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Impact of an annular solar eclipse on trace gases and meteorological parameters over Jaipur, Northwestern India

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This study aimed to identify the impact of an annular solar eclipse i.e., 21 June 2020 on the variation of meteorological parameters along with trace gases using statistical analyses. The study site is located at Poornima University, Jaipur (26.7796°N, 75.8771°E), Rajasthan, India. The observational analysis indicates a rapid decrease in solar direct radiation (SDR) which varied between 706 and 79 W/m^2 during the eclipse. SDR was reduced to 79 W/m^2 at the maximum peak of the solar eclipse at 11:55 a.m. at the study location. The comparative analysis shows the variation of SDR during the solar eclipse day, the previous day, and the day after the event. A strong dip was observed in SDR during the annular eclipse day concerning before (734.31 W/m^2) and after (734.375 W/m^2) eclipse event. Furthermore, the impact of the solar eclipse on temperature (Ts) and Relative Humidity (RH) was analyzed over Jaipur. The statistical analyses demonstrate an apparent decrease in temperature of about 2°C while RH shows a slight increment (3.45%) during the solar eclipse event. The results show an inverse correlation between the solar eclipse and trace gases variations during the eclipse due to the changes in solar radiation, surface temperature, and variation in winds that might affect the photochemical processes.

KEYWORDS

solar eclipse, solar radiation, Temperature, energy budget, trace gases, Northwestern India

Introduction

The solar eclipse is a rare natural phenomenon, which provides a unique opportunity to study the sudden changes in the atmosphere due to variation in solar direct radiation (SDR) (Tzanis et al., 2008). SDR plays a very important role in shaping the Earth's thermal balance. Solar eclipse leads to rapid cut-off in SDR for a duration of a few minutes to hours and has the ability to alter the Earth's Energy Budget. Abbott (1958) measured the radiative changes during the partial eclipse and reported that a small reduction in net SDR was much greater than the small obscuration of the Sun's disc and stated that the phenomenal decrease was due to penumbra in the atmosphere. The variation in the SDR is responsible for the abrupt changes in meteorological variables and photochemical processes in the atmosphere. A large number of studies carried out to understand the impact of the solar eclipse on the atmospheric phenomenon. The impact of the solar eclipse on meteorological variables i.e., RH, solar radiation, temperature, wind speed, wind direction, and precursor gases is quantified by many researchers (Srivastava et al., 1982; Fernadez et al., 1993a; Abram et al., 2000; Fabian et al., 2001; Zanis et al., 2001; Zerefos et al., 2001; Kolev et al., 2005; Tzanis, 2005; Zerefos et al., 2007; Gerasopoulos et al., 2008; Sharma et al., 2010a). The variation in RH and Ts occurs during a solar eclipse. The drop and rise in meteorological parameters are different for each location due to the percentage of Sun coverage, time of the day, latitude, synoptic condition, etc. during the solar eclipse. The change in surface temperature is one of the most noticeable meteorological parameters experienced by the observer. Generally, when the Sun is half covered the temperature drop becomes noticeable (Anderson, 1999), while other observers reported the immediate temperature response after the start of the solar eclipse (Anderson, 1972; Szalowski, 2002). In contrast, the RH shows the opposite signature during a solar eclipse. The minimum temperature found during a solar eclipse when the Sun is maximum covered by a celestial body.

The solar ultraviolet radiation at 312 and 365 nm showed a reduction of 3% and 7%, respectively at four stations in the greater Athens basin in Greece (Founda et al., 2007) during a solar eclipse. The air temperature dropped to ~0.7°C while RH increased and was found to be maximum at the end of the eclipse at the center of Athens. Jain et al., 2020 studied the impact of the solar eclipse on meteorological parameters and trace gases over Gadanki and reported that the Global Horizontal irradiance (GHI) decreased ~95.5% during the eclipse and was responsible for a temperature decrease of 4.36°C, sustained 100% RH and delayed atmospheric boundary layer development. The concentration of O_3 decreases up to 48% whereas NO_2 concentration has been increased by ~8 times. There has been a time lag (~52 min) in observing the effects which are generally attributed to the production and destruction mechanisms of these species and the meteorological parameters of the observation site. Similarly, the reduction in wind speed and ambient temperature was recorded at Thiruvanathapuram, India during a nearly total eclipse on 15 January 2010, whereas RH experienced the increment (Sharma et al., 2010a).

This is the first study of its kind on annular solar eclipse over Jaipur in the vicinity of the Thar Desert to understand the effect of eclipse on meteorological parameters and trace gases. In the current work, an investigation has been conducted to understand the impact of the solar eclipse that occurred on 21 June 2020, on meteorological variables i.e., RH, Ts, SDR, wind speed (WS), etc. and trace gases i.e., O_3, NH_3, NOx, and NO over Jaipur, Northwestern India. The study further compares these parameters with pre- and post-annular solar eclipse event.

Observation site and solar eclipse

This solar eclipse study was conducted at Poornima University, Jaipur (26.7796°N, 75.8771°E). Jaipur is located in the vicinity of the Thar Desert. Jaipur experiences a semi-arid climate with an average rainfall of ~60 cm (Verma et al., 2013). Jaipur is the capital of Rajasthan, the largest state of India. Jaipur has a very rich traditional culture and is known as Pink City (Prakash et al., 2013). Jaipur is a colorful city with an oscillation of organized architecture unveiling the royal culture, arts, and traditions as the heritage of Rajasthan.

The first solar eclipse of 2020 occurred on 21st June over Jaipur, Rajasthan (Figure 1). This annular solar eclipse started in Afric h and 45 min with start at the eastern part of the Democratic Republic of Congo at 4.48 GMT just at sunrise and ended in the Pacific Ocean at 8.32 GMT (Pratap et al., 2021). This eclipse is unique in a manner as it took place on June solstice (21st June i.e., the day which brings the longest day of the year). The maximum obscuration over Jaipur has been 88.1% (the eclipse intensity has been expressed in obscuration rather than phases because this has been a partial solar eclipse over Jaipur) with a maximum magnitude of 0.88 at around 11:56 IST (06:26 GMT). The total eclipse period observed at Jaipur has been about 3 h and 29 min starting at 10:14 IST (Indian Standard Time or 04: 44 UTC) and ending at 13:44 IST (8:14 GMT).

Methodology

For this study, an Automatic Weather Station (AWS) is installed on the rooftop of the Academic Block of Poornima University, Jaipur. The changes in meteorological parameters were recorded by the Automatic Weather Station (WatchDog 2900 ET Weather Station) manufactured by Spectrum Technologies, Aurora, IL, United States) during the Solar eclipse. The accuracy of WatchDog Sensor for Ts, RH, WS, wind direction, SDR, and Dew point is ± 0.6°C, ±3%, ± 3 km/h or ± 5%, whichever is greater; ± 4°, ± 5%, and ± 2°C, respectively. The meteorological parameters were recorded with a 1-min temporal resolution during the solar eclipse.

The trace gases observations were collected by the Continuous Ambient Air Quality Monitoring Stations (CAAQMS) under the national air quality monitoring network at Police Commissionerate Jaipur (26.916, 75.801) and this monitoring site is maintained by Rajasthan State Pollution Control Board (RSPCB), Jaipur. All the trace gases data set used in the present study is freely available at the website of the Central pollution control board (CPCB): https://app.

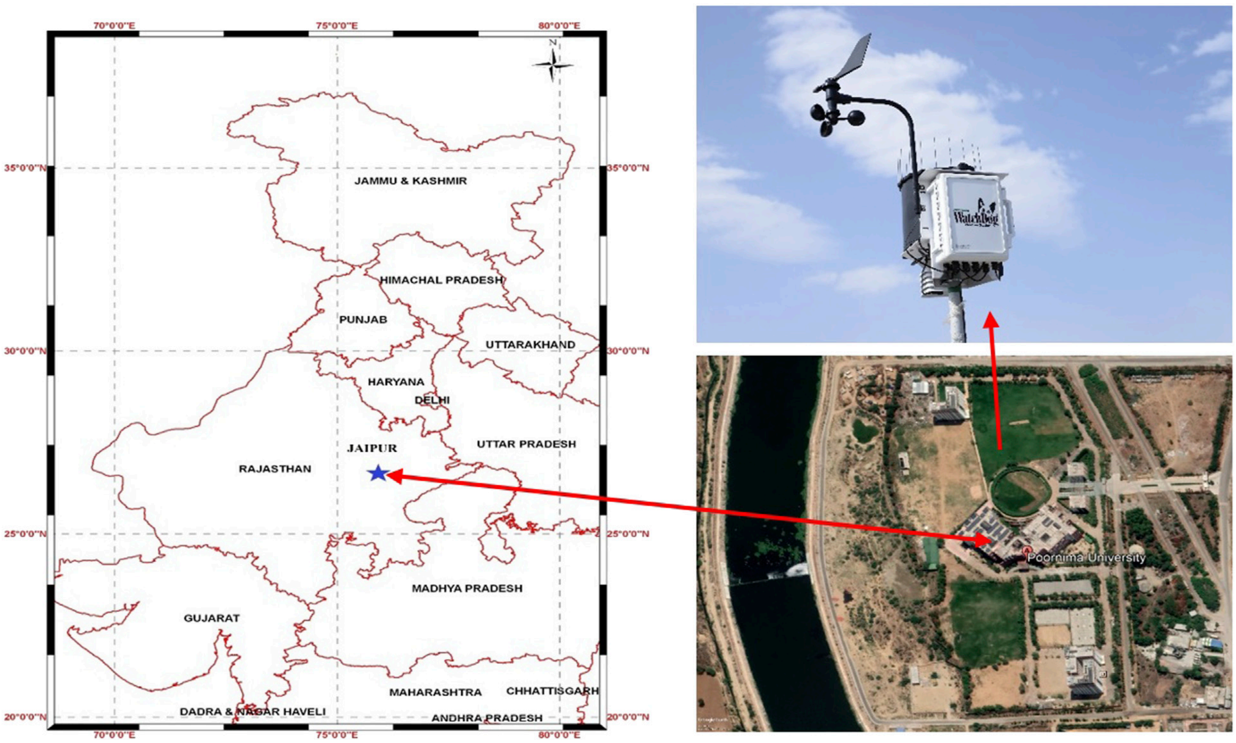

FIGURE 1
The location of study region and observational site for the solar eclipse study.

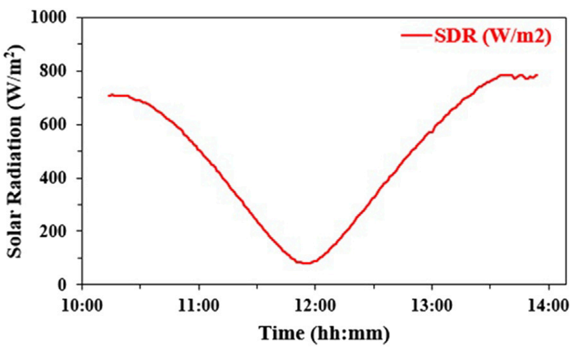

FIGURE 2
Temporal variations (10:15 a.m. to 1:45 p.m.) of SDR during the solar eclipse at Jaipur.

cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing/data. CPCB has deployed different types of instruments fitted with sensors certified by world meteorological organization to collect data (CAAQMS Guidelines, 2019). The monitors are reported to be regularly calibrated by operating bodies by the instruction manual of the equipment for ensuring the quality of the data.

Results and discussion

The solar eclipse of 21 June 2020, at Jaipur, northwestern India, started at 10:14 a.m. (IST) and ends at 01:44 p.m. (IST) with maximum solar coverage (88.1%) at 11:55 a.m. (IST) over the observation site. This solar eclipse occurred more than 3 h over Jaipur. The changes in meteorological parameters and trace gases during a solar eclipse are discussed in this section.

1) Impact of the annular solar eclipse on Solar Radiation

Figure 2 shows the temporal variation of SDR during the eclipse at Jaipur. The value of SDR varies between 706 and 79 W/m^2 during the eclipse. As the percentage of Sun's covered area started to increase, SDR started to decrease. For the maximum Sun coverage (88.1%), the SDR was reduced to 79 W/m^2 at the maximum peak of the solar eclipse at 11:55 a.m. The SDR's comparative analysis is also done a day before and after the solar eclipse. Figure 3 shows the variation of SDR during the solar eclipse and the day before and after the event. A strong dip was observed in average SDR during annular eclipse day (384.16 W/m^2) concerning previous (400.81 W/m^2) and after day (406.45 W/m^2) of the event (Figure 3).

The statistical analysis of the observed value was carried out to understand variation in SDR with Ts and RH as shown in

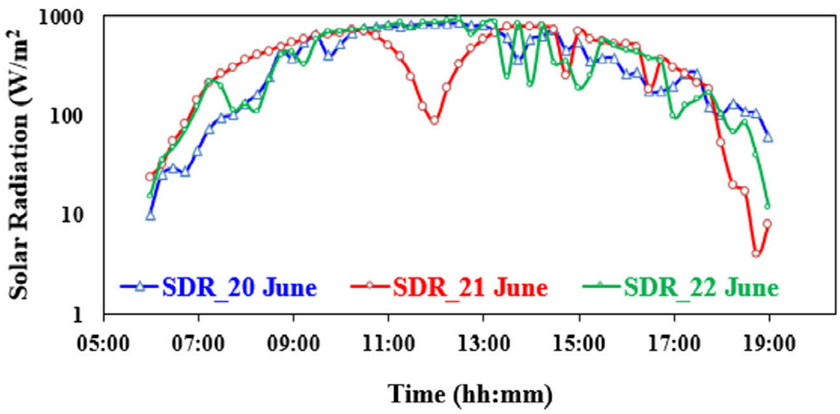

FIGURE 3
Temporal variations (6 AM to 7 PM) of SDR during the solar eclipse, a day before and a day after the event.

TABLE 1 Statistical analysis of observed parameters.

S. No.	Date	Solar radiation (W/m2)				Temperature (°C)				Relative humidity (%)			
		Max.	Min.	Mean	Std.	Max.	Min.	Mean	Std.	Max.	Min.	Mean	Std.dev
1	20 June	846	10	400	284	39.5	27.8	34.9	4.08	72.7	38.4	52	11.17
2	21 June	782	4	384	247	39.5	25.6	34.54	3.86	84.2	40.6	53.35	11.87
3	22 June	921	12	406	302	38.2	27.6	34.15	3.30	81.5	43.3	56.58	11.71

Table 1. From Table 1, it can be seen that the maximum and average SDR during solar eclipse day is found to be low than on other days during study period.

2) Meteorological parameters during an annular solar eclipse

The meteorological parameters play the important role in any natural phenomenon. The Temperature (Ts) and Relative humidity (RH) are the important meteorological parameters to understand the synoptic meteorology of any location. The variation in temperature and RH was also observed during the solar eclipse event. Jaipur experiences a hot temperature with less humidity during the summer season. The highest temperature in Jaipur reaches more than 45°C in the summer season.

The impact of the solar eclipse on temperature and RH was quantified over Jaipur and it is found that the temperature decreases about 2°C while RH shows a slight increment during the solar eclipse event (Figure 4).

Figure 5 shows the temporal variation of temperature during the event, a day before, and a day after. The temperature before the start of the event was higher than the day before and the day after but during an eclipse, the temperature dropped (−2°C) due to less availability of SDR.

The variation in wind speed was also observed during the solar eclipse and the average WS was found higher (78%) during the event than on previous as well as upcoming days (Figure 6). The wind speed did not show any specific trend during the solar eclipse. The previous studies reported a decrease in WS (e.g., Clayton et al., 1901; Anderson and Keefer, 1975; Fernandez et al., 1993b).

The wind direction was found mostly southwesterly during the annular solar eclipse (Figure 7).

3) Impact of the solar eclipse on Trace Gases

The concentration of trace gases plays important role to understand its adverse impact on human health. Concentration of ground Ozone can trigger a variety of health problems including chest pain, coughing, throat irritation, and congestion. Similarly, the Nitrogen Oxides also gives the adverse effect to human health, it may cause brief, nonspecific symptoms such as cough, shortness of breath, tiredness, and nausea. The high concentration of Ammonia causes immediate burning of the eyes, nose, throat and respiratory tract and can result in blindness, lung damage or death.

Previous studies also reported the changes in surface temperature, variation in winds, boundary layer height, and photochemical processes during the eclipse event over India

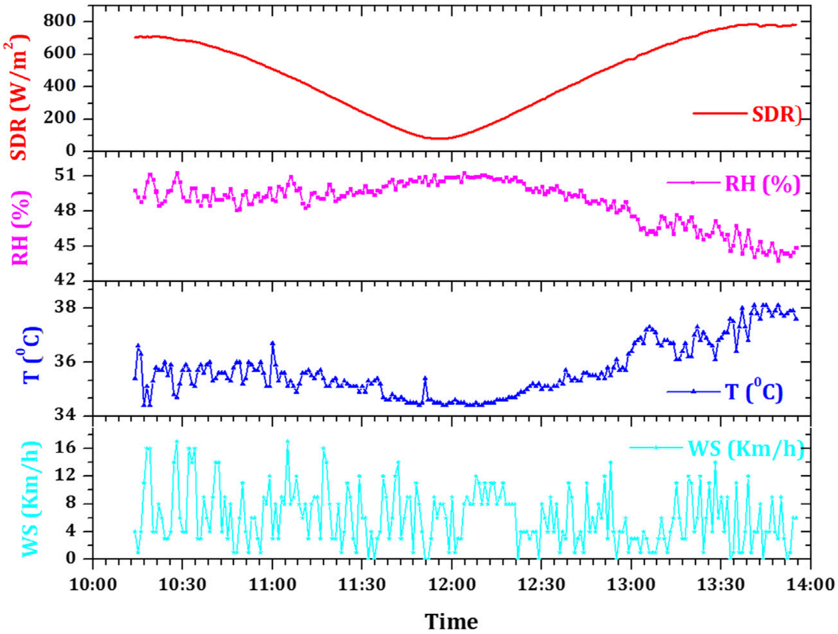

FIGURE 4
Temporal variations of meteorological parameters during the eclipse.

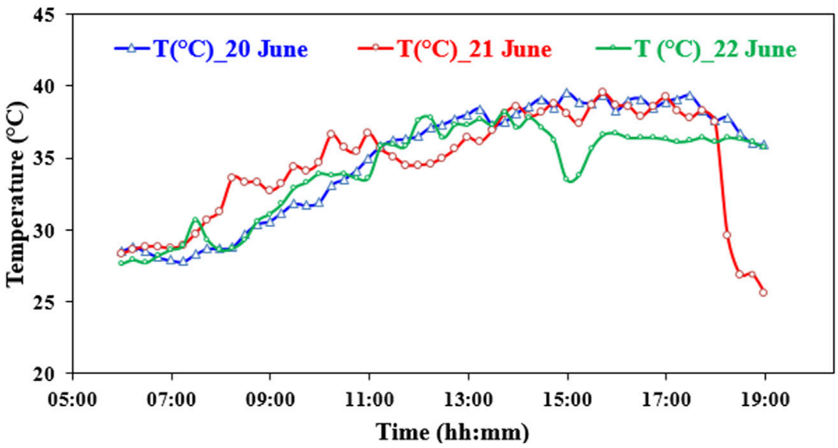

FIGURE 5
Temporal variations (6 a.m.–7 p.m.) of temperature during a solar eclipse, a day before and a day after at Jaipur.

(Naja and Lal, 1997; Sharma et al., 2010b; Venkat Ratnam et al., 2010; Girach et al., 2012; Girach et al., 2020; Jain et al., 2020). They have reported substantial variations in the surface level concentrations of the photochemical species such as O_3 and NOx which have a direct linkage to solar irradiation.

The concentration of trace gases i.e., O_3, NH_3, NOx, and NO shows the high variability during the solar eclipse at Jaipur (Figure 8). Ozone (O_3) is a secondary pollutant that forms in the presence of sunlight and its precursors viz, nitrogen oxides (NOx), and volatile organic compounds (Yadav et al., 2016; Yadav et al., 2020). Its concentration depends on photochemistry, physical/chemical removal, and transport over local, regional, and global scales (Lal et al., 2000). The concentration of O_3, NO, NO_X, and NH_3 over Jaipur varies between 38.65–54.17 μg/m^3; 5.33–7.54 μg/m^3; 17.16–22.35 μg/m^3; 26.12–32.37 μg/m^3, respectively. The lowest concentration

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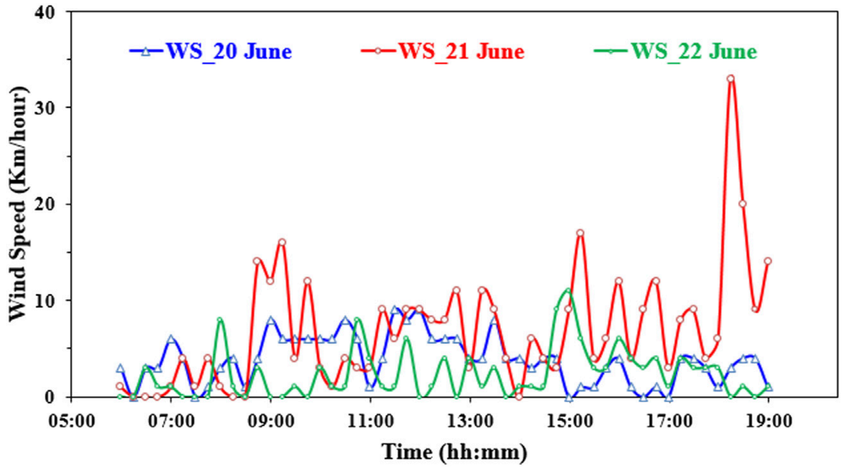

FIGURE 6
Temporal variations of wind speed during a solar eclipse, a day before and a day after at Jaipur.

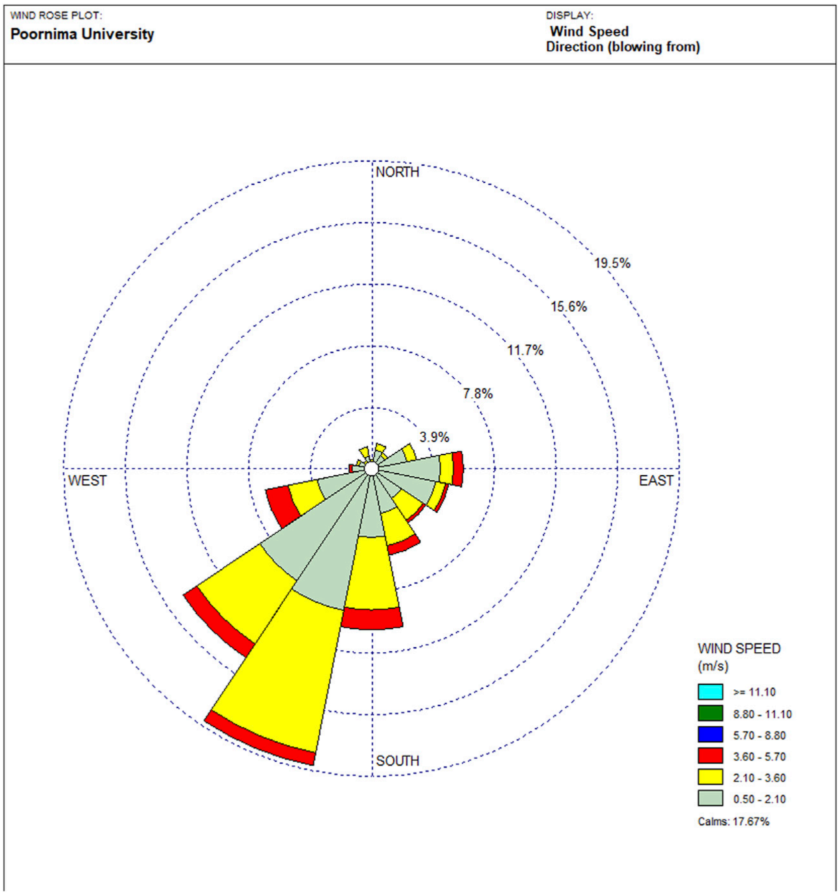

FIGURE 7
Wind rose diagram during the Solar Eclipse Day.

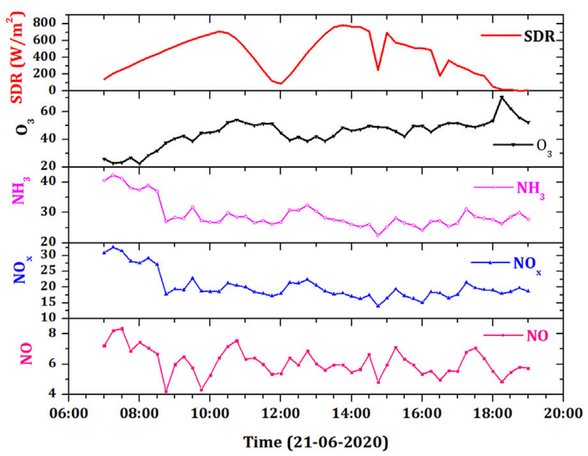

FIGURE 8
Trace Gases along with Solar Radiation during the solar eclipse.

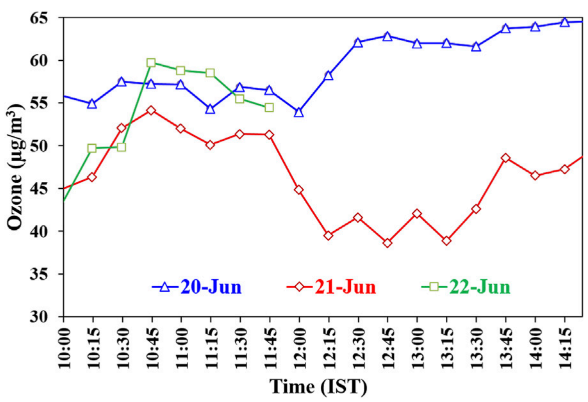

FIGURE 9
Comparison of ozone concentration during solar eclipse, a day before and a day after the event.

of NO and NO_X is found at the maximum Sun obscuration during a solar eclipse. The concentration of O_3 and NH_3 shows contradictory behavior during the solar eclipse.

O_3 concentration decreased by 23% during the solar eclipse day than the previous day (Figure 9). Even after more ozone formation due to the availability of more solar radiation on post-solar eclipse days, it is not visible in Figure 9 due to the non-availability of data. A similar trend in ozone concentration at Gadanki (Jain et al., 2020) and Yunnan province (Tian et al., 2022) during a solar eclipse. O_3 has shown a reduction in its concentration by up to 48% during solar eclipse days at Gadanki (Jain et al., 2020) and about 40% at Yunnan province (Tian et al., 2022). Similarly, the concentration of NO, NO_X, and NH_3 also decreased by 4.08%, 8.16%, and 7.19%, respectively during the solar eclipse day than the previous day. The concentration of NH_3 was also compared during the event. The concentration of NH_3 found low during solar eclipse days than pre and post-event.

Conclusion

The annular solar eclipse of 21 June 2020 brought the opportunity of studying changes in meteorological parameters and comparing them with a day before and a day after meteorological parameters. The value of SDR decreased from 706 and 79 W/m^2 during the eclipse. The temperature dropped to about 2°C during the solar eclipse due to less SDR reaching to the surface. As the temperature decreases, a slight increment was observed in RH. The wind speed also decreased due to a stable atmosphere during the solar eclipse. The concentration of trace gases also shows variability with about 23% deduction in O_3 during a solar eclipse.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

DP: Conceptualization, Writing—original draft. SV: Supervision, Methodology, Writing—review and editing. SP: Visualization, Writing—review and editing. VK: Validation, Data curation.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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