference evapotranspiration, Irrigation Science, (21), Pp. 57-62.

Ball, R., Purcell, L., and Carey, S., 2004. Evaluation of solar irradiation prediction models in North America, Agronomy Journal, (96), Pp. 391-397.

Besharat, F., Dehghan, A.A., and Faghigh, A.R., 2013. Empirical models for estimating global solar radiation : a review and case study, Renewable Sustainable Energy Review, (14), Pp. 798-821.

Bristow, K.I., and Campbell, G.S., 1984. On the relationship between incoming solar radiation and daily maximum and minimum temperature, Agricultural and Forest Meteorology, (31), Pp. 159-166.

Charfeddine, L., and Kahia, M., 2019. Impact of renewable energy, consumption and development on CO2 emissions and economic growth in MENA region: a panel vector autoregressive (PVAR) analysis, Renew Energy, (139), Pp. 198-213.

Chen, R., Kang, E., Lu, S., Yang, J., Ji, X., Zhang, Z., and Zhang, J., 2006. New method to estimate global radiation based on meteorological data in China, Energy Consion and Management, (47), Pp. 2991-2998.

Chowdhoury, S., and Al-Zahrani, M., 2022. Implications of climate change on water resources in Saudi Arabia, Arabian Journal for Science and Engineering, (14), Pp. 1959-71.

Chukwujindu, N.S., 2017. A comprehensive review of empirical models for estimating global solar radiation in Africa, Renewable and Sustainable Energy Review, (78), Pp. 955-995.

Das, M., and Mandal, R., 2022. Effect of solar radiation and operating factor of the PV module on the loss of lead probability of a PV-Battery system, Materialstoday Proceedings, (56), Pp. 2767-2773.

Elagib, N., and Mensll, M., 2000. New approaches for estimating global solar radiation across Sudan, Energy Conservation and Manageent, (41), Pp. 419-434.

Gregory, S., 1970. Statistical methods and Geographer, Longman Grou. Ltd., London, Pp. 277.

Güney, T., 2021. Solar energy, governance and CO2 emissions, Renewable Energy, (184), Pp. 791-798.

Gürel, A.E., Ağbulut, U., Bakir, H., Ergun, A., and Yildiz, G., 2023. A state of art review on estimation of solar radiation with various models, Heliyon, (9), Pp. e13167.

Hargreaves, G.H., and Samani, Z.A., 1982. Estimating potential evaporation, Journal of Irrigation and Drainage Engineering, 108IR3, Pp. 223-230.

Ho, Y., 2022. The relationship between renewable energy consumption, carbon emissions, output and export in industrial and agricultural sectors: evidence from China, Environmental Science and Pollution Research, (29), Pp. 63081-63098.

Kabir, E., Kumar, P., Kumar, S., Adelodun, A.A., and Kim, K.H., 2018. Solar Energy: Potential and Future prospects, Renewable and Sustainable Energy Review, (82), Pp. 894-900.

Keaman, O.A., Agirr, T.T., and Arsel, I., 2021. Estimation of solar radiation using modern methods, Alex. Eng. J, 14 (2), Pp. 2447-55.

Kean, A.T., Ella, V.B., Lampayan, R.M., and Consorcia E., Reaño, C.E., 2022. Modeling Reference Crop Evapotranspiration Using Support Vector Machine (SVM) and Extreme Learning Machine (ELM) in Region IV-A, Philippines, Water, 14, Pp. 754. https://doi.org/10.3390/w14050754.

Khan, M.S., Ramli, M.A.M., Sindi, H.F., Hidayat, T., and Bouchekara, H., 2022. Estimation of solar radiation on a PV Panel surface with an optimal Tilt Angle using Electric Change Particles Optimization, Electronics, 11 (13), Pp. 29.

Lima, A.O., Lyra, G.B., DeSouza, J.L., DeOlivera Jr, J.F., and Santos, A.R., 2019. Assessment of momnthly global solar radiation estimates using air temperature in different climates on the state of Rio de Janeiro, Southeastern Brazil, SN Applied Sceinces, 1, Pp. 1002.

McCormick, P.G., and Suehrcke, H., 2018. The effect of intermittent solar radiation on the performance of PV systems. Solar Energy, (171), Pp. 667-674.

Oliver, J.E., 1982. Climatology selected applications, Edward Arnold, V.H. Wiston and Sons, Pp. 260.

Rehman, S., and Mohandes, M., 2023. Artificial neural network estimation of global solar radiation using air temperature and relative humidity, Energy Policy, (36), Pp. 571.576.

Samani, Z., 2000. Estimating solar radiation and evaporation using minimum climatological data, Journal of Irrigation and Drainage Engineering, (126), Pp. 265-267.

Santamouris, M., Mihalakakou, G., Psiloglou, R., Eftaxias, G., and Asimakopoulos, D., 1999. Modeling the global solar radiation on Earth surface uding atmospheric deterministic and intelligent data-driven techniques, Journal of Climate, 12, Pp. 3105-3116.