Calculation of Sky Turbidity in the Kingdom of Saudi Arabia

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ABSTRACT
The atmospheric turbidity has been calculated using data from 29 locations around the Kingdom of Saudi Arabia, using a nine years solar radiation data covering the period from 1971 to 1980. The turbidity values were found to range from 0.1 to 0.4, and the long-term average of the turbidity was 0.281±0.056. The minimum value was in Sirr-Lasan (0.168±0.028) and the maximum value was in Riyadh 0.474±0.090. The low value of the turbidity indicates that the sky of Sirr-Lasan (2100 meter above sea level) may be the clearest in the country, when considering the turbidity as the main factor in preliminary site selection for astronomical observatory. Correlations between the turbidity and geographical coordinates have been investigated here, and have shown a weak relation between them. Also, seasonal variations studies have shown no significant distribution, which means that each station has its own trend. The low values of the turbidity indicate that the sky of Saudi Arabia has relatively slight polluted atmosphere in the period of study.

KEY WORDS: turbidity, global radiation, solar radiation, Saudi Arabia, clearance index, diffused radiation

INTRODUCTION
The sunlight reaching the ground is usually reduced by dirt such as dust, haze, aerosol particles and water vapor. The extinction of the incident solar radiation is affected by dirt, which is called the atmospheric turbidity (τ). It has been found that the direct sunlight was reduced by as much as 40% due to dirt in certain cities such as St. Louis, Missouri (Anthes et al, 1986).

Turbidity is used to quantify the attenuation by aerosols that is responsible for increasing the ratio of diffuse to total solar radiation, as well as responsible for changing the spectral composition (Alnaser, 1990).

The effective reduction of the direct component of the solar radiation caused by aerosol may be expressed in terms of power of 10 by Beer's law as follows,

$$\frac{H_r}{H_\circ} = 10^{-\tau m} \qquad \textbf{(1)}$$

where: τ is the extinction coefficient of broad band spectrum turbidity,
m is the optical airmass,
H_r is the direct solar radiation,
$H_\circ$ is the extra-terrestrial solar radiation on horizontal surface.

The aim of this work is to calculate the turbidity coefficient (τ) for the sky of Saudi Arabia as no previous work was made.

DATA COLLECTION

The data covered the period from 1971 to 1980. This nine years data where taken from the Saudi Arabian Solar radiation Atlas, published in 1983, by King Abdulaziz City for Science and Technology (KACST) - formally the Saudi Arabian National Center for Science and Technology (SANCST), hereafter is referred as SANCST (1983). The data include the mean monthly of daily solar global radiation on horizontal surface (H_t) and the mean monthly of daily extraterrestrial solar radiation on horizontal surface ($H_\circ$) for 29 selected stations distributed around the country, Fig. 1. The only place that was not covered in this study is the Ar Rub AlKhali desert (The Empty Quarter).

DATA REDUCTION

The data includes, the monthly mean of daily extraterrestrial solar radiation on horizontal surface ($H_\circ$) and as well as the mean monthly of daily global radiation on horizontal surface (H_t).

Following Monteith and Unsworth (1990) and Alnaser (1990) we used the following expression for the turbidity (τ):

$$\tau = \left(\frac{H_d}{H_t} - 0.10 \right) / 0.68 , \quad \textbf{(2)}$$

where, H_d is the diffused solar radiation calculated form the following formula (Klein, 1977):

$$H_d = H_t (1.39 - 4.027\, C + 5.53\, C^2 - 3.108\, C^3) \quad \textbf{(3)}$$

where C is the clearance index, which is equal to $H_t / H_\circ$.

The diffused solar radiation calculated from equation (3) had lead to the calculation of the atmospheric turbidity, by using equation (2).

RESULTS AND DATA ANALYSIS

The calculated annual average values of the turbidity τ are presented in table 1. This has been found by averaging the monthly values of turbidity for each station. The average value of turbidity was in the range 0.168±0.028 to 0.474±0.090, which means that the Saudi sky's has a small amount of aerosols and pollution in its atmosphere. The turbidity values were in the range 0.214±0.055 to 0.293±0.051 for twenty one stations. Seven stations have turbidity values greater than 0.3 and one station has shown less than 0.2, as illustrated in Fig. 2.

The long-term average value of τ (mean average of all stations) in Saudi Arabia was 0.281±0.056, which is compatible with the international values reported elsewhere; for example, Unsworth and Monteith (1972), reported that for Britain the value of turbidity was in the range 0.07 to 0.6. Also for Bahrain, Alnaser (1990), found that the average value of the turbidity was in the range 0.192 to 0.393.

Riyadh, the capital of Saudi Arabia, has shown the maximum average yearly value of turbidity (0.474±0.090). This not surprising since it has the largest population density and relatively heavy traffic. Also it is located in the middle of the desert, and is considered as an industrial city. On the other hand, Sirr-lasan is a mountain urban area (2100m above sea level) and has shown the minimum average yearly value of turbidity (0.168±0.028).

The correlation between the average yearly values of turbidity and the geographical coordinates such as latitude, longitude and the altitude, has been investigated, i.e. Fig. 3 a, b and c. It is clearly seen that in this study the relation between these parameters and the turbidity was weak.

Fig. 4 represents the curves of the averaged monthly values of turbidity τ for some selected stations in this study. From the curves it is clearly seen that each station has its own individual trend. However, the differences between maximum and minimum values of τ are noteworthy; for example, fifteen stations have shown an increase by 0.1 and for eleven stations the maximum was double of the minimum recorded value, while there are three stations whose maximum were trebled the minimum. On the other hand, Tabarjel station has the largest difference. It was four times the minimum. In addition, stations like Tabarjel and Riyadh have shown extremely high values of turbidity in their seasonal variations.

In comparison, our data have shown that there is a peak in winter season (either in December or January), which is different than the May peak that appears in some stations in USA, Flowers, McCormick and Kurfis (1969). Fig. 5 shows the number of peaks founded in the case of study and its clearly seen that no peak in the month of October.

CONCLUSION

The turbidity (τ) for the sky of Saudi Arabia has been calculated, for the first time, over 29 stations in the country. The calculated values of turbidity were in the range between 0.168±0.028 and 0.474±0.090 and the average value of turbidity for the whole country was 0.281±0.056.

The individual maximum and minimum values of the turbidity have no significant seasonal trend, which means that each station has its own trend. Correlation between turbidity values and geographical parameter was found to be weak (r –squared values were 0.116, 0.0179 and 0.022 for the altitude, the longitude and the latitude respectively).

The low values of the turbidity indicate that Saudi's sky has a relatively small disturbance in the atmosphere.

This study may give us a further knowledge about the Saudi Arabian Sky, which will help in astronomical site selections as well as benefit future solar energy studies and applications.

According to WMO (1967) one should have at least 30-year period of records to establish climatological weather condition. However, these values give primary information about the sky quality in the Kingdome of Saudi Arabia and shows reference of the solar radiation measurements.

FUTURE WORK

In this work we used the data published in 1983, i.e. seven years before the beginning of the second Gulf war. In another work, we will compare our case of study with a data collected after the second Gulf war.

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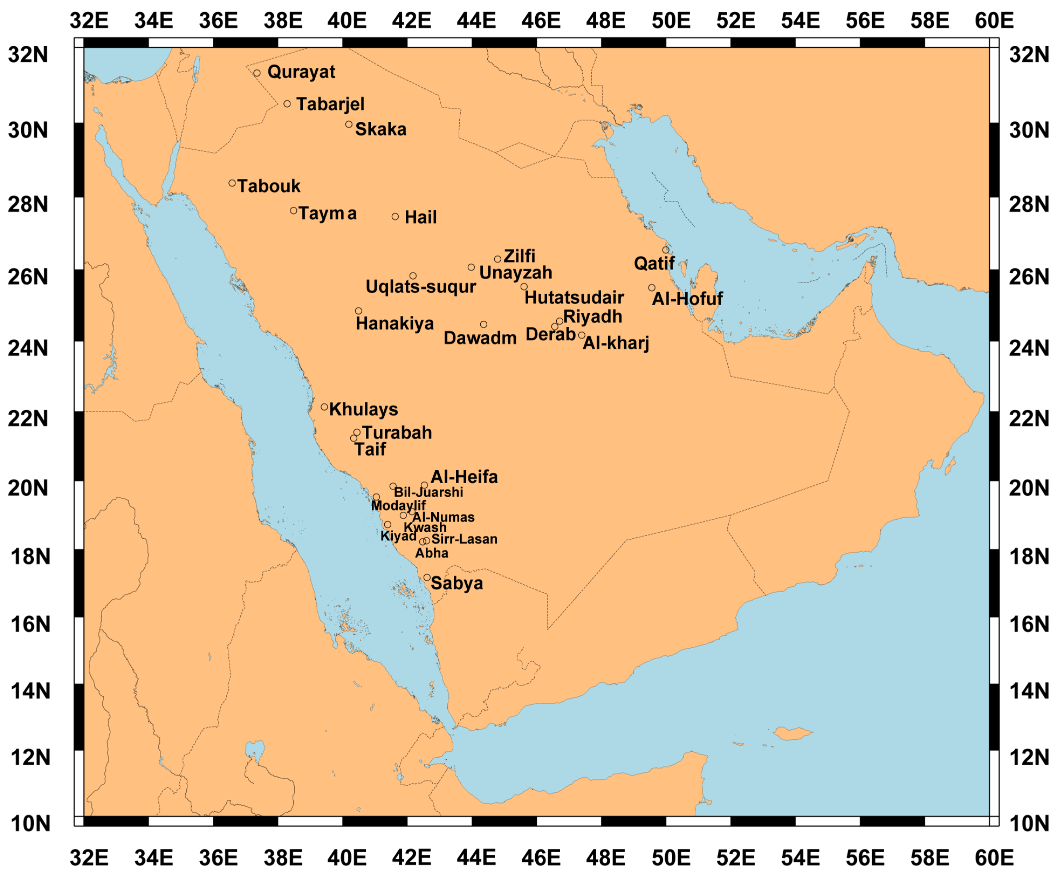

Figure 1. The map of the Kingdom of Saudi Arabia and the places that this work covered.

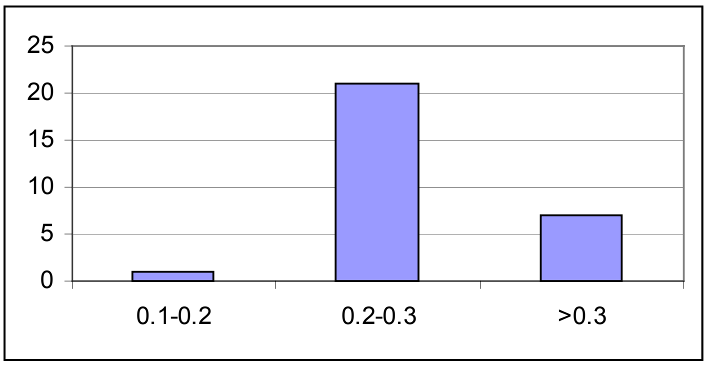

Figure 2. The turbidity distribution over Saudi Arabia. The abscissa is the turbidity range, the ordinate is the number of stations.

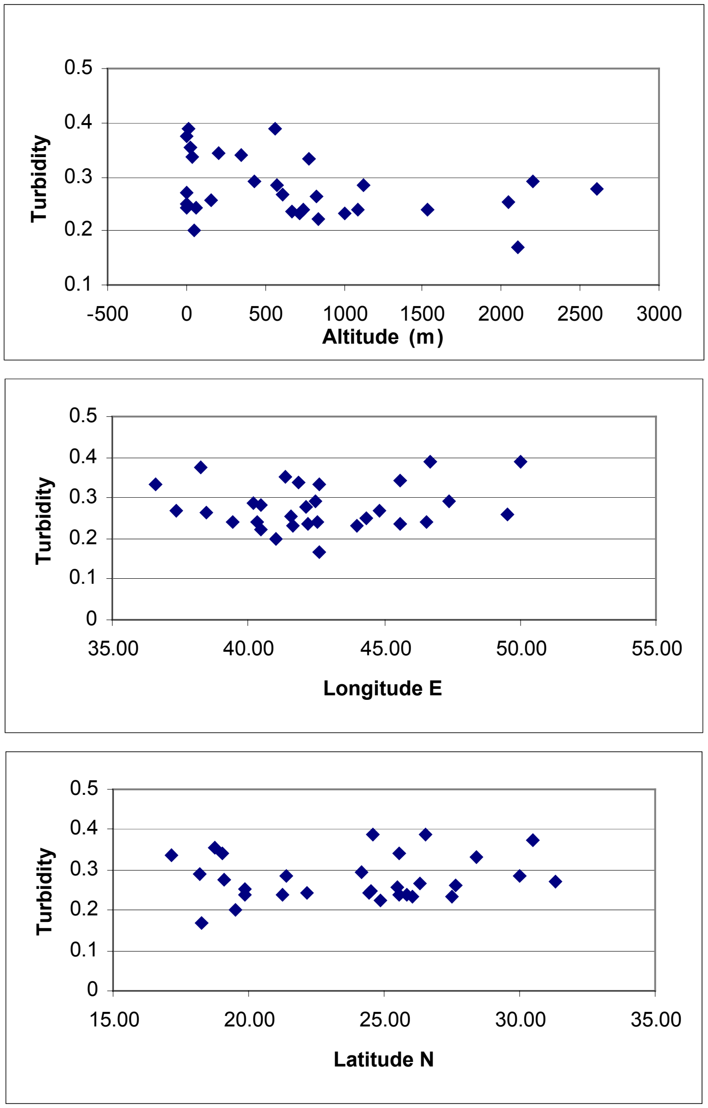

Figure 3. The variations of the turbidity with the geographical coordinates.

a. Turbidity versus Altitude.

b. Turbidity versus Longitude.

c. Turbidity versus Latitude.

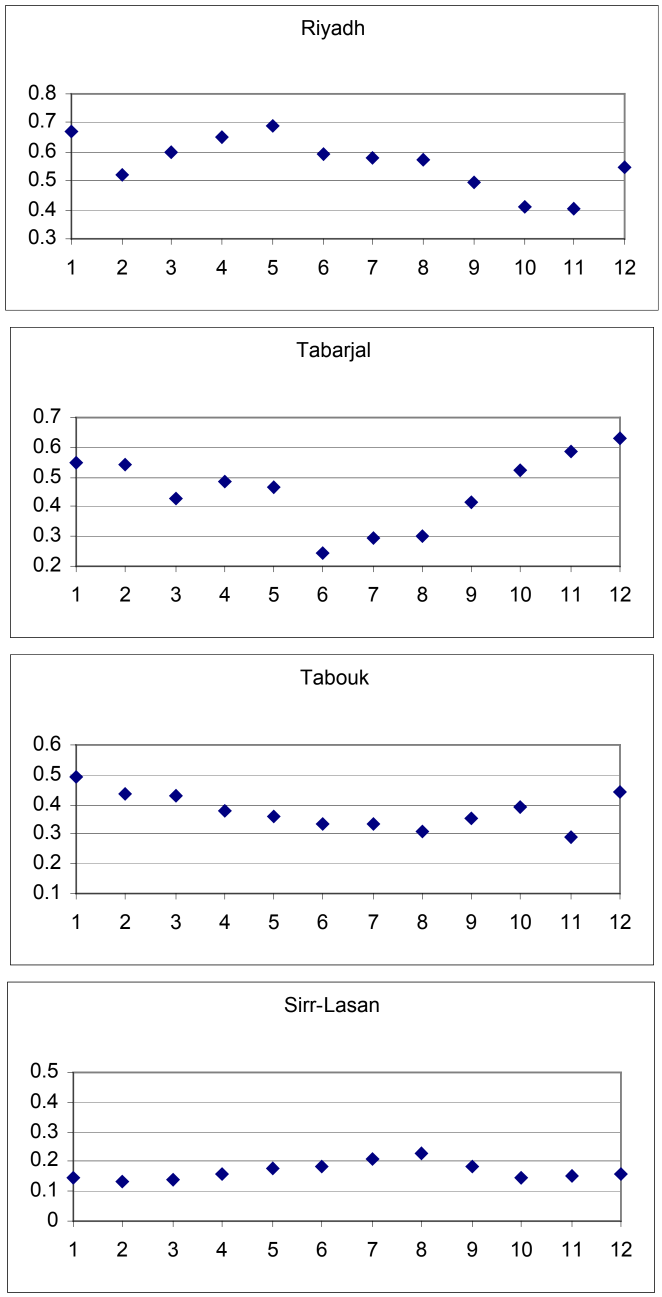

Figure 4. The averaged monthly τ for selected stations. The abscissa is the number of the month; the right ordinate is the turbidity.

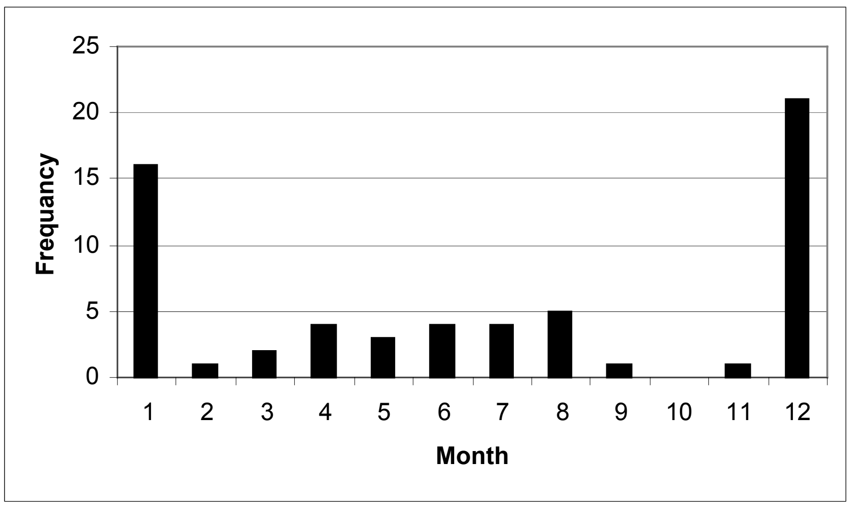

Figure 5. The monthly peaks distribution for all stations over the period of study, which clearly shows the winter peaks.

Table (1). The annual average of the turbidity (τ) for each stations. In column one the name of the station, in columns 2-4 the altitude, latitude and the longitude of the places respectively. In column 5 the averaged τ.
The errors are represented in columns 6.

City	Altitude (m)	Latitude N	Longitude E	τ	Error of τ ±
Abha	2200	18.22	42.48	0.290	0.037
Al-Hofuf	1 60	25.50	49.57	0.258	0.017
Al-Heifa	1090	19.87	42.53	0.239	0.041
Al-kharj	430	24.17	47.40	0.293	0.051
Al-Numas	2600	19.10	42.15	0.277	0.095
Bil-Juarshi	2040	19.85	41.57	0.254	0.088
Dawadmi	0	24.48	44.37	0.250	0.042
Derab	0	24.42	46.57	0.214	0.055
Hail	1010	27.47	41.63	0.233	0.035
Hanakiya	840	24.85	40.50	0.223	0.041
Khulays	60	22.13	39.43	0.243	0.031
Kiyad	30	18.73	41.40	0.353	0.045
Hutatsudair	665	25.53	45.62	0.237	0.029
Kwash	350	19.00	41.88	0.400	0.065
Modaylif	53	19.53	41.05	0.205	0.028
Qatif	8	26.55	50.00	0.390	0.091
Qurayat	2	31.33	37.35	0.246	0.033
Riyadh	564	24.57	46.72	0.474	0.090
Sabya	40	17.17	42.62	0.372	0.062
Skaka	574	29.97	40.20	0.285	0.029
Sirr-Lasan	2100	18.25	42.60	0.168	0.028
Tabarjel	3	30.52	38.28	0.351	0.123
Tabouk	773	28.38	36.58	0.379	0.060
Taif	1530	21.23	40.35	0.24	0.047
Tayma	820	27.63	38.48	0.264	0.022
Turabah	1130	21.40	40.45	0.283	0.066
Unayzah	724	26.07	43.98	0.232	0.050
Uqlats-suqur	740	25.83	42.18	0.238	0.050
Zilfi	605	26.30	44.80	0.267	0.027

حساب عكارة الجو في سماء المملكة العربية السعودية

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ملخص

تم حساب عكارة الغلاف الجوي لعدد تسع وعشرين موقعاً في المملكة العربية السعودية، وذلك باستخدام أرصاد تسع سنوات للفترة من 1971م إلى 1980م. وقيمة العكارة المحسوبة كانت بين 0.1 و 0.4 ، والمتوسط الكلي للقيم كان 0.281± 0.056 .وأقل قيمة كانت في سيرلسن (0.168 ±0.028)، وأعلى قيمة كانت (0.474± 0.090) في الرياض. القيمة المنخفضة تعتبر مؤشر على أن سماء سيرلسن (2100 متر فوق سطح البحر) من الممكن أن تكون أصفى مكان في المملكة، إذا أخذنا عكارة الجو كمؤشر أولي لاختيار المواقع الفلكية. وتشير نتائج البحث أن العلاقة بين عكارة الجو والإحداثيات الجغرافية (خطوط الطول والعرض والارتفاع) ضعيفة وكذلك بين عكارة الجو والتغيرات الفصلية، وهذا يعني أن كل موقع له منحاه الخاص به. والقيمة المنخفضة لعكارة الجو تعني أن سماء المملكة العربية السعودية قليلة التلوث في الفترة المدروسة.