A Study of the Atmospheric Turbidity Coefficients in Jazan Atmosphere, the Kingdom of Saudi Arabia

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Abstract: ***This study investigates atmospheric turbidity in Jazan, Saudi Arabia, using data on global, diffuse, and direct solar radiation collected between 1983 and 2005. The analysis incorporates Linke turbidity factor, Angstrom turbidity coefficient, clearness index, and diffuse solar fraction. Findings indicate that Jazan experiences higher atmospheric turbidity during summer, attributed to seasonal dust storms, while maintaining a clearer atmosphere in other months. The study's results contribute to understanding the region's atmospheric conditions and their implications on solar energy applications.***

Keywords: Atmospheric turbidity, solar radiation, clearness index, Linke turbidity factor, air pollution.

1. Introduction

Radiation passing through the atmosphere is attenuated by absorption and scattering. Gases such as oxygen and nitrogen, along with water vapor, are considered primary sources of radiation absorption, predominantly at discrete wavelengths. Also, molecular and particulate scattering occurs at continuous wavelengths near ultraviolet, visible and infrared regions of the spectrum. Aerosol particles in the atmosphere have an important effect on the radiative transfer and thus play an important role in determining the climate (Mitchell, 1971 and Yamamoto et al., 1972).

Spectral extinction coefficients of solar radiation caused by aerosols can be computed using the spectral distribution of direct solar irradiation at ground level. If the extinction along the path is high, radiation reaching the instrument may be too weak to measure. The outward manifestations of air pollution are decreasing visibility, damage to vegetation, deterioration of materials, ill-health and discomfort to human-beings by various degrees (McCormack, 1971). Determining atmospheric turbidity is crucial as it reflects the total aerosol load in the atmosphere. Atmospheric turbidity is generally recognized as the extinction of solar radiation by suspended particles with radii from 0.1 to 10 μm. Total or spectral measurements of the intensity of direct solar radiation are frequently used to calculate a turbidity index. Each index is referred to the extinction at a specific wavelength or spectral interval (Annual Report of WMO, 1978).

Total suspended particles and solar radiation over the selected regions of Egypt (Cairo and Aswan), have been Studied. Clearness index (Kt) and the diffuse fraction (Kd) for both regions have been calculated beside an investigation to the extinction coefficient due to aerosol particles at different spectral bands over the mentioned sites (Fathy *et al.*, 2001).

Analysis of the atmospheric turbidity levels at two Tunisian sites has also been studied. The diurnal and monthly variations of the Linke turbidity factor values T_L during 1999 are found to vary between 2.5 and 8 in August and December, respectively. Values of the Angstrom turbidity coefficient β have been determined in 2001, with averaged values vary between 0.15 and 0.33 in April and July respectively (Chaâbane, 2008).

2. Methodology

The Linke turbidity factor is as below, which was calculated from the expression according to a study elsewhere (Pinazo, et al., 1995):

$$L= P(m)\,[\log I_0 - \log I - 2 \log R] \qquad (1)$$

Where, (I_0) is the extraterrestrial solar radiation, P(m) is a function of the air mass m and R is the earth-sun distance in astronomical units. The values of P(m) which are used in this study are obtained by the next formula which is the best fit of the values given by Coulson:

$$P(m)= 22.64\, m^{-0.801} \quad \text{or } 1\leq m \leq 4 \qquad (2)$$

It is easy to appreciate that a turbidity factor of 1.5 represents a rather clear atmosphere, while a turbidity factor of say 5 refers to turbid air, while its value can vary from 1 to 10 (Mitchell, 1971).

On the other hand, the Angstrom turbidity coefficient can be calculated from:

$$\beta = (B /1.069) \qquad (3)$$

Where, B may be calculated for any of the spectral intervals from the following relationship:

$$B = \frac{\ln\frac{I_0\Delta\lambda}{I\Delta\lambda}.s}{m.\ln 10} - (\bar{\tau}_R + \bar{\tau}_Z) \qquad (4)$$

Where, the factor (s) is the correction of the mean sun-earth distance, m is the air mass, $I_{0\Delta\lambda}$ is the spectral irradiance observed outside the atmosphere at the mean sun-earth distance in the spectral band Δλ, $I_{\Delta\lambda}$ is the spectral irradiance observed at the instrument in the same spectral interval and $(\bar{\tau}_R + \bar{\tau}_Z)$ is the average Rayleigh and ozone attenuation (Fröhlich and Brusa, 1981).

Angstrom turbidity coefficient (β) is currently determined from the measurements of the direct beam of solar radiation (I). Its value varies typically from 0.0 to 0.5. (β) values less than 0.1 normally denote to a very clear condition whereas values greater than 0.2 are a distinctly hazy condition. (Iqbal, 1983), shows parameters for various degrees of atmospheric cleanliness as, the clean atmosphere has (β) equal to 0.0, while clear atmosphere has (β) 0.1, and turbid atmosphere has (β) 0.2 while very turbid atmosphere has (β) 0.4. Through this study we calculate the angstrom turbidity coefficient using the normal incidence solar radiation in the spectral range (I = 280< λ< 2800 nm).

The diffuse ratio or the diffuse fraction (Kd) can be calculated using three methods which are Collares (KdC), Page (KdP) and the theoretical method.

The first equation calculates the daily diffuse solar fraction depending on clearness index (Kt), which is given by (Collares, 1979):

$$KdC = D/G = a\text{-}bc \qquad (5)$$

Where, $a = 0.775+0.00606\ (H_s - 90)$,
$b = 0.505+0.00456\ (Hs - 90)$.
$c = \cos\ (115\ Kt - 103)$,
$Kt=G/Go$.
Where, (Hs) is the hour angle.

The value of Kd lies between zero and unity, depending on atmospheric conditions, Kd, approaches unity under heavily overcast conditions.

Also, the diffuse fraction can be calculated by Page equation (Liu and Jordan, 1960) as following:

$$KdP = 1\text{-}1.13\ Kt \qquad (6)$$

Finally, Kd can be calculated according to the theoretical method as:

$$Kd = D / G \qquad (7)$$

Where D and G are the measured diffuse and global solar radiation.

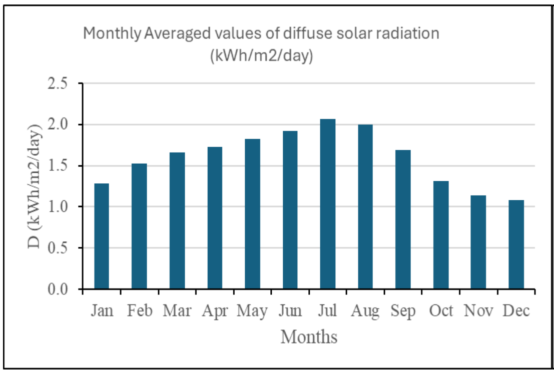
Data base

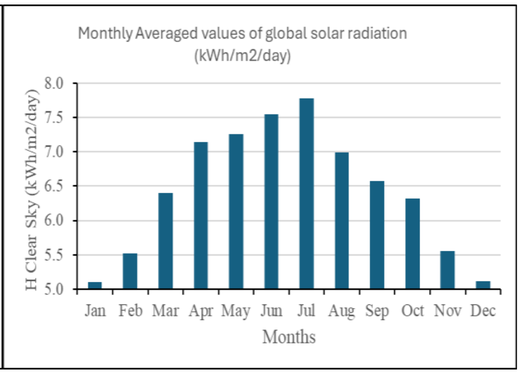
This work is directed to study the atmospheric turbidity using the solar radiation components distributions over Jazan, Saudi Arabia, (17° 30' N, 42° 30' E, Elev: 7 m), which lie in the Southwest of KSA, for the years (1983-2005). This data are the hourly mean values of global, direct and diffuse solar radiation beside the clearness index (G, I, D and Kt) (Fathy, 2023).

3. Results and Discussions

This study is significant as it provides insights into Jazan's atmospheric conditions, which have implications for solar energy utilization, climate modeling, and environmental health. Understanding seasonal turbidity variations helps optimize solar panel efficiency and predict climate trends. In this work studying of the atmospheric turbidity using the solar radiation components distribution over Jazan, Saudi Arabia has been done. The parameters studied are, Linke turbidity factor, Angstrom turbidity coefficient (β), clearness index (Kt) and diffuse solar fraction calculated using three models (theoretical Kdt, Page Kdp, and Collares Kdc).

Fig. 1 shows the monthly mean variations of the global (G), direct (I) and diffuse (D) solar radiation. Where monthly mean (G) highest values were in summer months with value 7.78 ($kWh/m^2/day$) in July, while the lowest values in winter months with value 5.01 ($kWh/m^2/day$) in January. Monthly mean (D) highest values in summer months with value 2.06 ($kWh/m^2/day$) in July, while lowest values in winter months with value of 1.08 ($kWh/m^2/day$) in December. Monthly mean (I) highest value in July with value of 7.78 ($kWh/m^2/day$), while lowest value was in January with value of 5.63 ($kWh/m^2/day$).





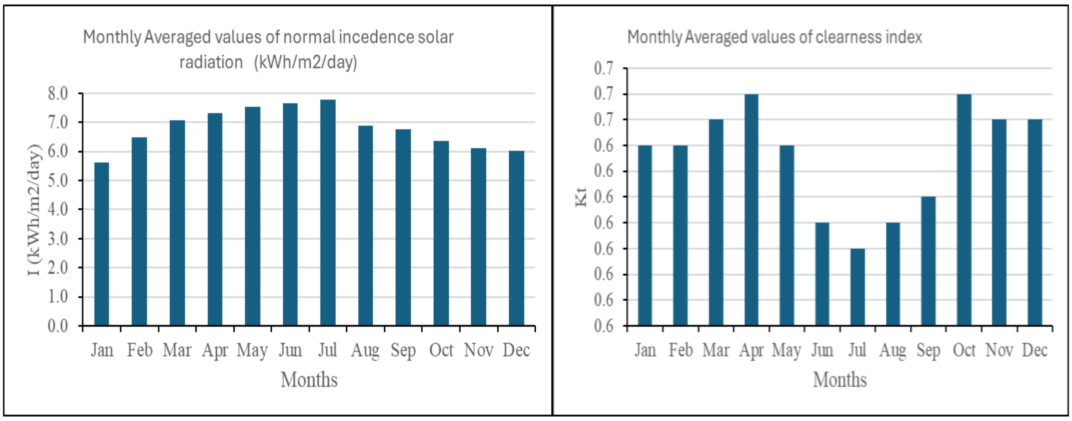


Figure 1: Monthly mean values of global, direct and diffuse solar radiation and clearness index.

The Clearness Index Kt is defined as the ratio of the horizontal global irradiance (H) to the corresponding irradiance available outside of the atmosphere (Ho). Therefore, the Clearness Index Kt may be considered as an attenuation factor of the atmosphere. A value of Kt $\rightarrow 1$ connotes to the fact that the Atmosphere is clear, while a value of Kt $\rightarrow 0$ depicts that the atmosphere is considered polluted. The highest Kt value was in winter and spring months with value 0.66 in April and October, while the lowest value was in summer months with value 0.57 in July. It has an annual mean value 0.63. From these results we consider Jazan atmosphere seem to be a pollute in summer months, while it is clean atmosphere through the rest of the year months. The lowest Kt values in summer months were due to the dust storms blowing in Jazan in summer months.

Linke turbidity factor of Jazan has been studied as shown in Fig. 2, where the highest value was in summer months (August) with value 5.65 while the lowest value was 2.67 in January with annual mean value 4.06. From the Linke turbidity factor of Gazan, we consider Gazan as a turbid atmosphere in summer months and a clear atmosphere through the rest of the year months.

Angstrom turbidity coefficient of Gazan also has been studied ad shown in Fig. 2, where the highest value was in summer months (July) with value 0.204 while the lowest value was 0.123 in January with annual mean value 0.162. From the Angstrom turbidity coefficient of Gazan, we consider Gazan seem to be a turbid atmosphere in summer months while a clear atmosphere through the rest of the year months.

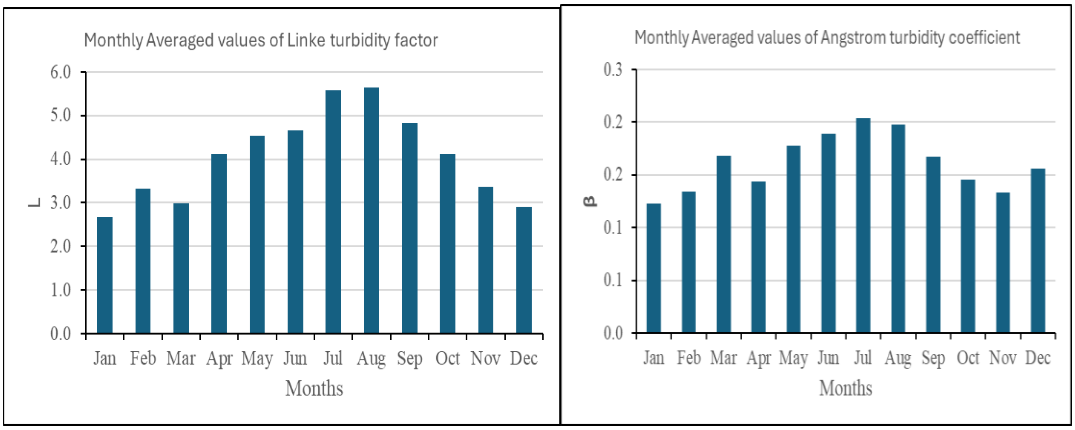


Figure 2: Monthly mean values of Linke turbidity factor (L) and Angstrom turbidity coefficient (β)

Diffuse solar fraction has been calculated using three models, theoretical, Page and Collares. Fig. 3 shows the diffuse fraction for the three mentioned models over Gazan, where we find that Page model is better than Collares model for Gazan because it has nearly the same annual mean value as the theoretical model, where for Collares it was 0.330, while it was 0.167 for the theoretical method and 0.198 for Page method. Also, from the diffuse fraction values of Gazan, we consider it seem to be a turbid atmosphere through the summer months and a clear atmosphere through the rest of the year months.

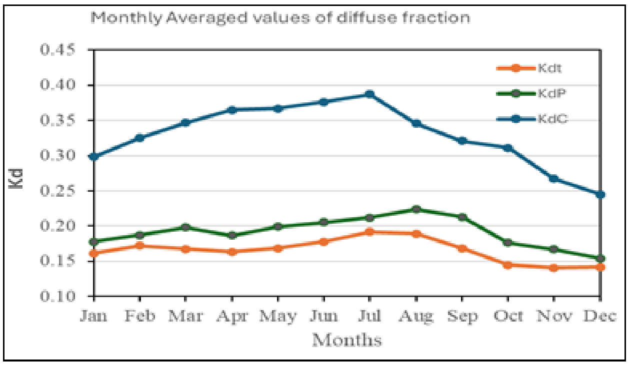


Figure 3: Monthly mean values of the diffuse fractions using three models.

4. Conclusions

This study analyzed atmospheric turbidity in Jazan, Saudi Arabia, using data from 1983 to 2005. Results indicate that summer months experience higher turbidity levels due to dust storms, while the rest of the year remains relatively clear. The study confirms that Page's model is more suitable for calculating diffuse solar fractions in this region. These findings contribute to optimizing solar energy applications and understanding atmospheric conditions in arid environments.

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