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Long-Term Visibility Trends in the Riyadh Megacity, Central Arabian Peninsula and Their Possible Link to Solar Activity

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Abstract

In this study, atmospheric visibility (AV) data from Riyadh, Saudi Arabia (24.91˚N, 46.41˚E, 760 m), for the period 1976-2011 were utilized to investigate the interannual, monthly, and seasonal AV variations and trends. The magnitudes of these trends were characterized and tested using mann-kendall (MK) rank statistics at different significance levels. No significant trend in AV was observed during the 36-year period. However, a significant increase in the annual mean AV by 0.24 km per year for the period between 1976 and 1999 was found. For the period 1999-2011, AV decreased significantly by 0.16 km per year. The potential effects of air temperature and relative humidity on AV were investigated. While these two variables could explain the observed trend of AV over some periods, they failed to do so for the whole study period. To search for extraterrestrial causes for long-term AV variations, correlation analyses between the time series of cosmic ray (CR) data (measured by NM and muon detector) and solar activity (represented by sunspot number) and AV were conducted and showed that these two variables are able to explain the AV variations for the whole study period. Additionally, power spectra analyses were conducted to investigate periodicities in the AV time series. Several significant periodicities, such as 9.8, 5.2, 2.2, 1.7, and 1.3 years were recognized. The obtained periodicities were similar to those reported by several investigators and found in solar, interplanetary, and CR parameters. The spectral and correlation results suggested that, with the expected effects of terrestrial and meteorological conditions on AV, long-term AV variations can also be related to the solar activity and associated CR modulations.

Keywords

Visibility, Long-Term, Trend, Arabian Peninsula, Solar Activity, Mann-Kendell, Anthropogenic Activities

1. Introduction

Atmospheric visibility (AV) is a measure of the light extinction caused by atmospheric aerosols and is considered a good indicator of air pollution. Depending on the prevailing atmospheric conditions, visibility may vary widely, from a few meters at some severely polluted sites to a few hundred kilometers within nonpolluted, pristine atmospheres e.g., (Lee, 1983; Malm, et al., 1996; Lee et al., 2005; Jaswal et al., 2013). Because of the adverse effects of air pollution on human lives, visibility has been a major concern in everyday life, mainly in the aviation industry, surface traffic, and climate change studies and climatology e.g., (Deng et al., 2011; Pui et al., 2014).

AV trends and the impact of air pollution on them have attracted scientists from all over the world, and many studies have been conducted to evaluate visibility trends at the local, regional, continental, and global scale (Miller et al., 1972; Sloane, 1982; Lee, 1994; Cheng et al., 1997; Doyle & Dorling, 2002; Ghim et al., 2005; Tsai, 2005; Molnar et al., 2008; Chang et al., 2009; Zhao et al., 2011; Sabetghadam et al., 2012; Balarabe et al., 2015). These include investigating the link between atmospheric composition and visibility. These investigations demonstrate that visibility is markedly influenced by the size, chemical composition, and concentration of airborne particles (Appel et al., 1985; Seinfeld & Pandis, 1998; Baumer et al., 2008; Tiwari et al., 2011; Lee et al., 2017). Other studies have attempted to link AV variations to changes in meteorological parameters (Dayan & Levy, 2004; Lee, 1990). While temperature (T), relative humidity (RH), wind speed (ws), and wind direction (wd) do not directly affect clear-sky visibility, they can influence the sources and sinks of trace gases and aerosol particles in the atmosphere. However, the characterization of the long-term AV trend over the central region of the Arabian Peninsula has never been reported.

In this study, datasets covering the period 1976-2011 were utilized to investigate the seasonal and long-term visibility variations for the last 36 years in Riyadh, Central Arabian Peninsula.

These results provide for the first time a better understanding of long-term visibility characteristics. The magnitudes of annual visibility trends are studied and statistically tested using Mann-Kendall rank statistics at different significance levels. Detailed results of this work will be presented here.

The first part of this study presents the long-term and seasonal trends of the AV in Riyadh during the last few decades. The correlation of long-term visibility trends with air temperature and RH was also examined. The second part will investigate the possible association between long-term variations in AV and cosmic rays (CRs).

2. Data and Methods

The study area of Riyadh lies in the central region of the Arabian Peninsula (24˚43'N, 46˚40'E, 764 m a.s.l.). Riyadh is the capital of Saudi Arabia and also its largest city; its population was 7 million according to the 2017 census. This purely urban area is one of the most polluted regions in the Arabian Peninsula, as it is surrounded by industrial areas and major traffic routes and is experiencing a dramatic urbanization that has led to increasingly noticeable air pollution, which has become a serious environmental and health issue in recent years.

The prevalent arid conditions and continentality at this site are responsible for large seasonal temperature differences, with cool winters and extremely hot summers. Local aerosol sources are mainly the heavy traffic on the major roads of the city along with the resuspension of material on the ground, especially during the warm season when reduced rainfall and dry terrain increase the contribution of local mineral dust (Maghrabi et al., 2011).

AV and meteorological data, including temperature and RH, were obtained from the national climatic data center (NCDC) for the past 36 years (1976-2011). The NCDC subjects the data to extensive automated quality control to correctly decode as much synoptic data as possible and eliminate many of the random errors found in the original data (available at https://www.ncdc.noaa.gov/). The data are comparable to those obtained from the ministry of environmental protection (MEP) of Saudi Arabia.

To avoid the effect of natural factors contributing to low visibility such as rain and fog, the observation days included only visibility data with RH < 90% for analysis because in a humid environment, the scattering cross section of a hygroscopic particle could increase by five or more times than in a dry environment (Malm & Day, 2001).

Linear interpolation procedures were followed to replace the missing data to complete the series. These interpolations were kept at a reasonable level to preserve the nature of the information contained in the data. With these considerations, 13, 540 days became available for analysis.

The mann-kendall (MK) test and Sen's slope estimator identified the presence of AV trends in Riyadh. These are nonparametric statistical tests that are widely used for analyzing trends in climatologic time series e.g., (Yue & Wang, 2004; Maghrabi, 2019).

The MK test can be applied to a time series x_i ranked from $i = 1, 2, \cdots, n-1$ and x_j ranked from $j = i+1, 2, \cdots, n$ such that

$$\operatorname{sgn}\left(x_j - x_i\right) = \begin{cases} 1 & \text{if } \left(x_j - x_i\right) > 0 \\ 0 & \text{if } \left(x_j - x_i\right) = 0 \\ -1 & \text{if } \left(x_j - x_i\right) < 0 \end{cases} \tag{1}$$

The Kendall test statistic S can be computed as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(x_j - x_i\right) \tag{2}$$

where x_j and x_j are data values at times j and i, $j > i$, respectively, and $\operatorname{sgn}(x_j - x_i)$ is the signum function. S is assumed to be asymptotically normal, with the expectation value $E(S) = 0$ for a sample size of $n \geq 8$ and variance as follows (Yue &

Wang, 2004):

$$V(S)=\frac{1}{18}\left[n(n-1)(2n+5)-\sum_{p=1}^{q}t_p(t_p-1)(2t_p+5)\right] \tag{3}$$

Here, q is the number of tied groups, and t_p is the number of data values in group p.

The values of S and $V(S)$ are used to compute the test statistic Z as follows:

$$Z=\begin{cases}\frac{S-1}{\sqrt{V(S)}} & \text{if } S>0\\ 0 & \text{if } S=0\\ \frac{S+1}{\sqrt{V(S)}} & \text{if } S<0\end{cases} \tag{4}$$

The standardized MK test statistic Z follows the standard normal distribution with a mean of zero and a variance of one and is used to measure the significance of the trend. If $|Z|$ is greater than Z_{crit} (Z_{crit} is the $(100 \times (1 - \alpha/2)))^{th}$ percentile of the standard normal distribution with a chosen significance level α (e.g., 5% with $Z_{0.025} = \pm 1.96$), then the null hypothesis is invalid, implying that the trend is significant.

Meanwhile, Sen's measure is a nonparametric slope estimation method. According to (Sen, 1986), if a linear trend exists in a time series, then the slope (change per unit time) can be estimated using Equation (5):

$$f(t)=Qt+C \tag{5}$$

where C is a constant and Q is the slope and can be calculated from

$$Q_{ij}=\frac{x_j-x_i}{j-i} \tag{6}$$

The median of N values of Q is represented as Sen's slope estimator, which is given as

$$Q_{med}=Q_{\left[\frac{N+1}{2}\right]} \quad \text{if } N \text{ is odd} \tag{7}$$

$$Q_{med}=\frac{1}{2}\left(Q_{\left[\frac{N}{2}\right]}+Q_{\left[\frac{N+2}{2}\right]}\right) \quad \text{if } N \text{ is even} \tag{8}$$

and is computed for all N pairs of time steps (i, j). The Q_{med} sign indicates data trend (increase/decrease over time), while its value indicates the steepness of the trend.

3. Results and Discussion

3.1. General Visibility Trends

The variation in yearly mean visibility values over Riyadh from 1976 to 2011 is in **Figure 1**. The AV in Riyadh for the available data ranges between 7.2 km and 0.4 km with a mean of 5.68 ± 0.81 km. The obtained visibility at this site is lower compared with the average visibilities reported at several sites around the world.

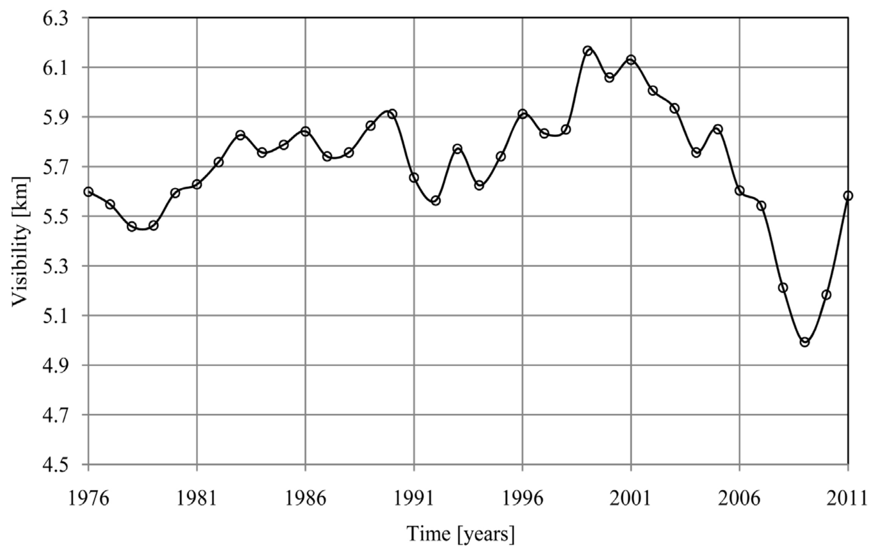


Figure 1. Presents the yearly mean atmospheric visibility values between 1976 and 2011.

Meanwhile, this value is comparable with those reported in several arid and polluted sites e.g., (Chang et al., 2009; Singh & Dey, 2012; Chen & Xie, 2013; Chen & Xie, 2013).

From 1976 to 1995, the visibility ranged between 5.4 and 5.7 km. The mean visibility appears to increase from 5.4 km in 1995 to a maximum of 6.2 km in 1999. During this period, a significant drop in visibility (9%) was seen in 1991 compared with the previous year. This reduction may be attributed to the Kuwaiti freedom war, during which the region witnessed huge military activities e.g., (Abdi Vishkaee et al., 2012) and references therein. There was an obvious decrease in the AV trend from 2005 to a minimum value of about 4.8 km in 2009. The decrease in visibility during this period may be attributed to the increase in frequencies of dust storms and/or anthropogenic aerosols from local sources due to the mega-projects initiated by the Saudi government in the city of Riyadh (Saudi stats agency record).

During the 36-year period, the annual visibility in Riyadh showed no significant changes. However, there were two distinctive periods in which AV changed substantially. These were the period between 1976 and 1999 and between 2000 and 2011. Hence, MK analyses were performed separately for these two periods (**Table 1**).

For the period between 1976 and 1999 (24 years), MK analyses showed a significant increasing trend of 0.24 km per year (0.6 km per 24 years) at the 99% confidence level. This value was about 10% of the mean visibility in Riyadh during the study period.

For the second period between 2000 and 2011, MK results at the 0.01 significance level indicated a decrease of 0.16 km per year. This decline was 1.27 km during the 12-year period, which is about 22% of the 36-year average visibility in Riyadh.

Table 1. Summary of the Mann-Kendall test results, Sen slope, and changes in visibility values for Riyadh in the period 1976-2011 on different timescales.

Time series	1976-2011			1976-1999			2000-2011		
	Sig.	Slope	km/36 yrs.	Sig	Slope	km/24yrs.	Sig.	Slope	km/12yrs.
Annual				***	0.024	0.60	***	−0.16	−1.92
January				***	0.027	0.65	**	−0.14	−1.76
February				***	0.031	0.75	***	−0.12	−1.44
March				+	0.021	0.50	**	−0.13	−1.56
April				**	0.033	0.79	**	−0.17	−2.04
May				+	0.025	0.60	**	−0.15	−1.80
June				**	0.035	0.84	***	−0.18	−2.16
July				**	0.025	0.60	**	−0.16	−1.92
August				***	0.020	0.48	**	−0.07	−0.84
September	+	0.007	0.25	***	0.017	0.41	*	−0.04	−0.57
October	**	0.010	0.36	***	0.025	0.60			
November				***	0.014	0.33			
December	+	0.009	0.32	**	0.030	0.72			
Winter				***	0.027	0.65	**	−0.18	−2.16
Spring				**	0.030	0.73	***	−0.14	−1.68
Summer	**	0.013	0.48	***	0.026	0.63	**	−0.04	−0.48
Fall				***	0.016	0.40			

***trend at α = 0.001 level of significance; **trend at α = 0.01 level of significance; *trend at α = 0.05 level of significance; + trend at α = 0.1 level of significance.

3.2. Seasonal and Monthly Trends

To investigate the seasonal variation, we divided the data into four seasonal groups: Winter included December, January, and February (DJF); spring included March, April, and May (MAM); summer included June, July, and August (JJA); and fall included September, October, and November (SON). Figure 2 indicates the annual variations in seasonal visibility during the study period. The visibilities during fall and summer remained between 5.3 and 6.1 km and 5.4 and 6.1 km, respectively, and showed little variation during the study period. Meanwhile, visibilities in spring and winter presented distinct variations. In spring, the visibilities were 6.2 km in 1996 and 4.5 km in 2011. It dropped by about 1.1 km between 1990 and 1991 and rose by about 900 m between 1994 and 1995. Between 1990 and 1991, the visibility in winter reduced by 400 m. Between 2005 and 2008, it decreased by 1800 m.

The MK results for seasonal visibilities are presented in Table 1. At the 0.01 significance level, summer was the only season that showed a significant increase of about 0.013 km per year during the 36-year study period. The rest of the seasons showed no significant changes in the visibility trend during this period.

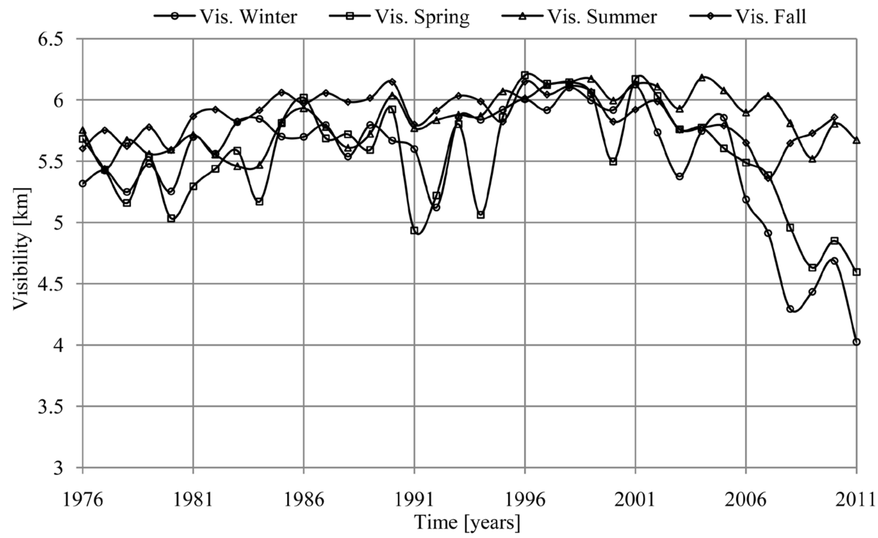


Figure 2. Presents the yearly mean atmospheric visibility values for the four seasons between 1976 and 2011.

Between 1976 and 1999, AV increased significantly (0.001 significance level) in winter, spring, summer, and fall by 0.65 km/24 years, 0.73 km/24 years, 0.63 km/24 years, and 0.40 km/24 years, respectively.

Contrarily, for the period 2000-2011, visibility decreased significantly (95% confidence level) by −2.16 km/12 years in the winter season, −1.68 km/12 years (99% confidence level) in spring, −0.48 km/12 years in summer, and no significant changes during the same period in the fall.

To investigate the visibility trends for each month individually, the mean visibilities were categorized into 12 months during the study period. The MK tests for each month are illustrated in Table 1. With different confidence levels, only three months showed a significant increase in visibility trends during the 36-year study period. At $\alpha = 0.01$, visibility increased by 0.25 km/36 years and 0.32 km/36 years in September and December, respectively. October showed a significant increasing trend of 0.36 km/36 years at the $\alpha = 0.01$ confidence level. For the rest of the months, no significant changes in AV were observed.

For the period 1976-1999, the AV in Riyadh for each month increased considerably with different significance levels and magnitudes. At the 0.1 significance level, it increased in March and May by 0.021 and 0.025 km per year, respectively. For the same period and at the 0.01 significance level, the visibility increased by 0.79 km/24 years in April, 0.84 km/24 years in June, 0.60 km/24 years in July, and 0.72 km/24 years in December.

In January, visibility increased by 0.65 km/24 years, in February 0.74 km/24 years, in August 0.48 km/24 years, in September 0.41 km/24 years, in October 0.60 km/24 years and in November 0.33 km/24years during the 24-year period at the 0.001 significance level.

For the period between 2000 and 2011 and at the 0.01 significance level, visibility decreased by −1.92 km/12 years in January, −1.56 km/12 years in March,

−2.04 km/12 years in April, −1.80 km/12 years in May, −1.92 km/12 years in July, and −0.84 km/12 years in August. For the same period, visibility decreased by −1.44 km/12 years in February and −2.16 km/12 years in June at the 0.001 significance level. For October, November, and December, visibility showed no significant changes.

3.3. Meteorological Effects on Atmospheric Visibility

Several sources may explain the long-term variations in AV during the whole study period or during certain periods within this time range. These include the influence of meteorological conditions, including temperature; RH; large-scale variations; dust storms from local, regional, and global sources; and climate change (Al Senafi & Anis, 2015; Mahowald et al., 2007; Miller et al., 2008). Moreover, additional direct or indirect causes include anthropogenic emissions from human and industrial activities as well as the increase in population and associate activities (Appel, et al., 1985; Malm & Kreidenweis, 1997; Tsai et al., 2007; Zhao et al., 2011). The effects of meteorological conditions on atmospheric aerosols have been reported by several investigators. Meteorological factors influence air pollutant deposition, dispersion, transport, formation, and removal from the atmosphere. The variations in these factors and their subsequent effect on atmospheric aerosols and particles affect AV (McMurry & Stolzenburg, 1989; Malm & Kreidenweis, 1997; Mahowald et al., 2007; Miller et al., 2008).

In this subsection, the effect of meteorological variables on the AV in Riyadh, mainly RH and air temperature, will be investigated.

There are two significant periods in which the behaviors of the two variables present remarkable changes (**Figure 3**). These are between 1976-1990 and 1991-2011. MK analyses showed that the first period was characterized by a sharp and significant decrease in RH (−0.48%/year) and a weak significant decrease in air temperature (0.03˚C/year). Meanwhile, the period between 1991 and 2011 was marked by a strong and significant increase in temperature (0.11˚C/year).

Correlation analyses between AV and both air temperature and RH during the 36-year period and the two abovementioned periods showed no significant relationships between them. Yet there were some years when AV had clear correlations with the two variables. For instance, AV and RH followed a decreasing trend between 2006 and 2008 whereas both variables are anticorrelated between 1986 and 1990. Moreover, both AV and air temperture followed the same decreasing trend between 1999 and 2005. It can be seen that, while air temperature and RH can explain some of the AV trends during some periods, they fail to explain the visibility trends over wider ranges.

4. Discussion

It is well-known that throughout the 1970s and 1980s, the massive inflow of revenue from high oil prices allowed the kingdom to increase its infrastructure

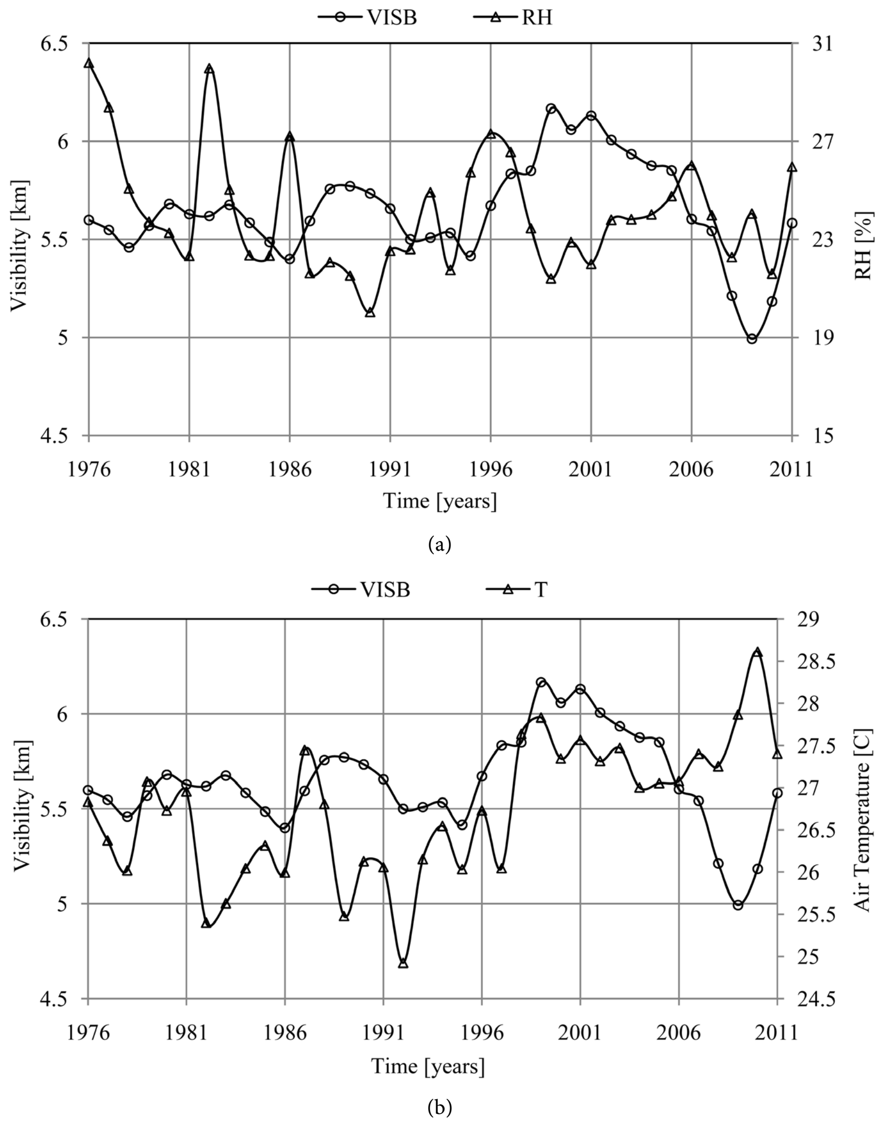


Figure 3. Presents the yearly mean atmospheric visibility values and (a) RH and (b) air temperatures (T) between 1976 and 2011.

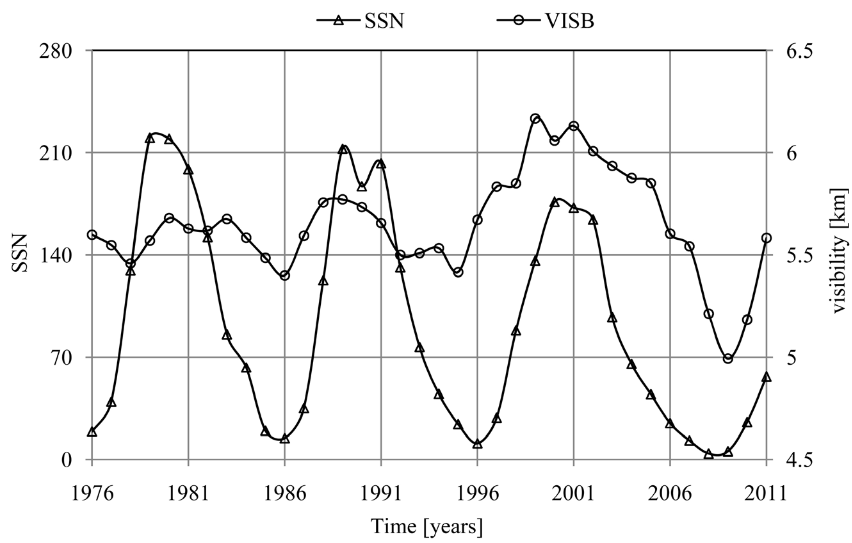
projects, leading to an increase in population and urbanization, which affect the air quality in Riyadh (Knauerhase, 1974). However, it was evident that during these periods the atmospheric AV showed an increasing trend, which is inconsistent with expectations. The results presented in the previous subsection indicated that meteorological conditions may explain some of the trends in observed visibilities during some periods but not all of them. Meanwhile, the effect of atmospheric aerosols can overwhelm meteorological effects at some periods and vice versa. This was clear during the last six years of the study period, when the effects of mega-projects established by the Saudi government and more frequent dust storms contributed to AV reduction in Riyadh. However, this cannot explain the trends in other years.

Therefore, considering long-term variability, the idea to search for extraterrestrial causes came to our attention (Maghrabi, 2019; Maghrabi & Kudela, 2019).

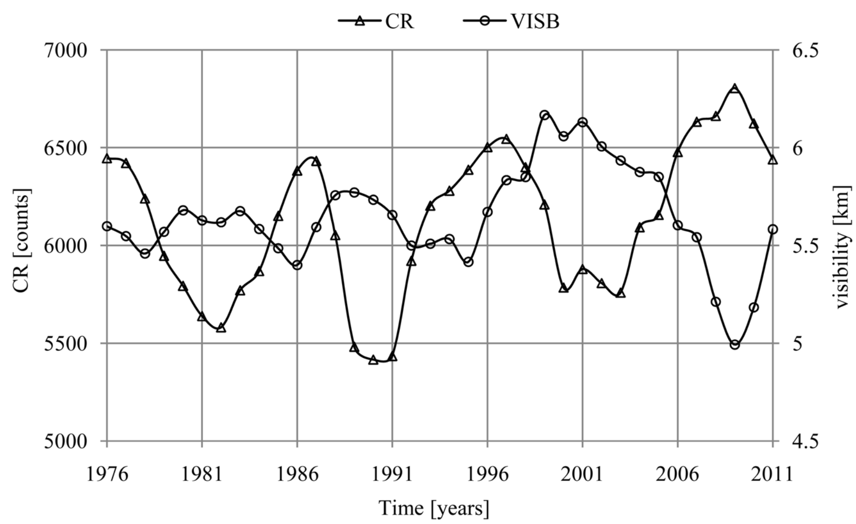
For this purpose, the sunspot number (SSN) and CR data were used to investigate possible causes of the long-term variations in AV. Daily averages of CR data for the study period were obtained from the Oulu neutron monitor (http://cosmicrays.oulu.fi/). Similarly, SSN version 2 was obtained from WDC-SILSO, Royal Observatory of Belgium, Brussels (Clette & Lefèvre, 2016).

It can be seen that, apart from the absence of relationships during limited periods, AV is anticorrelated (correlated) with CRs (SSN) in most of the periods (**Figure 4**).

While there are spreads in the relationships between AV and the two variables, evidently AV is generally correlated with SSN and negatively with CR (**Figure 5**). Correlation analyses were conducted and showed significant ($p <$ 0.05) nonzero relationships between AV and the two variables.



(a)



(b)

Figure 4. Shows the time series of the yearly mean values of atmospheric visibility and (a) SSN and (b) CR data between 1976 and 2011.

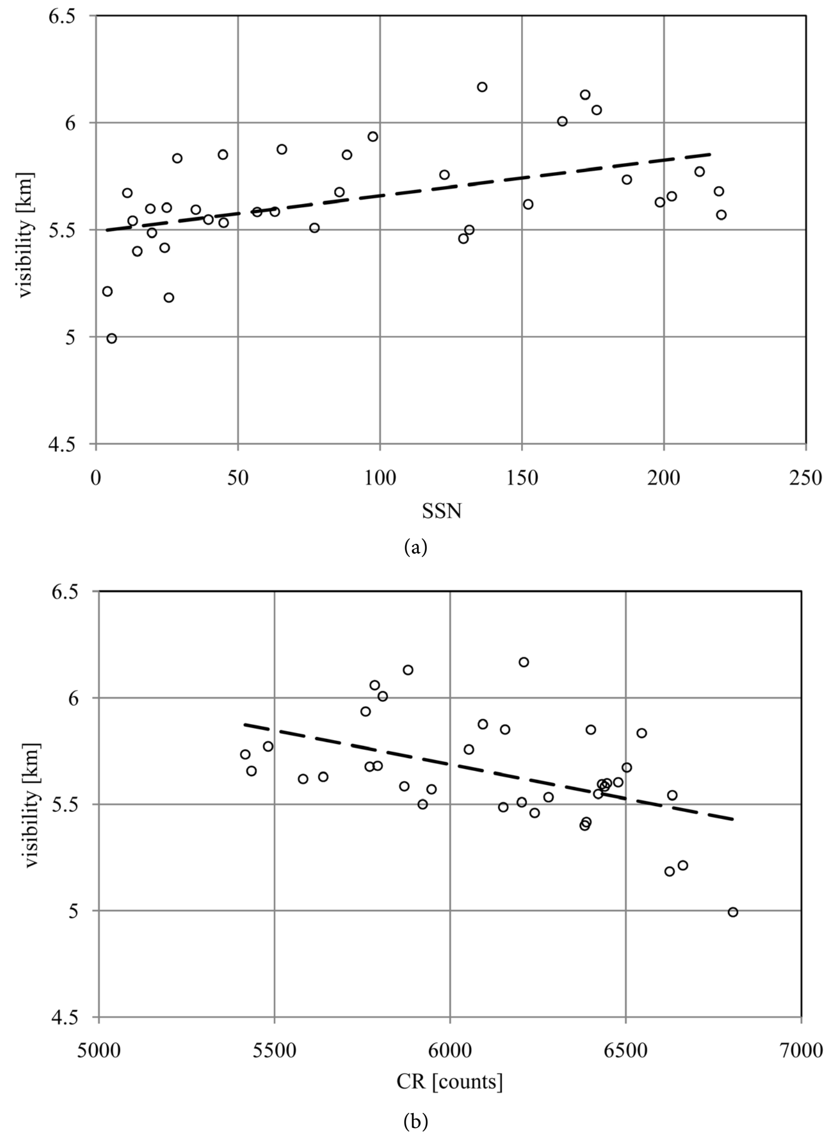


Figure 5. Scatter plots between yearly mean values of the atmospheric visibility and (a) sunspot number (SSN) and (b) cosmic ray (CR) neutrons from Oulu neutron monitor. The solid line is the regression line.

The regression equations between AV and SSN and CR, respectively, are

$$\text{AV} = 0.0011\left[\pm 5.5\times 10^{-5}\right]\text{SSN} + 5.61\left[\pm 0.0.061\right]$$

(correlation coefficient = 0.32; F_{value} = 5.3 > critical value (F_{α} 0.05(1, 36)) = 4.08 at 95% confidence level).

$$\text{AV} = -0.00031\left[\pm 9.91\times 10^{-5}\right]\text{CR} + 7.58\left[\pm 0.61\right]$$

(correlation coefficient = 0.47; F_{value} = 9.5 > critical value (F_{α} 0.05(1, 36)) = 4.08 at 95% confidence level).

This result is consistent with the previous finding reported by (Maghrabi & Kudela, 2019), which established a positive relationship between CR and atmospheric aerosols.

Based on the obtained results, significant correlations between time series of CR data measured by the NM and sunspot number and the AV were found. Consequently, using data that cover several solar cycles are recommended to further confirm the finding of this study.

Furthermore, power spectral analyses using the Fourier transform (FT) technique were conducted to search for periodicities in the AV time series data. The mean monthly values of the AV data between 1976 and 2011 were used for this purpose. The procedures followed in calculating the power spectra presented in this study are similar to those reported in e.g., (Kudela & Mavromichalaki, 2010; Maghrabi & Kudela, 2019; Maghrabi et al., 2021). **Figure 6** shows a Lomb periodogram for all frequencies showing the main peaks of the visibility data (95% confidence level). The spectrum presents several significant peaks with different amplitudes. The most obvious peaks are 9.8 years, 5.2 years, and 1 year. The one-year peak is expected to be, in one way or another, of terrestrial origin and mainly associated with seasonal variations in meteorological parameters. However, the other peaks are expected to be of extraterrestrial origin.

Because of the effect of high peaks (mainly the one-year peak), which masks the presence of other periodicities in the AV data, two low-frequency filters were applied to the visibility data spectrum (Kay, 1988; Maghrabi, 2019; Maghrabi & Kudela, 2019; Maghrabi et al., 2021). These filters were between 0.02 and 0.05 month^{-1} (**Figure 7(a)**) and between 0.051 and 0.077 month^{-1} (**Figure 7(b)**).

For the first filter, the 3.8, 3.3, 2.8, 2.2, 2, and 1.7-year peaks are clear whereas the 1.5, 1.3 and 1.1-year peaks are seen in the second graph. Most of these periodicities are similar to those reported by several investigators and found in solar, interplanetary, and CR parameters e.g., (Pap et al., 1990; Antalova et al., 2000; Kane, 2005; Kudela, et al., 2002; El Borie & Al Thoyaib, 2002; El Borie, 2002, Mavromichalaki, et al., 2003; Maghrabi & Kudela, 2019; Maghrabi et al., 2021).

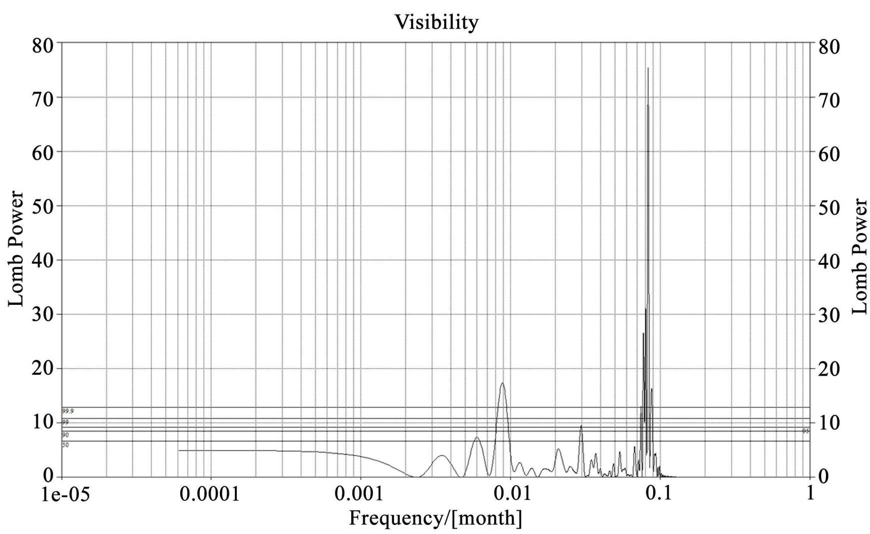


Figure 6. Lomb-Scargle spectrum of the time series of the monthly mean AV data for 1976-2011. The horizontal lines are 50%, 90%, 95%, 99%, and 99.9% confidence levels.

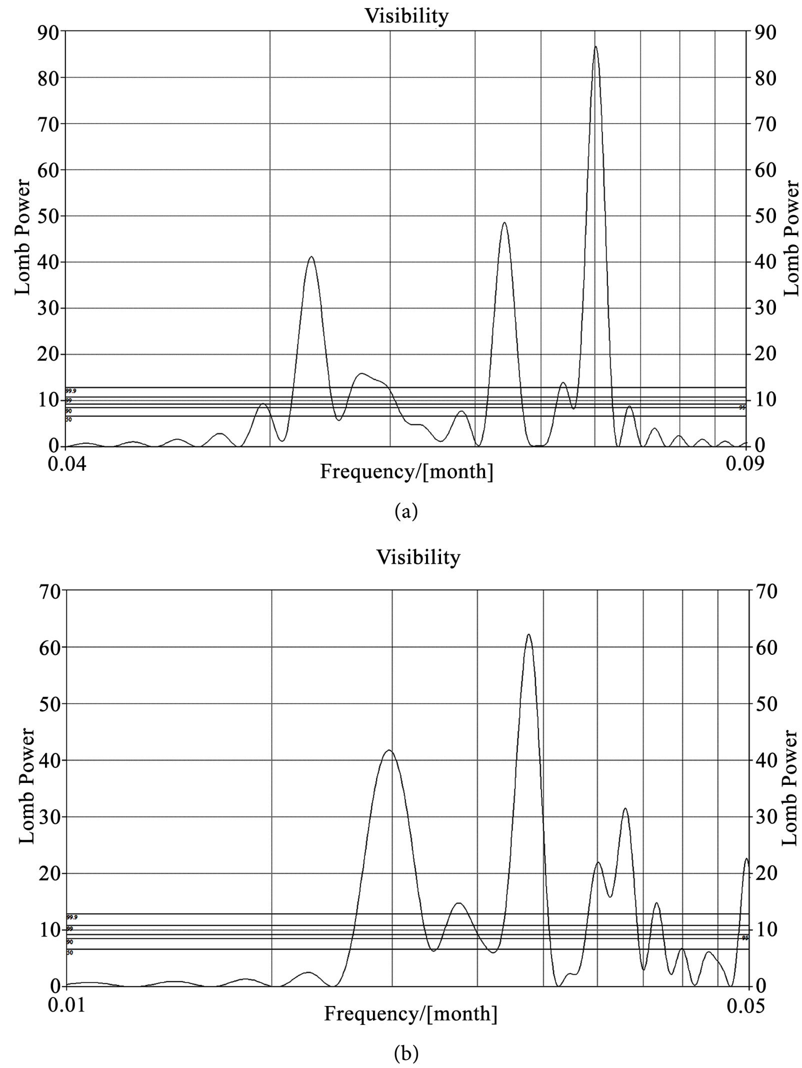


Figure 7. The same diagrams as in **Figure 6**, but here, low-frequency filters at (a) 0.02 - 0.05 month^{-1}, and (b) 0.051 - 0.077 month^{-1} have been applied.

It is well-known that solar activity and associated geomagnetic disturbances affect the propagation of high-energy CR. During high solar activity (high SSN), the number of CRs is modulated (decrease) because of the increase in magnetic activity, which affects the rate of CRs at the top of the atmosphere. This modulation in the flux of the primary CRs affects the level of atmospheric ionization because CR particles are one of the main sources of atmospheric ionization. This will result in changes in the rate of aerosol formation (Kristjánsson et al., 2002; Kristjánsson et al., 2004; Marsh & Svensmark, 2000; Svensmark & Friis-Christensen, 1997; Maghrabi & Kudela, 2019; Maghrabi et al., 2021). Since atmospheric aerosols are one of the major factors affecting AV through scattering and absorption, solar activity and associated CR modulation can be considered to affect AV directly or indirectly (Maghrabi & Kudela, 2019).

The results presented in this study are preliminary, and it is recommended that more detailed investigations be conducted.

5. Conclusion

AV data for the period 1976-2011 in Saudi Arabia were used to investigate interannual, monthly, and seasonal variations. Nonparametric MK tests were performed to detect AV magnitude and trends. No significant trends in AV were observed during the 36 years. However, between 1976 and 1999, both significant increases and decreases in AV between 2000 and 2011 were found.

The possible effects of meteorological parameters, mainly relative humidity and air temperature, on AV during the study period were investigated. While these two variables could explain the visibility trend over some years, they failed to explain it in most of the others.

The possible effects of solar activity and the associated CR modulation on the long-term trend of visibility were examined as well. This was done using regression analyses and power spectral analyses. Correlation analyses showed a nonzero positive and significant correlation between the AV time series and CR (from Oulu NM) and a negative and significant correlation with solar activity (SSN).

Power spectra analyses using the FT technique were performed for the period 1976-2011 and revealed several long, mid- and short-term periodicities.

These include 9.8 years, 5.2 years, 2.2 years, 1.7 years, 1.3 years, and 1-year periods, the last one mainly of terrestrial origin (seasonal variation). The long- and mid-term periodicities are similar to those reported by several investigators and found in solar, interplanetary, and CR parameters. Therefore, we suggest that solar signals may directly or indirectly affect long-term variations in AV.

Correlation and power spectral analyses indicate possible mutual relations between both CR intensity and solar activity and variations in AV observed on the ground at specific positions analyzed here. The possible reason for this relationship was the fact that solar activity modulates CR, which affects the level of atmospheric ionization and aerosol formation. Since aerosols scatter and absorb light, the physical mechanism of the relationship can be considered.

Further confirmations are recommended. It is important to note that the effect of local, regional, and global sources of atmospheric aerosols and meteorological effects cannot be ignored when studying the effect of atmospheric aerosols and visibilities over certain periods.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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