Assessment of UVB solar radiation in four different selected climate locations in Saudi Arabia

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ABSTRACT
In this paper, we used the data measurements of average hourly and monthly of UV solar radiation from 2003 to 2017 at four different selected locations in Saudi Arabia for optimisation and evaluation of UVB, UVB$_{tot}$, UVI and $K_{UVB}$ solar radiation and total ozone column TOC (DU). The scattering phenomena on by stratospheric ozone is high extremely attenuation of UVB solar radiation. The predicted values of UVB solar radiation are a good agreement with the measurement of the UVB solar radiation. The accuracy between measured and predicted values of UVB solar radiation in selected locations in the present research varies from 1.27 to 3.87%. The maximum values of the total ozone column TOC are occur between March and April in April and the months, and in whole the highest values of TOC occur about spring time in all study locations. The relation between UVI and (SZA) at all selected locations in the present research is discussed. The monthly average has a correlation coefficient equal to 72%, 82%, 85% and 83% at Al-Baha, Abha, Jeddah and Taif sites, respectively, so the SZA is responsible for variations of UVI by 72%, 82%, 85% and 83% at Al-Baha, Abha, Jeddah and Taif locations for the monthly values respectively.

1. Introduction
The UV solar radiation takes up a small portion of the total solar irradiance (usually about 5–7%), but is a key component for the sustenance of life on Earth (Dillan Raymond Roshan et al. 2020). The UVR solar radiation covers the frequency run 100–400 nm, and is isolated into three classifications; right off the bat UVA (315–400 nm), second UVB (280–315 nm), and third UVC (100–280 nm). The major portion of solar radiation energy is regularly discovered in the noticeable and infrared range. The UV solar radiation speaks with an exceptionally little bit of the complete radiation from the sun that arrives at the world’s surface (Som AK 1992). All UVC solar radiation and closest 90% of UVB solar radiation are consumed by ozone, water fume, oxygen and carbon dioxide. However, the UVA solar radiation is less influenced by the climate. At that point, the UV solar radiation arriving at the Earth’s surface is to a great extent made out of UVA with a little UVB segment (Elhadidy MA et al. 1990; Mujahid AM 1994).

The UV-B and UV-C solar radiation found that the portion of the recurrence extend that is prepared for hurting normal living things and it’s partially devoured by the ozone layer over the earth. The imperative UV-C solar radiation is devoured by ozone and to some degree relative few to show up at the world’s surface. On account of the UV solar radiation, extra factors are ozone and height above ocean level. The most significant factor is the aggregate sum of ozone that solar radiation experiences before arriving at the world’s surface (Martinez-lozano J A. 1994, 1999; Foyo-Moreno I and Alades 1998). This is alluded to as “segment ozone” since it is the aggregate sum of ozone in a segment between the world’s surface and the head of the stratosphere. This is typically communicated as “Dobson Units” and condensed as “DU” (Kerr J.B. also, McElroy 1993; Stolarski R. 1997; Caldwell, M.M. et al. 1998).

Over the most recent twenty years, the presence in the air ozone-draining substances has been lessening the ozone focus in the stratosphere over high and mid-spheres of the two sides of the equator. The decrease of stratospheric ozone has been perceived as the fundamental driver of the expansion of UVB irradiation at the World’s surface. This expansion has been assessed in the range of 5–13% over the most recent twenty years (Samy A. Khalil and M.A. Shaffie 2013). UVB solar radiation has different direct unfavourable impacts on human wellbeing (skin disease, immuno-suppression, and eye problems), earthbound plants and seagrowing living beings. Additionally, because of the distinctions in UVB affectability and variation among the different species, shifts in species organisation may happen as a result of expanded UVB radiation, accordingly driving by implication to
modifications in environments (Khalil and Shaffie 2013a). As the improvement of sunlight-based UVB is exceptionally frequency explicit and increments when the frequency diminishes, activity spectroscopy assumes a focal function in evaluating the impacts of ozone consumption on the biosphere (Samy A. khalil and M.A. Shaffie 2016). Several authors study the relation of UV radiation to global radiation in the eastern Mediterranean area (Trabea and Salem 2001) and (Roba 2004) reported an average per cent ratio of 3.5% over Cairo, Egypt (Martinez-Lozano et al. 1994; Foyo-Moreno et al. 1998b) reported monthly mean values ranging between 2.7% and 5.2% over several Spanish sites. (Koronakis et al. 2002) reported an annual mean value of 4.1% over polluted Athens, Greece. The reported range of correlations suggests the desirability of local calibration to account for specific climatic conditions (Kudish et al. 2005).

During quite a long while later, the sensational stratospheric ozone consumption has been seen over the Antarctic landmass (Samy A. khalil and M.A. Shaffie 2018). This was likewise found over the North Pole (Samy A. khalil and M.A. Shaffie 2019). Huge reductions in complete ozone section are additionally recorded at high and mid-scales with attending increments in solar radiation UVB (280–315 nm, C.I.E. definition) at the World’s surface (Booth and Morrow 1997). The high vivacious short frequency radiation influences most types of life on this planet. It is answerable for expanded occurrences of skin malignancy in people, higher paces of waterfalls, immunosuppression just as different ailments. UVB solar radiation has been accounted for to influence earthly and seagoing biological systems and may have critical ramifications for the science of the lower atmosphere (Smith et al. 1993; Acosta and Evans 2000; Aas and Højerslev 2001; Samy A. khalil 2013).

Practically all outside living life forms are presented to solar radiation (UV). The significance of the solar radiation of the living life forms and the connection between the environmental absolute content (TOC) and the UVB solar radiation invigorate the work in this field (Ilyas et al. 1999). Biological systems experience from morning to night a solid variety of UV force because of diurnal changes in solar radiation height, which relies upon the scope and season. These progressions are the most predominant factor causing momentary variations in UV radiation on Earth. The UV solar radiation-run dissipating measures are additionally significant and reflection from the beginning radiation levels estimated at the surface. All adjustments in UV brought about by climatic components, for example, ozone exhaustion, expanded measure of vaporisers or expanded overcast spread, impact obviously the measure of UV for water. In a few examinations it has been indicated that there is an extraordinary fluctuation in UV infiltration both in new water and marine conditions, because of various water quality (Fioletov et al. 1997; Koronakis et al. 2002; M.H. Korany and H.A. Basset 2007; Zaki Almostafa, et al. 2015).

The main objective of this paper is assessment of average hourly and monthly of UVBext, UVB, UVBext−UVI and KUVB solar radiation and total ozone column TOC (DU) during the period time from 2003 to 2017 at four different selected locations in Saudi Arabia. The data in this research were obtained part of the Meteorological and Environmental Protection Agency (MEPA) in Saudi Arabia and another part of the observation station in Al-Baha University.

2. Material and methods of present study

2.1. Geography and climate of Saudi Arabia

Saudi Arabia is a country situated in Southwest Asia and includes approximately four-fifths of the Arabian Peninsula between scopes 16° and 33°N and between longitudes 34° and 56°E. Saudi Arabia contains the world’s largest continuous sand desert, Al-Rub Al-Khali (the Empty Quarter). The oasis region of Al-Ahsa occupies much of the Eastern Province as shown in Figure 1. KSA is well placed for capitalising solar energy with the average daily solar radiation level reaching 6 kWh/m² and 80–90% of clear sky days over the year. The annual solar radiation level reaches over 2400 kWh/m² as shown in Figure 2. KSA climate is generally hot and dry, although nights are cool, and frosts occur in winter. The humidity along the coasts is high. The temperature during the summer is high, reaching well over 45°C, with generally cold nights. Extreme temperatures well below 0°C are frequent in winter. The average monthly temperatures observed in

![Figure 1. Geographic map of Saudi Arabia.](attachment:image)
KSA over the last century ranged between a low of 15.5°C from December to February to 30°C from May to September (Samy A. Khalil et al. 2019).

The geographical locations in Saudi Arabia are highly favourable for solar energy investment due to its proximity to the European Union and as a part of one of the Sunbelt countries (Kada Bouchouicha et al., 2019). The geographical distribution of the selected locations in the present research is illustrated in the map presented in figure 1, and the solar radiation map of Saudi Arabia presented in figure 2. Further information about the selected location details is provided in Table 1.

### 2.2. Collected data and geographical locations

In this study, we used the hourly and monthly data on UV solar radiation collected during the period time from 2003 to 2017 at four regions located in Saudi Arabia (Al-Baha, Abha, Jeddah and Taif locations). The proposed by present research to assess the hourly and monthly average of the ultraviolet (UV) solar radiation component (UVBext, UVB, UVI and clearness index UV) and total ozone column (TOC). The data were obtained from the Meteorological and Environmental Protection Agency (MEPA) in Saudi Arabia and the observation station in Al-Baha University. The Al-Baha meteorological research station carried out hourly value measurements of ultraviolet solar radiation (UV, MJ m-2 h-1) at the horizontal surface. Ultraviolet irradiation is measured using an Eppley radiometer TUVR No. 31,737. Its sensitivity and cosine response are approx. 150 μV/ (W/m2) and ± 3.5% from normalisation 0–70° zenith angle. The Combilog Datalogger (No. 1020, TH. Friedrichs & CO. “Germany”) recorded the values of hourly UVB. This instrument traceable to the World Radiometric Reference (WRR) maintained at Davos, Switzerland (World Radiation Center -WRC), 1985, 1995). The absolute accuracy of calibration is ±3%-4%. The resolution of these instruments is 1 Wm⁻². In addition, total ozone column data (TOC, DU) were obtained from Total Ozone Mapping Spectrometer (TOMS) satellite (http:juic.gsfc.NASA.Gov/index.html) which was given around 12:00 GMT (Adam and Ahmed 2013).

The monthly average of the main statistics (Minimum, Maximum, Range, Mean, Median, Standard error, Average deviation and Standard deviation) of UVB, UVBest., Kuvb and TOC (MJ.m⁻².h⁻¹) at the selected locations in the present research during the period time from 2003 to 2017 are shown in tables 2 & 3. From these tables, we indicate that the values of mean and median for all locations in the present research are nearest to them. This is due to the quality of data used in this paper is good. In addition to the values of standard deviation, average deviation and standard error are very small. The accuracy of the data of the present study does not exceed 8%.

The data frequency histogram of the selected locations (Al-Baha, Abha, Jeddah and Taif) during the period time from 2003 to 2017 is clearly in figure 3. The high variability of the monthly values of both UVB radiations during the period time in this research is demonstrated by cumulative frequencies of monthly total UVB radiation.

Moreover the Geography and atmosphere of chose areas in the current research as follows: Al-Baha city is isolated geologically into three undeniable parts: Sarah, which contains the high Hejaz mountains depicted by quiet atmosphere and rich plant spread due to commonly high yearly precipitation, Tihama which is the marsh, seashore a front area westward of

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**Table 1. Information on the selected locations in the present study.**

| Locations | Al-Baha | Abha | Jeddah | Taif |
|-----------|---------|------|--------|------|
| Latitude (°N) | 20.02 | 18.13 | 21.32 | 21.16 |
| Longitude (°E) | 41.20 | 42.30 | 39.11 | 40.24 |
| Elevation (m) | 2470 | 2200 | 12 | 1879 |
| The period of data | 2003–2017 | 2003–2017 | 2003–2017 | 2003–2017 |
| Mean T (°C) | 23.4 | 24.7 | 29.2 | 25.4 |
| Missing data percentage | 4.5% | 6.9% | 6.3% | 5.7% |
Table 2. The main statistics of UVB, UVBest., K_{UVB} and TOC (MJ.m⁻²h⁻¹) at Al-Baha and Abha sites.

|                | Al-Baha | UVB | UVBest. | K_{UVB} | TOC | Abha | UVB | UVBest. | K_{UVB} | TOC |
|----------------|---------|------|---------|---------|-----|------|------|---------|---------|-----|
| Number of values | 180     | 180  | 180     | 180     | 180 | 180  | 180  | 180     | 180     | 180 |
| Minimum         | 0.0033  | 0.0031| 0.0630  | 272.1   | 0.0031| 0.0031| 0.0117| 0.0117  | 275.3   |     |
| Maximum         | 0.0128  | 0.0129| 0.122   | 344.3   | 0.0129| 0.0132| 0.123 | 337.2   |         |     |
| Range           | 0.0095  | 0.0098| 0.059   | 72.2    | 0.0098| 0.0101| 0.1113| 61.9    |         |     |
| Mean            | 0.0080  | 0.0081| 0.096   | 305.2   | 0.0080| 0.0081| 0.0942| 303.3   |         |     |
| Median          | 0.0080  | 0.0079| 0.095   | 298.6   | 0.0078| 0.0079| 0.0950| 297.7   |         |     |
| Standard error  | 0.0002  | 0.0002| 0.0012  | 1.289   | 0.0002| 0.0002| 0.0113| 1.124   |         |     |
| Average deviation| 0.0025  | 0.0025| 0.0134  | 14.85   | 0.0026| 0.0026| 0.0145| 13.06   |         |     |
| Standard deviation| 0.0029  | 0.0029| 0.0158  | 17.30   | 0.0030| 0.0030| 0.0177| 15.08   |         |     |

Table 3. The main statistics of UVB, UVBest., K_{UVB} and TOC (MJ.m⁻²h⁻¹) at Jeddah and Taif sites.

|                | Jeddah | UVB | UVBest. | K_{UVB} | TOC | Taif | UVB | UVBest. | K_{UVB} | TOC |
|----------------|--------|------|---------|---------|-----|------|------|---------|---------|-----|
| Number of values | 180     | 180  | 180     | 180     | 180 | 180  | 180  | 180     | 180     | 180 |
| Minimum         | 0.0029  | 0.0028| 0.0115  | 279.6   | 0.0031| 0.0031| 0.059 | 225.3   |         |     |
| Maximum         | 0.0129  | 0.0131| 0.1220  | 334.8   | 0.0129| 0.0132| 0.123 | 337.2   |         |     |
| Range           | 0.0100  | 0.0103| 0.1105  | 55.2    | 0.0098| 0.0101| 0.064 | 111.9   |         |     |
| Mean            | 0.0076  | 0.0078| 0.0900  | 302.2   | 0.0077| 0.0079| 0.092 | 301.2   |         |     |
| Median          | 0.0076  | 0.0079| 0.0915  | 297.6   | 0.0076| 0.0079| 0.092 | 296.6   |         |     |
| Standard error  | 0.0002  | 0.0002| 0.0013  | 0.9304  | 0.0002| 0.0002| 0.012 | 1.109   |         |     |
| Average deviation| 0.0024  | 0.0024| 0.0139  | 10.5    | 0.0025| 0.0025| 0.014 | 12.12   |         |     |
| Standard deviation| 0.0028  | 0.0028| 0.0178  | 12.48   | 0.0029| 0.0029| 0.016 | 14.88   |         |     |

Figure 3. The data frequency histogram from 2003 to 2017 for selected sites in the present research (MJ/m²/h).

the Hejaz portrayed by rankling and the wet atmosphere and basically no precipitation ordinary, and the eastern slants depicted by a rise of 1,550 to 1,900 metres above sea level with cool winters, boiling summers and small plant spread. The greatest city in the domain, both in people and the zone is Baljurashi the resulting one is Al-Mandaq. In Tehama, there are two critical metropolitan networks: Qilwah and Al-Mikhwah (Al-Baha 2012).

Abha is arranged in the southern area of Asir at an ascent of around 2,270 metres above sea level. Abha lies on the western edge of Mount Al-Hijaz close to Jabal Sawda, the most raised top Saudi Arabia. With respect to Asir Mountains as a significant part of the Sarawat, the scene is regardless directed by the Sarawat Mountains. The environment of Abha is semi-dry and it is influenced by city’s high stature. The city’s atmosphere is ordinarily smooth, reliably, getting recognisably cooler during the “low-sun” season (Climat Abha, 2013).

Jeddah was a noteworthy city of Hejaz Vilayet, the Kingdom of Hejaz and other commonplace political substances as shown by Hijazi history books. Jeddah incorporates a dry environment under Koppen’s climate game plan, with a tropical temperature run. Jeddah holds its warm temperature in winter.
Summer temperatures are unbelievably rankling. Summers are moreover extremely sweltering, with dew concentrates. Precipitation in Jeddah is generally insufficient, and regularly occurs in November and December (Samy A. Khalil et al. 2019).

Taif lies south east of Jeddah and the Holy City of Mecca. Taif is arranged in the mountains above Makkah and Jeddah. In the winter the temperature can find a workable pace as three degrees and as high as eighteen degrees. In spring and autumn, it some time downpours and the atmosphere is gentle with a little virus wind. Taif’s rise gives it a far cooler and lovelier atmosphere than either Jeddah or Makkah and without the awkward dampness of the previous (Taif, 2019).

3. Methodology

The estimations of UVI solar radiation have been gotten from other worldly determined weighted by the erythema activity range (Foyo-Moreno I. et al. 1998; Trabea A.A., Saten A.I. 2001; La, Casinier et al. 2002; Sabziparvar A. 2009, Lindfors A., Vuilleumier L. 2007; Webb A., Steven M.D. 1986; Oguniobi K.O., Kim Y.J., 2004). They are spoken to by (UVI) display and can be acquired by the following expression:

\[
(UVI)_{model} = K_e \int_{290}^{400} E_{\lambda} S_{\lambda}(\lambda) d\lambda
\]  

Where \(K_e\) is 40 m^2 W^{-1}, \(E_{\lambda}\) is the UV spectrum wavelength dependent (Wm^{-2}nm^{-1}) and \(S_{\lambda}\) is the erythema weighting function accepted by CIE (Commission International d’Eclairage) and given by (Samy A. Khalil et al. 2008, J.A. Duffie, W.A. Becton 1994, El-Noshar A.M. 1991; WMO 1994; Frederick J. E. 1993).

The UBV hemispherical transmittance can be defined in the following way (Frederick et al. 1993; Herman J.R. 1996; Madronic J. S. Flooke 1997; Webb A.R. 2006).

\[
KTUV = \frac{UVB}{UVB_{ext}}
\]  

Where, UVBext., is the extraterrestrial solar radiation value on a horizontal surface it is given by:

\[
UVB_{ext.} = ISCUBV(12/\pi)E_0 \int_{\omega_2}^{\omega_1} \sin(\theta) d\omega
\]  

Where \(\theta\) is the solar elevation angle, \(E_0\) is the correction factor for the eccentricity of the Earth’s orbit, \(w_i\) \((i = 1 \text{ and } 2)\) is the solar our angle at the beginning of the period and at the end of period, respectively, and \(ISCUBV\) is the UBV solar constant (21.51 Wm^{-2}). It has been obtained from the spectral values given by (Robaa SM. 2004; Sabziparvar A.A, Shine K.P. 1999; Al-Aruri Sd. 1990; Preez R. et al. 1990; Anton M. et al. 2009; Serrano A. 2008).

The slant total ozone column (TOC), Dobson (DU) represents the actual ozone amount in the atmosphere as follows (Zerefos C. et al. 2001; Krzyscin JW et al 2003; Cando J. Pedro, G. Bosca 2003; Kudish A. I. et al. 2005; El-Nouby 2010):

\[
Z = \frac{TOC}{SZA}
\]  

Where (SZA) is the cosine of the solar zenith angle, this expression is only valid for the direct solar irradiance.

The relation between the UV index and solar zenith angle (SZA) as following equation (Sabziparvar A., Shetaee H.2007, H. Frouk et al. 2012,120):

\[
UVI = a (SZA)^b
\]  

Where (a) and (b) were determined from the least squares fitting.

The popular statistical tools are used for assessing the data in the present research. Following are the statistical tools described below: Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE), correlation coefficient (R) and t-statistics (t-test).

\[
MBE = \frac{1}{n} \sum_{i=1}^{n} (X_i - Y_i)
\]  

\[
RMSE = \left\{ \frac{1}{n} \sum_{i=1}^{n} (X_i - Y_i)^2 \right\}^{1/2}
\]  

\[
MPE\% = \frac{1}{n} \sum_{i=1}^{n} \left( \frac{X_i - Y_i}{X_i} \right) \times 100
\]  

\[
R^2 = \frac{n\sum Y_i X_i - (\sum Y_i)(\sum X_i)}{\left[ n\sum X_i^2 - (\sum X_i)^2 \right] \left[ n\sum Y_i^2 - (\sum Y_i)^2 \right]^{1/2}}
\]  

\[
t - test = \left\{ \frac{(n - 1)(MBE)^2}{(RMSE)^2 - (MBE)^2} \right\}^{1/2}
\]

Where: \(X_i\) & \(Y_i\) are the measured and the estimated values, respectively, and \(n\) is the number of data points (observations).

4. Result and Discussion

Figures 4&5 show, the average hours of UBV_{ext.}, UBV, UBV_{ext.}, solar energy (M.J.m^{-2}h^{-1}) and clearness index \(K_{UVB}\) during the period time from 2003 to 2017 at Al-Baha, Abha, Jeddah and Taif locations. From these figures, we indicate that the highest values of the average hourly of UBV_{ext.}, solar energy are
0.0915 ± 0.011, 0.0941 ± 0.016, 0.0895 ± 0.015 and 0.0911 ± 0.013 at 1200 LST in the present research at Al-Baha, Abha, Jeddah and Taif respectively. The values of UVBext, solar energy is represented nearly 1.42 of the corresponding extraterrestrial global solar radiation (6.25 MJ.m\(^{-2}\).h\(^{-1}\)), (5.87 MJ.m\(^{-2}\).h\(^{-1}\)), (5.96 MJ.m\(^{-2}\).h\(^{-1}\)) and (5.63 MJ.m\(^{-2}\).h\(^{-1}\)) at the selected sites in the present work respectively. These ratios have nearly variables the same values for each hour from 800 to 1600 LST. These values vary from 1.48 to 1.69 in the selected locations, the average hourly of UVBeast. Irradiance are reduced from 1200 to 1600 LST (0.0518 ± 0.013, 0.0556 ± 0.016, 0.0435 ± 0.015, 0.0531 ± 0.017) in the selected locations Al-Baha, Abha, Jeddah and Taif respectively. And too we indicate that from these figures, the intensity of UVB solar energy varies between 0.0031 ± 0.002, 0.0095 ± 0.005 and 0.0028 ± 0.003 at 800, 1200 and 1600 LST in Al-Baha location, while it varies in Abha between 0.0033 ± 0.004, 0.0099 ± 0.007 and 0.0048 ± 0.005 at

Figure 4. Average hourly of UVBext, solar radiation (MJ.m\(^{-2}\).h\(^{-1}\)) and clearness indices (K\(_{\text{UVB}}\)) during the period time from 2003 to 2017 at selected locations in the present research.

Figure 5. Average hourly comparison between UVB and UVB\(_{\text{ext}}\), solar radiation (MJ.m\(^{-2}\).h\(^{-1}\)) during the period time from 2003 to 2017 at selected locations in the present research.
Figure 6. Monthly mean values solar radiation of UVBest, UVB, and UVBext. solar radiation (MJ.m\(^{-2}\)h\(^{-1}\)) during the period time from 2003 to 2017 at selected locations in the present study.

Figure 7. Monthly mean values of cleaner’s indices K\(_{UVB}\) during the period time from 2003 to 2017 at selected locations in the present study.

800, 1200 and 1600 LST, also in Jeddah site UVB solar energy varies between 0.0029 ± 0.001, 0.0093 ± 0.004 and 0.0035 ± 0.002 at 800, 1200 and 1600 LST and the end it is varies between 0.0032 ± 0.003, 0.0095 ± 0.004 and 0.0038 ± 0.004 at 800, 1200 and 1600 LST. On the whole of these figures, the assessed estimations of UVB solar radiation in the chose areas are a decent concurrence with the measured values of the UVB solar radiation, as indicated by the above conversation the conduct of UVBext. is because of the diurnal obvious movement of the sun around the Earth. The impact of the climate on UVB radiation is reflected in the examination of its conduct at the Earth’s surface. Also from Figures 4& 5, we notice that the average hourly values of the clearness index (K\(_{UVB}\)) in the selected locations from 2003 to 2017 in the present research. These values of (K\(_{UVB}\)) are less than the corresponding values of k\(_{i}\) for global solar radiation, then the values of (K\(_{UVB}\)) are 0.063, 0.104 and 0.054 at 800, 1200 and 1600 LST in Al-Baha site respectively, and the values of (K\(_{UVB}\)) in Abha location are 0.071, 0.105 and 0.086 at 800, 1200 and 1600 respectively, in
the same way the values of clearness index \( K_{\text{UVB}} \) at 800, 1200 and 1600 LST in the locations Jeddah and Taif are 0.083, 0.103, 0.071 and 0.070, 0.102, 0.072 respectively. The above outcomes are because of the high very constriction of UVB solar radiation by stratospheric ozone and dissipating wonders.

For the most part, the UVB transmission through the climate can be evaluated during the period time in the current exploration; the normal hourly estimations of UVB transmission are decreasing because of the air as an element of daytime, the greatest and least estimations of UVB transmission happen in 1200 and 1600 LST separately, in light of the fact that the air through which the radiation must pass has adjusted the UVB arriving at the Earth’s surface. This change is an element of the length of the radiation’s pass through the environment and the measure of every attenuator along that way length. Thus, the way length of the early afternoon hours 1200 LST is not as much as its qualities in the first part of the day hours 800 LST and evening hours 1600 LST.

The monthly mean values of UVB ext., measured and estimated values UVB solar radiation, clearness index \( K_{\text{UVB}} \), and total ozone column TOC (DU) during the period time from 2003 to 2017 at the selected locations in the present research are shown in Figures 6–8. From these figures, we sign that, the greatest estimations of the above significant boundaries happen around the late spring months, while the base qualities in winter months, however the estimations of these factors are evident that, in the spring and autumn months fall between the estimations of the summer and winter months, and furthermore evident that from Figures 6–8, the anticipated estimations of UVB solar radiation a decent concurrence with the deliberations of the UVB solar radiation. The distinction between the assessed and estimated estimations of UVB solar radiation changes 1.96–2.75%, 1.27–3.18%, 2.32–3.57% and 2.15–3.87% at Al-Baha, Abha, Jeddah, and Taif areas from 2003 to 2017 respectively. The maximum values of \( K_{\text{UVB}} \) solar radiation occur between summer and autumn months, while the minimum values occur between winter and spring months for all different locations. Also from these tables we clear that the maximum values of the total ozone column TOC occur between March and April months at all selected locations with exception Taif site which occur between April and May months, and in whole the highest values of TOC occur about Spring time in all study locations. The correlations between measured and estimated UVB values of sites in the present study are shown in Figure 9. Good agreements of measured and estimated values of UVB were obtained.

The average monthly mean of the UV index (UVI) solar radiation during the period time from 2003 to 2017 at around noon time (10 am – 2 pm) at the selected locations in the present work is illustrated in figure 10. From this figure we notice that the maximum values of UVI occur around the summer and spring months at the selected locations during the period time in the present study, while the minimum of UVI occurs around winter and autumn months. Also from this figure, we clear that the high levels of UVI are varied between 9.49, 9.47, 9.15 and 9.12 at Abha, Taif, Al-Baha and Jeddah respectively, while the low levels of UVI in the selected sites through the present research vary between 2.47, 2.85, 3.15 and 3.27 at Al-Baha, Taif, Jeddah and Abha locations. The differences between high and low levels in the present study vary between 27%, 34%, 35% and 30%

![Figure 8. Monthly mean values of total ozone column (TOC) during the period time from 2003 to 2017 at selected locations in the present study.](image-url)
at Al-Baha, Abha, Jeddah and Taif locations. Hence, the maximum variance of levels occurs in Jeddah and Abha sites, while the minimum variables occur in Taif and Al-Baha locations.

On the other side, the low level of UVI between 2.47–3.51, 3.27–3.96, 3.15–3.72 and 2.85–3.71 was found in December, January and February months at Al-Baha, Abha, Jeddah and Taif sites respectively. But

Figure 9. The correlation between measured and estimated UVB values for sites: (a) Al-Baha (b) Abha (c) Jeddah (d) Taif.

Figure 10. The average monthly mean of the UV index (UVI) solar radiation during the period time from 2003 to 2017 in around noon time (10 am – 2 pm) at the selected locations in the present work.
the high level of UVI between 7.53–9.15, 7.81–9.49, 7.41–9.12 and 7.82–9.47 was found in December, January and February months at Al-Baha, Abha, Jeddah and Taif sites respectively. Also the moderate level of UVI between 4.26–6.81, 4.86–6.53, 4.55–6.25 and 4.65–6.71 was found in March, April and May months at Al-Baha, Abha, Jeddah and Taif locations respectively.

Figure 11 shows the average month of the relationship between the UVI and solar zenith angle (SZA) at the selected locations during the period time 2003–2017 in the present work. From this figure, we notice that the relation between the levels of UVI and solar zenith angle (SZA) at all selected locations is inversely related. The data information in this paper around the noon time because the path of the solar radiation through the atmosphere is shortest to avoid the effect of atmospheric components. Also from this figure, we indicate that the monthly average has a correlation coefficient equal to 72%, 82%, 85% and 83% at Al-Baha, Abha, Jeddah and Taif sites respectively, so the solar zenith angle (SZA) is responsible for variations of UVI by 72%, 82%, 85% and 83% at Al-Baha, Abha, Jeddah and Taif locations for the monthly values respectively.

The monthly average of statistical parameters: Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE%), correlation coefficient ($R^2$) and t-statistics (t-Test) of the selected locations in Saudi Arabia during the period time from 2003 to 2017 are listed in Table 4, indicates clearly the values of MBE, RMSE, and MAE were lower than the experimental error at less than (0.124, 0.175, and 0.137), (0.168, 0.184, and 0.161), (0.138, 0.152, 0.141) and (0.142, 0.171, and 0.138) for Al-Baha, Abha, Jeddah and Taif locations respectively. The $R^2$ values for all months in the present study exceeded 0.942 and the highest value is 0.994.

Generally, the results of this study are similar to those reported by another author who used the daily values of UVB and global solar radiation (G) to develop empirical models between them such as, Robaa 2008, Adam 2013, and Adel A. Ghoneim 2013. In addition, Kushid and Evseen 2000 used the hourly values of UVB and G to assess the relationship between them at Neve Zohar (Dead Sea) and Beer Sheva for each month and season.

5. Conclusion

In this research the maximum values of the average hourly of $UV_{Bext}$, solar radiation are $0.0915 \pm 0.011$, $0.0941 \pm 0.016, 0.0895 \pm 0.015$ and $0.0911 \pm 0.013$ at 1200 LST in the present research at Al-Baha, Abha, Jeddah and Taif respectively. The behaviour of UVBext. is because of the diurnal obvious movement of the sun around the Earth. The impact of the climate on UVB radiation is reflected in the exploration of its conduct at the Earth’s surface. The high very strictricton of UVB sunlight-based radiation happens by stratospheric ozone and dispersing marvels. The normal hourly estimations of UVB transmission are decreasing because of the climate as a component of daytime. The most extreme and least estimations of UVB transmission happen in 1200 and 1600 LST separately, in light of the fact that the air through which the radiation must pass has changed the UVB arriving at the Earth’s surface. The anticipated estimations of UVB solar radiation are a decent concurrence with the deliberation of the

![Figure 11](image-url). The relationship between UVI and ZSA on monthly average values in selected locations in the present work during the period time 2003–2017.
UVB solar radiation. The distinction between the assessed and estimated estimations of UVB sun-based radiation shifts 1.96–2.75%, 1.27–3.18%, 2.32–3.57% and 2.15–3.87% at Al-Baha, Abha, Jeddah, and Taif respectively. The maximum values of $K_{\text{UVB}}$ solar radiation occur between summer and autumn months, while the minimum values occur between winter and spring months for all locations in the present study through the time research. Also the maximum values of the total ozone column TOC occur between March and April months at all selected locations with exception Taif site which occur between April and May months, and in whole the highest values of TOC occur about Spring time in all study locations. The maximum values of UVI occur around the summer and spring months at the selected locations during the period of time in the present study, while the minimum of UVI occurs around winter and autumn months. The relation between the levels of UVI and solar zenith angle (SZA) at all selected locations is inversely related. The monthly average has a correlation coefficient equal to 72%, 82%, 85% and 83% at Al-Baha, Abha, Jeddah and Taif sites respectively, so the solar zenith angle (SZA) is responsible for variations of UVI by72%, 82%, 85% and 83% at Al-Baha, Abha, Jeddah and Taif locations for the monthly values. The values of ($R^2$) ranged from 0.942 to 0.994. The values of (MBE), (RMSE), and (MPE) are lower than the experimental errors.

**Nomenclature**

| UV | is the ultraviolet solar radiation (MJ m$^{-2}$ h$^{-1}$) at wavelength (100–400nm). |
| UVB | is the ultraviolet solar radiation (MJ m$^{-2}$ h$^{-1}$) at wavelength (280–315nm). |
| UVB$_{ext.}$ | is the extraterrestrial solar radiation on horizontal surface (MJ m$^{-2}$ h$^{-1}$). |
| UVI | is the ultraviolet solar radiation index. |
| $K_{\text{UVB}}$ | is the clearness index. |
| TOC | is the total ozone column. |
| $E_A$ | is the ultraviolet spectrum wavelength dependent (W m$^{-2}$ nm$^{-1}$). |
| $S_{\text{er}}$ | is the erythema weighting function accepted by CIE. |
| $I_{\text{SCUVB}}$ | is the UVB solar constant (21.51 Wm$^{-2}$). |
| $E_o$ | is the correction factor for the eccentricity of the Earth’s orbit. |
| $\theta$ | is the solar elevation angle. |
| $\omega$ | is the solar Greenwich. |
| SZA | is the solar zenith angle. |
| MBE | is the mean bias error. |
| RMSE | is the root mean square error. |
| MPE | is the mean percentage error. |
| $R$ | is the correlation coefficient. |
| t-test | is the statistical indicator (t-statistics). |

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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