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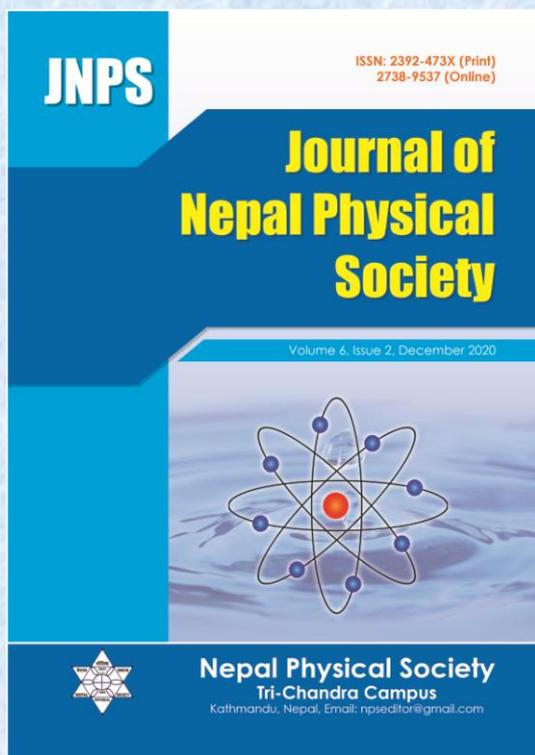
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Study of Linke Turbidity Factor over Bode, Bhaktapur

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Abstract

The daily aerosol optical depth (AOD) data are derived from AERONET over Bode, Bhaktapur (27.68° N, 85.39° E, 1297 m above sea level) for a period of one year 2013. Annual mean of Atmospheric turbidity factors are calculated. The effect of different physical as well as meteorological parameters on the Linke turbidity factor was analyzed. The yearly mean of solar insolation, Angstrom exponential(α), Angstrom coefficient of turbidity(β) and Linke turbidity(L_T) were found $4.70 \pm 1.10 \text{ kWh/m}^2/\text{day}$, 1.13 ± 0.21 , 0.18 ± 0.14 and 5.70 ± 2.46 respectively. Annual average of visibility is 2.98 ± 2.13 km. Result of this research work is beneficial for the further identification, impact and analysis of atmospheric turbidity at different places.

Keywords: Aerosol, Angstrom exponential, Angstrom turbidity, Linke turbidity, solar insolation.

1. INTRODUCTION

Sun is the closest star from the Earth. Solar energy has been identified as the largest renewable resources of energy for earth. Solar energy passing through the atmosphere is scattered and absorbed by molecules and particles. Solar energy interacts with large particle of atmosphere such as water droplets, dust and aerosol. The opacity of atmosphere for solar energy gives atmospheric turbidity. Study of atmospheric turbidity and its dependence on different meteorological parameters are used agriculture, hydrology, and Climate change.

Nepal is a land locked south east mountainous Asian country with a large area of beautiful landscape. Within this small and beautiful setting it possesses diversity in biosphere and variation of climate. Nepal lies in sun belt (latitude 15° to 35°). Annual solar isolation is 3.6 to 6.2 kWh/m²/day and sunshine duration is 300 days in Nepal [1]. In FY 2016/017, 538.6 TJ energy is consumed in which traditional fuel is 73%, commercial fuel is 25% and renewable energy is 2% [2]. 4,37,614 vehicle

register in Nepal in BS 2074/075 [3]. Large foreign currency is used to export petroleum product. Due to petroleum fuel based vehicle, air pollution increases. Study of air pollution is needed.

Kathmandu Valley (combination of Kathmandu, Lalitpur and Bhaktapur districts) covers area 893 km². Kathmandu valley is bowl shaped. Kathmandu valley is surrounded by four mountain ranges: Shivapuri at north, Phulchowki at south, Nagarjun Hill at North West and Chandragiri at west. The maximum and minimum global solar radiations (GSR) are 25.3 MJ/m²/day and 14.6 MJ/m²/day in May and January respectively. The annual average solar energy measuring 5.19 kWh/m²/day is found in Kathmandu from 2009 to 2010[4]. The average values attenuation coefficient in Kathmandu during the pre-monsoon period of 1999 is found to be 0.6027 ± 0.022 respectively [5]. The values of Angstrom coefficient of turbidity (β) found to vary from 0.16 ± 0.03 to 0.35 ± 0.15 with high values in summer and low values in winter from December 2011 to March 2013[6]. The yearly mean of atmospheric transmittance due to Rayleigh

scattering followed by ozone, water vapor, gas mixture and aerosols are found 0.889, 0.983, 0.881, 0.987 and 0.698 respectively for 2012 on Kathmandu Valley (Lat.:27.72° N, Long.: 85.32° E and alt.: 1337 m a.s.l.) [7].

Bode (27.68° N, 85.39° E, 1297 m above sea level) is an ancient Newari city in the east corner of the Kathmandu Valley, lies in Bhaktapur district. It covers area 0.41 sq.km, has population 6,364 with 1389 houses and population density 16,000 per sq. km [8]. Map of Bode is shown in figure 1. Due to high population density, air pollution may high. So study of air pollution is required. The average value of Angstrom exponential (α) is 1.18 ± 0.1712 and Angstrom coefficient of turbidity (β) 0.20 ± 0.1315 from December 2012 to July 2016 [9].

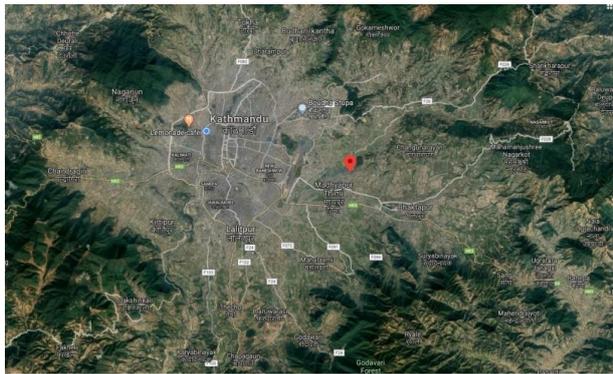


Fig. 1: Map of Bode [source: www.google.map.np]

2. METHODOLOGY AND MATERIAL

By Beer Lambert's law, direct normal solar spectral irradiance on outer layer of atmosphere ($I_{o\lambda}$) is attenuated exponentially in atmosphere due to absorption, reflection, scattering. Then direct normal solar spectral irradiance on ground (I_λ) is [10]

$$I_\lambda = I_{o\lambda} e^{-K_\lambda m}$$

Here m is optical air mass and K_λ is total extinction coefficient (total optical depth). Total extinction coefficient is sum extinction coefficient due to ozone ($K_{o\lambda}$), mixed gas ($K_{g\lambda}$), water vapor ($K_{w\lambda}$), aerosols ($K_{a\lambda}$) and Rayleigh scattering ($K_{r\lambda}$). The aerosol extinction coefficient ($K_{A\lambda} = K_{w\lambda} + K_{a\lambda}$) is also called as aerosol optical depth (AOD). According to Angstrom relation [11]

$$K_{A\lambda} = \beta \lambda^{-\alpha}$$

Angstrom turbidity coefficient (β) measures the aerosol concentration and accounts for all scattering constituents other than Rayleigh. Angstrom exponential (α) is particle size distribution. α and β are calculated by linear regression method. Spectral bands 675, 500, 440, 380 and 340 nm is used.

$$\log(K_{A\lambda}) = \log(\beta) - \alpha \log(\lambda) \dots \dots \dots (1)$$

According to Dogniaux (1974)[12], Linke turbidity factor is

$$L_T = \left(\frac{85 + \gamma}{39.5 e^{-w} + 47.4} + 0.1 \right) (16 + 0.22w) \beta \dots \dots \dots (2)$$

Here γ is solar height ($90 - \theta_z$) and w is water content in cm. Solar zenith angle (θ_z) is function of solar declination (δ), latitude (ϕ) of the place, solar hour angle (ω) and day no. of year (n_d) [13]

$$\theta_z = \cos^{-1}(\sin \delta \sin \phi + \cos \delta \cos \phi \cos \omega)$$

$$\delta = 23.45 \sin \left(\frac{360}{365} (284 + n_d) \right)$$

Atmospheric transmittance of aerosol is [14,15]

$$\tau_a = (0.1244 \alpha - 0.0162) + (1.003 - 0.125 \alpha) e^{-\beta m_a (1.089 \alpha + 0.5123)}$$

Where optical air mass is

$$m_a = \frac{P}{101325} \frac{1}{\cos \theta_z + 0.15(93.885 - \theta_z)^{-1.253}}$$

P = atmospheric pressure at the place

The spectral aerosol optical depth data of Bode from 2013 measured by CIMEL -318 sun photometer are available in the AERONET homepage of NASA. It is multichannel radiometer which measures direct solar irradiance. Solar insolation data are collected from [https://power.larc.nasa.gov/data-access-viewer/]. Meteorological data are collected from [https://www.worldweatheronline.com/].

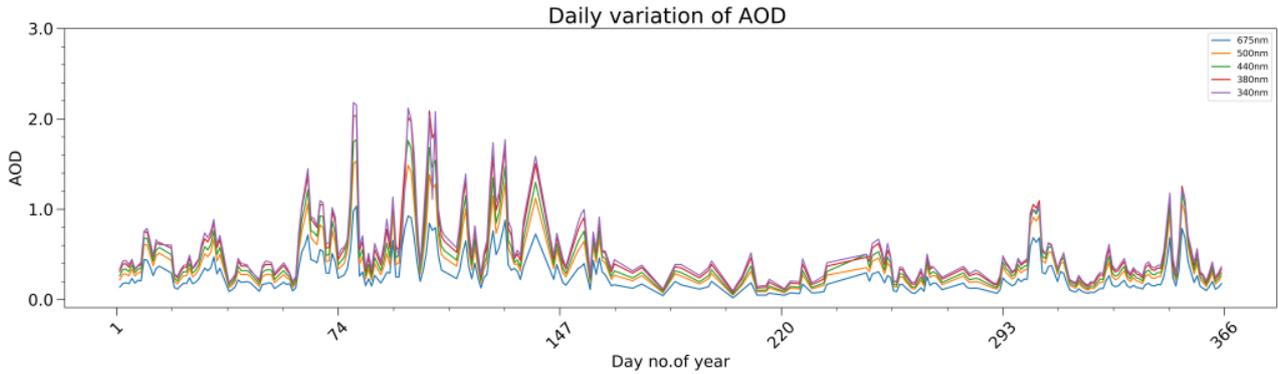
Open source software Python 3.7 software is used to analysis data and plot graph. Mean standard deviation, correlation coefficient are used as Statistical tool. Standard error is used as error bar in graph. Least square method is used to find trend line.

3. RESULTS AND DISCUSSION

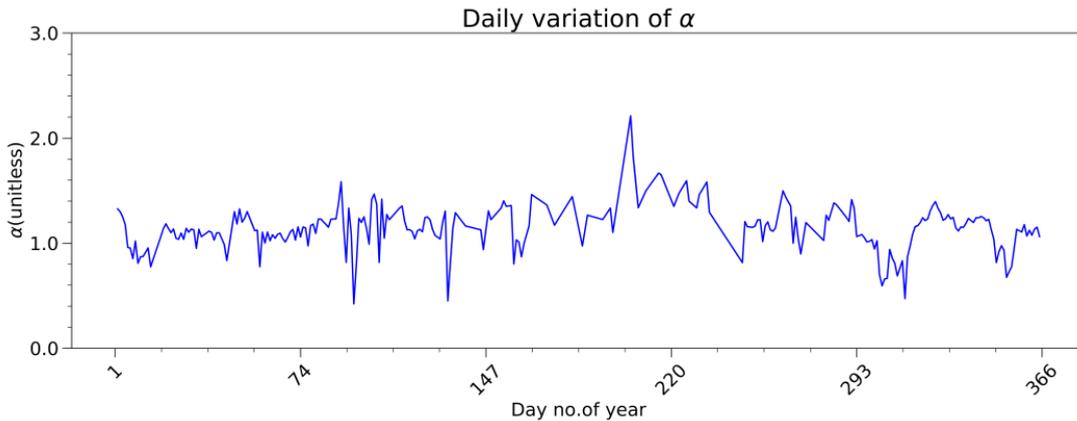
Figure 2(a) indicates daily variation of spectral AOD. The maximum value of AOD for 675 nm, 500nm, 440 nm, 380 nm and 340 nm are in 68th,

68th, 68th, 91th and 67th day of year (DOY) respectively due to high temperature. The minimum value of AOD for 675 nm, 500 nm, 440 nm, 380 nm and 340 nm are in 143th day of year (DOY) due to low temperature. Figure 2(b) shows daily variation of Angstrom exponential (α). The maximum value of α is in 143th day of the year due to present of large no. of smaller particle and minimum value in 82th day of the year due to present of large no. of big particle. Figure 2(c)

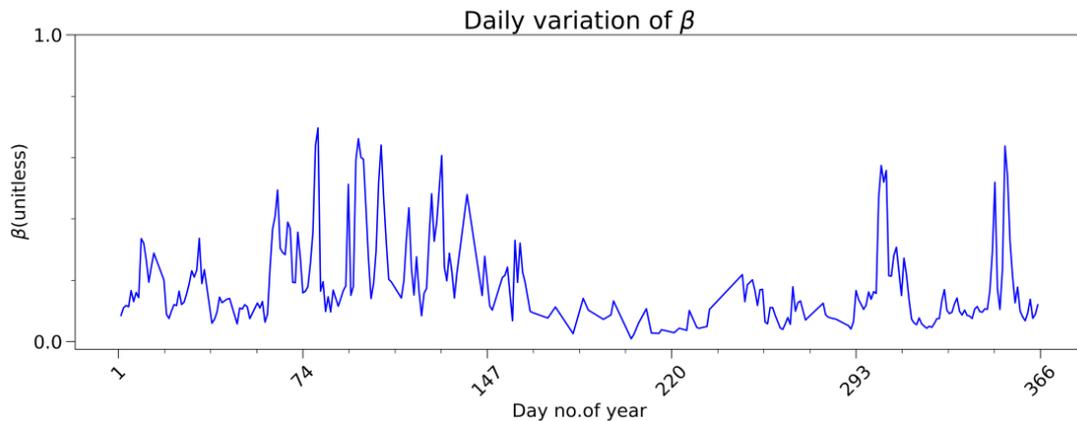
shows daily variation of Angstrom turbidity coefficient(β). The maximum value of β are in 68th day of the year due to present of large no of aerosols and minimum value is in 143th day of the year due to present of small no. of aerosols. Figure 2(d) shows daily variation of Linke turbidity(L_T). The maximum value of L_T are in 68th day of year due to air pollution and minimum value is in 217th day of the year. Statistics of those parameters are shown in Table 1.



a) AOD



b) Angstrom exponential



c) Angstrom turbidity coefficient

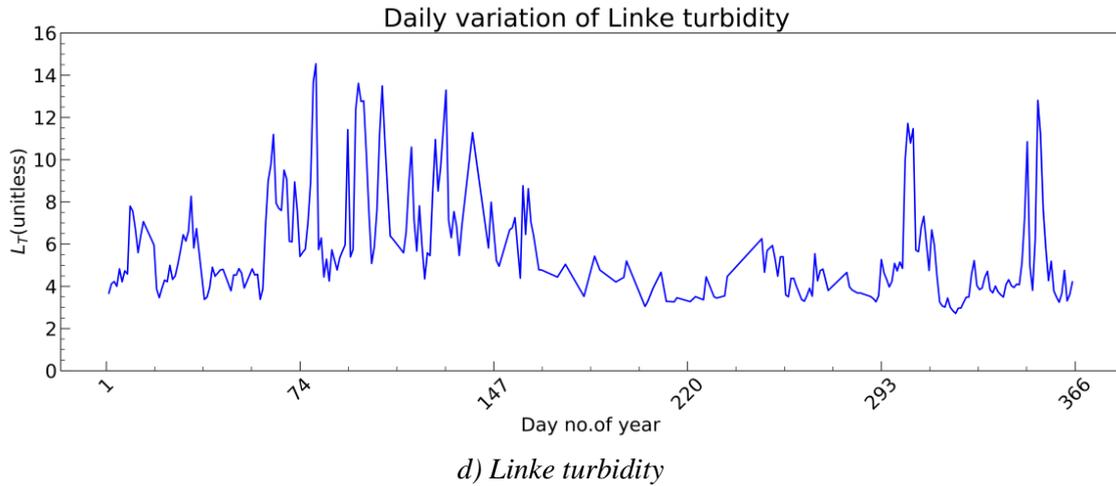


Fig. 2: Daily variation of parameters (AOD, Angstrom exponential, Angstrom turbidity coefficient, Linke turbidity)

Table1: Statistics of parameters

| Parameters | Max. | Min. | Mean | sd |
|---------------|--------|--------|--------|--------|
| AOD for 675nm | 1.0333 | 0.0208 | 0.2724 | 0.1938 |
| AOD for 500nm | 1.5361 | 0.0507 | 0.4054 | 0.290 |
| AOD for 440nm | 1.7706 | 0.0584 | 0.4680 | 0.3364 |
| AOD for 380nm | 2.0871 | 0.0797 | 0.5395 | 0.3842 |
| AOD for 340nm | 2.1790 | 0.0971 | 0.5673 | 0.3905 |
| α | 2.21 | 0.42 | 1.13 | 0.21 |
| β | 0.69 | 0.01 | 0.18 | 0.14 |
| T_L | 14.54 | 2.71 | 5.70 | 2.46 |

Figure 3(a) indicates monthly variation of solar insolation. The maximum value of solar insolation is 6.15 ± 6.15 in May due to large day length and small solar declination and minimum value of 3.73 ± 1.55 in October due to small day length and large solar declination. Figure 3(b) shows monthly variation of Angstrom exponential (α). The maximum value of α is 1.48 ± 0.12 in July due to rainy season and minimum of 1.05 ± 0.14 in January. Figure 3(c) shows monthly variation of Angstrom turbidity coefficient (β). The maximum value of β is 0.33 ± 0.17 in April due to high temperature and minimum value of 0.05 ± 0.02 in July due to rain. Figure 3(d) shows monthly variation of Linke turbidity (L_T). The maximum value of L_T is 8.55 ± 2.82 in April due to high

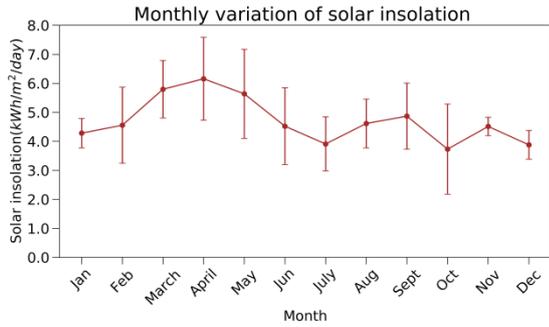
temperature and minimum value of 3.62 ± 0.42 in July due to rain. Figure 3(e) shows monthly variation of transmittance of aerosol (τ_a). The maximum value of τ_a is 0.8846 ± 0.045 in July and minimum value of 0.6656 ± 0.1191 in April.

According to Koschmier (1924)[16], visibility in km is

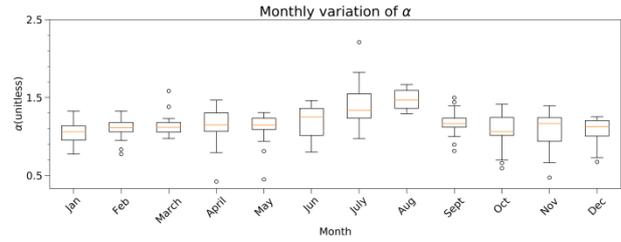
$$V_m = \frac{0.693}{b_{ext}}$$

Here b_{ext} is AOD for 550nm wavelength. Figure 3(f) shows monthly variation of visibility. Maximum value of visibility is 6.54 ± 2.28 km in August and minimum value of 1.33 ± 0.62 km in April.

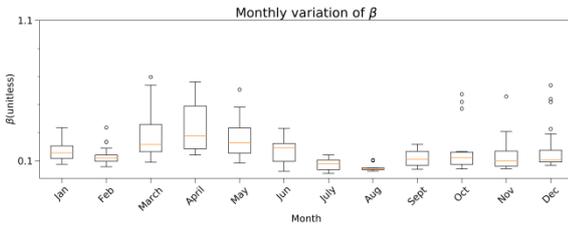
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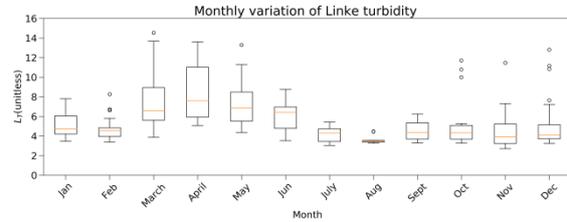
a) Solar insolation



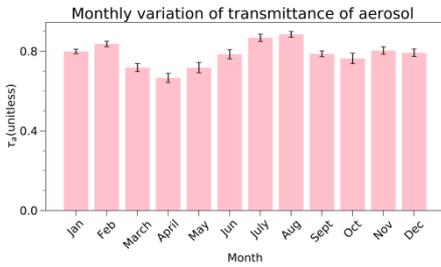
b) Angstrom exponential



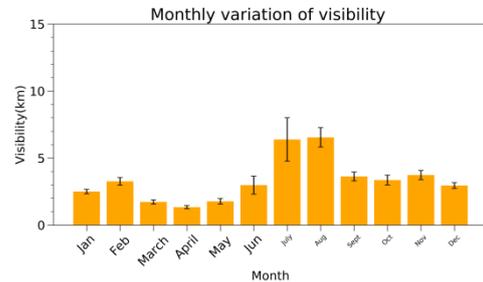
c) Angstrom turbidity coefficient



d) Linke turbidity



e) Transmittance of aerosol

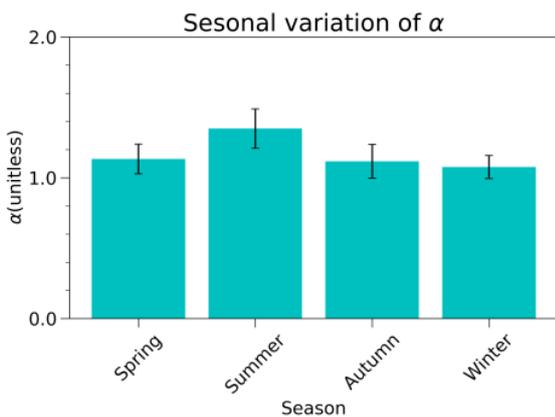


d) Visibility

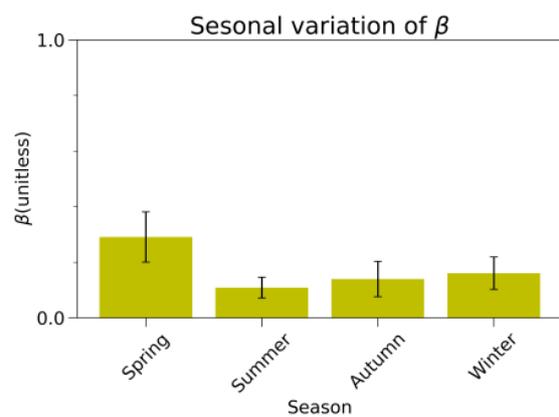
Fig. 3: Monthly variation of parameters (Solar insolation, b) Angstrom exponential, Angstrom turbidity coefficient, Linke turbidity, Transmittance of aerosol, Visibility)

Figure 4(a) shows seasonal variation of Angstrom exponential (α). The maximum value α is 1.34 ± 0.24 in summer and minimum value of 1.07 ± 0.14 in winter. Figure 4(b) shows variation of Angstrom turbidity coefficient (β). The maximum value of β is 0.29 ± 0.15 in spring and minimum value of 0.10 ± 0.06 in summer. Figure 4(c) shows seasonal variation of Linke turbidity L_T . The maximum value of L_T is 7.79 ± 2.6 in summer and minimum value of 4.69 ± 1.79 in autumn.

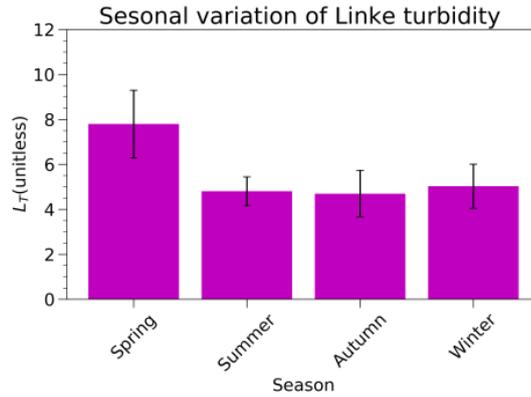
is 0.29 ± 0.15 in spring and minimum value of 0.10 ± 0.06 in summer. Figure 4(c) shows seasonal variation of Linke turbidity L_T . The maximum value of L_T is 7.79 ± 2.6 in summer and minimum value of 4.69 ± 1.79 in autumn.



a) Angstrom exponential



b) Angstrom turbidity coefficient

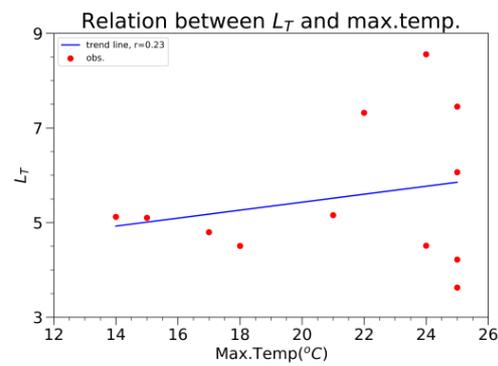


c) Linke turbidity

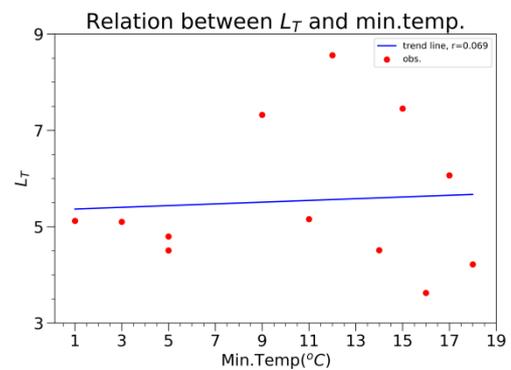
Fig. 4: Seasonal variation of parameters (Angstrom exponential Angstrom turbidity coefficient, Linke turbidity)

Figure 5(a) shows variation of Linke turbidity with maximum temperature. Correlation coefficient is 0.23. The annual mean of maximum temperature is $21.2 \pm 4.1^{\circ}\text{C}$. Figure 5(b) shows variation of Linke turbidity with minimum temperature. Correlation coefficient is 0.07. The annual mean of minimum temperature is $10.5 \pm 5.8^{\circ}\text{C}$. Linke turbidity is less

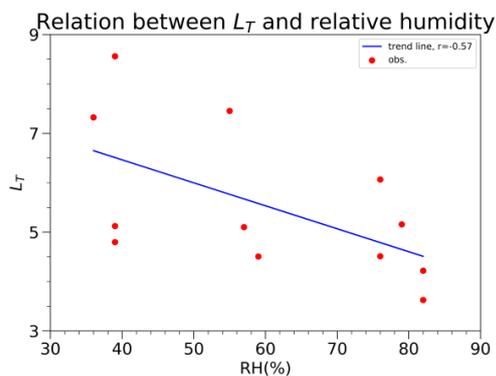
correlated with temperature. Figure 5(c) shows variation of Linke turbidity with relative humidity. Correlation coefficient is -0.57. The annual mean of relative humidity is $59.9 \pm 18.5\%$. Figure 5(d) shows variation of Linke turbidity with cloud percentage. Correlation coefficient is -0.36.



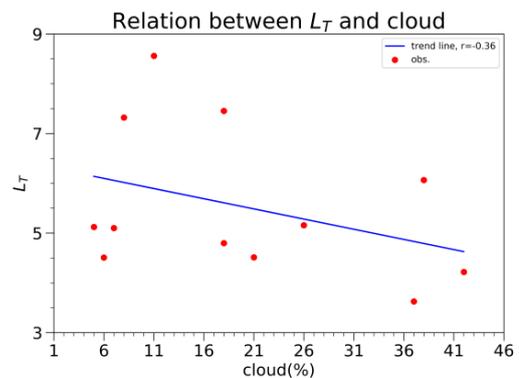
a) Maximum temperature



b) Minimum temperature



c) Relative humidity



d) Cloud

Fig. 5: Relation of Linke turbidity with of parameters (Maximum temperature, Minimum Temperature, Relative humidity, Cloud)

Figure 6(a) shows variation of Linke turbidity with water content. Correlation coefficient is -0.27. Annual mean of water content is 1.61 ± 1.00 cm. Figure 6(b) shows variation of Linke turbidity with ultraviolet. Correlation coefficient is 0.46. Figure 6(c) shows variation of Linke turbidity with total ozone column (TOC). Correlation coefficient is 0.65. Figure 6(d) shows variation of Linke turbidity with NO_2 . Correlation coefficient is 0.77. Linke turbidity is highly correlated with NO_2 . Figure 6(e) shows variation of Linke turbidity with wind. Correlation coefficient is 0.49.

Correlation coefficient is 0.65. Annual mean of TOC is 270.8 ± 1.9 DU. Figure 6(d) shows variation of Linke turbidity with NO_2 . Correlation coefficient is 0.77. Linke turbidity is highly correlated with NO_2 . Figure 6(e) shows variation of Linke turbidity with wind. Correlation coefficient is 0.49.

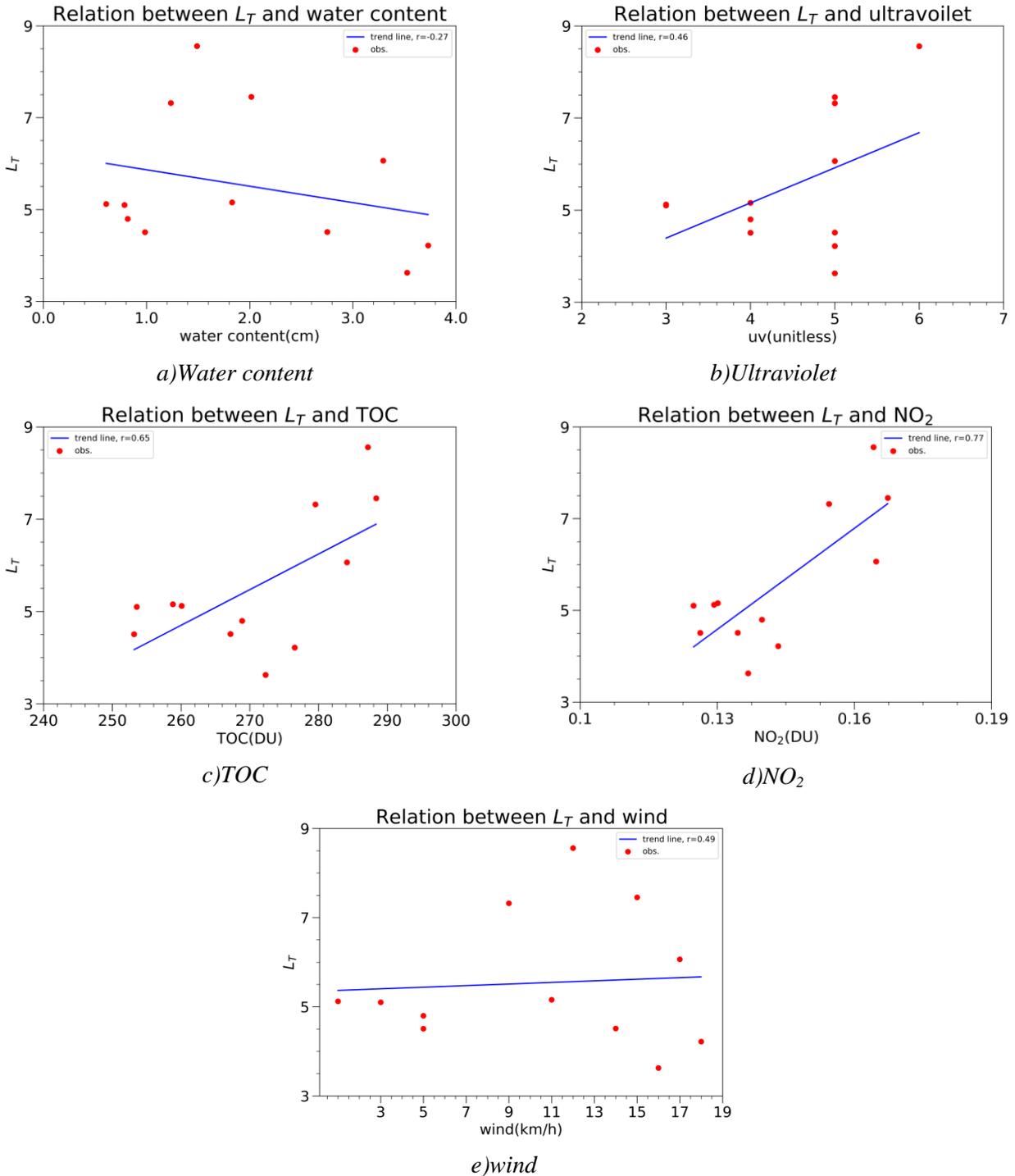


Figure 6: Relation of Linke turbidity with of parameters (Water content, Ultraviolet, TOC, NO_2 , wind)

4. CONCLUSIONS

The annual mean value of parameter of Bode for study period 2013 is calculated. The annual mean of solar insolation, Angstrom exponential(α), Angstrom turbidity coefficient(β), Linke turbidity factor(T_L) and visibility are 4.70 ± 1.10 kWh/m²/day, 1.13 ± 0.21 , 0.18 ± 0.14 , 5.70 ± 2.46 and 2.98 ± 2.13 km respectively. Linke turbidity is positively varies with TOC and NO₂.

According to Wang [14], Linke turbidity values is 3.3 to 7.7 in Wuhan (latitude 30°32' N, longitude 114°21' E and 30 m a.s.l.), Central China from 2010 to 2011. According to Laxmi Narain and S.N. Garg [17], on eight years (1993 – 2000) study, Linke turbidity for four cities of India are $T_L = 7.5$ for Kolkata (26.93° N, 88.45° E, 431 m a.s.l.), $T_L = 4.6$ for Poona (18.53° N, 73.85° E, 559 m a.s.l.), $T_L = 6.4$ for Jaipur (26.93° N, 88.45° E, 431 m a.s.l.) and $T_L = 6.8$ for New Delhi (22.65° N, 88.45° E, 216 m a.s.l.). A comparison of observed values of turbidity parameter with other major cities of the world shows that Bode is as highly polluted as cities like Jakarta, Kansas, Beijing, Vienna, etc.

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