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Spectral analysis of aerosol optical depth over AERONET sites of Nepal

Aashma Acharya[1], Binod Adhikari[1,2,*], Pratik Bhattarai[1], Gopal Jha[1], Shambhu Acharya[3], Ritesh Shah[1]

[1]Department of Physics, St. Xavier's College, Maitighar, Kathmandu, Nepal

[2] Department of Physics, Patan Multiple Campus, Tribhuwan University, Lalitpur, Nepal

[3]Ministry of Education, Science and Technology, Singha Durbar, Kathmandu

[*]Email: binod.adhi@gmail.com

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ABSTRACT

The suspended particle aerosols especially anthropogenic are recognized to have degradation in the quality of the atmosphere and one of the factors to cause uncertainty in climate. In this paper, we have investigated the trend of the parameter 'Aerosol Optical depth' and by application of spectral based wavelet analysis; we extracted spatial and temporal variation over the selected AERONET sites of Nepal. We have taken the site Kyanjin_gompa, Lumbini, Pokhara and Kathmandu under the consideration of our study because of their geographical variability which is a significant factor for causing variation in local as well as global circulation of aerosols As per data retrieved from Ground-Based remote sensing system for the year 2018 over the site Kyanjin gompa, Lumbini and Pokhara and for the year 2016 over the Kathmandu, we extracted the periodicity and frequency of the variation in AOD for each site by the application of continuous wavelet analysis on AOD at three different wavelengths. On reviewing the previous studies, it is seen that the area lying at the Indo-Gangetic plain exhibit high aerosol loading in comparison with the Himalayan foothills and central Himalayas of Nepal. We found not only the higher aerosol loading in atmosphere over site Lumbini but also higher periodicity. Likewise, we also found Pokhara as highly polluted as Lumbini. The investigation of data records over the site Kathmandu has shown increment in aerosol loading in the year 2016 compared with previous years.

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1. Introduction

Besides gas molecules the atmospheric air consists of minute solid particles and liquid droplets called aerosols which are the suspension of minute solid particles or liquid droplets in the gas. Atmospheric aerosols are commonly the mixture of particulate matter and atmospheric gas.

The term aerosol is often used in reference to PM, but technically refers to both the condensed phase particles and the gaseous medium they are suspended in. Particularly they are described on the basis of size, concentration, and chemical composition. There are considerable differences in the size ranges, chemical nature and the sources of the aerosol that occur in these layers. Often, the different aerosol groups clump together to form the hybrid of both the natural and anthropogenic aerosols. Majority of the aerosol are naturally occurring such as dust, pollen grains, sea salt, fly ash, soot and carbon particle mixes in atmosphere by several natural processes. While the another one is anthropogenic abundant in polluted area formed due to human activities such as fossil fuel combustion, biomass burning, industrial smoke, power plants, coal mining and other several activities.

The location of aerosols' suspension in the Earth's atmosphere is varied over different surface. Aerosols have 2 different types: primary and secondary aerosols. Primary aerosols are atmospheric particles that are found in the atmosphere by direct injection or emission. The primary aerosol particles result either from fragmentation processes or from combustion. Of course, their shape can change because of a number of physicochemical processes like humidification, gas–particle reactions, coagulation, etc. [1]. The formation of secondary aerosols can be aided and catalyzed by the primary aerosols present in the atmosphere of the Earth. Secondary aerosol particles appear in the carrier gas as a consequence of gas to particle conversion [2]. They serve as the centers for heterogeneous nucleation of water vapor. No aerosols – no clouds, so one can imagine how our planet would look without the secondary aerosol particles [1].

Aerosols are short lived with a residence time of about a week in the lower troposphere. Due to their short lifetimes and widely distributed sources, aerosols exhibit large spatial and temporal variabilities. Aerosol possesses horizontal and vertical distribution over the atmosphere, which is called spatial distribution. The variation with the time is the temporal distribution. Distribution of aerosols in various atmospheric layers depends upon the microphysical properties, chemical properties and environmental conditions. Air pollution near the ground is closely related with the terrain; the high elevation would take advantage of the spread of contamination. The structure of pollution layer of the high elevation seems to be the same as the low elevation. The main emission mechanisms of the aerosols are related to the local circulation in the boundary layer caused by the surface temperature heterogeneity and relief and possibly connected with electrical charging of dust particles. The planetary boundary layer is an important parameter to analyze the aerosol particles vertical distribution. The PBL is the closer turbulent layer closest to the Earth's surface. Its height, which can vary mainly from 1 to 2 km at midday, is crucial to many aspects of weather and climate. The ground-based Lidar can show atmospheric temporal variation (at a fixed location), while space-borne Lidar can obtain atmospheric variation in space (in large-scale region). Aerosol particles are mainly constrained in PBL but it also gets injected to the stratosphere. Volcanic aerosols have the potential to be injected to stratosphere. Volcanoes emit sulfur dioxide gas (SO_2), which reacts with water in the atmosphere to form sulfuric acid (H_2SO_4). When volcanic plumes are emitted powerfully enough to reach the stratosphere the H_2SO_4 can form a persistent haze of liquid droplets, reflecting away sunlight and cooling the earth for a year or two.

Aerosol optical depth is the measure of amount of light that aerosol scatter or absorbs in the atmosphere telling us the amount of direct sunlight being prevented to reach the earth surface. Aerosol Optical Depth (AOD) helps us to know the amount of the columnar atmospheric aerosol content [3] for example: urban haze, smoke particles, desert dust, sea salt, etc. distributed within a column of air from the instrument (Earth's surface) to the top of the atmosphere [4]. Considering mathematically and more technically, Aerosol Optical Depth is defined as the integrated extinction coefficient over a vertical column of unit cross section. The aerosol optical depth is measured using ground-based sun photometers or radiometers. In addition to the optical depth due to extinction of aerosol other atmospheric constituents can scatter light and must be considered when calculating the AOD. The optical depth due to water vapor, Rayleigh scattering, and other wavelength-dependent trace gases must be subtracted from the total optical depth in due course of obtaining the aerosol component [5]. In this paper, we will try to analyze the spectrum of aerosol optical depths in the aeronetsites of Nepal using continuous wavelet transform.

2. Dataset

This research will be focusing on applying wavelet based spectral analysis to the time series analyzed aerosol optical depth, collected by the remote sensing using sun photometers. We have collected data from the link: (https://aeronet.gsfc.nasa.gov) . The site selection for this project is done according to the data availability for Nepal to achieve maximum utilization of available data and resources. Among the selected sites, each one is taken in consideration for this study on the basis of their geographical structure variability focusing on the fact that variability occur with the geographical differences.

The locations of the equipment placed for the data collection are:

S.N	Station Name	Geographic latitude	eographic Longitude
1	Kyanjin Gompa	28.2141° N	85.5245° E
2	Lumbini	27.6792° N	83.5070° E
3	Pokhara	28.2096° N	83.9856° E
4	KathmanduBode	27.6909° N	85.3905° E

3. Methodology

In this section, we discuss the methodology implement for the spectral analysis of aerosol optical depths in the aeronet sites of Nepal.

Wavelet analysis

The mathematical tools that can be used to transform data representation into its multilevel components are termed as wavelet transformation. The basics idea of wavelet is small wave, localized wave and decay amplitude on the basis of time and frequency [6-8]. Originally, applied in geophysics in due course of analysis of seismic signals, the wavelet transforms were better and broadly formalized [6]. The main application of wavelet analysis is time-frequency localization. This tool provides the contribution of different frequency band of different locations [9]. The main task of this tool is to decompose the signals into the signal details that show trends as the function of time. Wavelet analysis is used as the alternative to Fourier transformation. When we plot time-domain signals, we obtain a time-amplitude representation of the signal. This representation is not always the best representation of the signal for most signal processing related applications. In many cases, the most distinguished information is hidden in the frequency content of the signal. The frequency spectrum of a signal is basically the frequency components (spectral components) of that signal. The frequency spectrum of a signal shows what frequencies exist in the signal [10]. When we use Fourier transformation as a tool for representing frequency components it gives us Frequency-Amplitude representation. FT gives the frequency information of the signal, which means that it tells us how much of each frequency exists in the signal, but it does not tell us when in time these frequency components exist. If we want to know, what spectral component occurs at what time (interval), then Fourier transform is not the right transform to use. When the time-frequency localization of the spectral components is needed, a transform giving the time frequency representation of the signal is needed. The ultimate solution for this is Wavelet analysis. Wavelet transform helps us to provide the time and frequency information simultaneously, providing a time-frequency representation of the signal [10] . A more detailed description of the wavelet technique can be found in Domingues et al. [7], Mendes et al. [11] , Ojeda et al. [12], Klausner et al. [13]

4. Result and Discussion

Here, we discuss the aerosol optical depths in the different aeronet sites of Nepal and their spectral analysis using continuous wavelet transform. Figure 1 shows AOD at three typical wavelengths 1640 nm, 1020 nm and 675 nm. The site kyanjin_gompa has maximum aerosol loading at wavelength 675nm with the variation of time in comparison to remaining two wavelengths. This logically means the submicron aerosol particles are dominant in this region than that of coarse mode aerosol. . Minimum aerosol loading in atmosphere was observed during the month of January over the region Kyanjin_Gompa as per the AOD whose value was very low ranging from 0 to 0.05 for the month January.

The time series is showing episodic changes in aerosol optical depth over this region. From about the 61st day of the year 2018 which is March 2nd the AOD variation is slowly rising than before. From the plot, we can observe drastic changes starting slowly from the beginning March eventually reaching its peak variability at the end of March and start of April.. Winter 2018 in Northern Hemisphere began on Saturday, December 22 and ended on Thursday, March 21, 2019. With the increase in temperature, the aerosol loading is increasing from ending of March reaching maximum during mid-April. The AOD during this period is ranging from 0.3 to 0.35. Then with gradual decrease in variability, the AOD again increase during end of April ranging from 0.15 to 0.2. The month May shows episodic variation of AOD from minimum value to 0.2. With the beginning of monsoon during end of July the AOD has shown tremendous decrease. It is quiet fair because rainwater washes out huge amount of aerosol particles from atmosphere. Throughout the winter the variability is very low which is because of less humidity.

Lumbini lies in southern slope of central Himalayas in the indo-Gangetic plain. The starting of January shows less aerosol loading up to mid-January but the value of AOD is tremendously larger than that of site Kyanjin_Gompa during this period ranging from 0.5 to 1. By the last week of January, the AOD value exceeds 1. During this period the submicron aerosol of AOD at 675 nm are dominant. From mid-February, the value of AOD exceeds by 1 ranging from 1 to 1.5. Third week of May shows maximum aerosol loading for the wavelength 1020nm which shows dominance of coarse mode aerosol which are usually wind-blown dust. The last 15 days of June shows maximum AOD with value 2 at 1640nm which is coarse mode particle relatively large size of aerosols along with AOD at 675nm. This period is just before the starting of monsoon (pre-monsoon). During the end period of June AOD value for 675nm reaches one and exceeds above one. As the monsoon start the AOD at all three wavelengths decreases below 1 reaching to 0.5.

The AOD for 136 days of the year 2018 of Pokhara is analyzed as variation with time as per as data availability by AERONET. During the month of January, the AOD values are very low below 0.5 which is normal. As the February starts the AOD value gradually reaches 1 which is large amount of aerosol loading in atmosphere. Then the aerosol loading is gradually decreasing reaching very low value during mid-February. After the 46th day of the year (15 February) the AOD value reaches 1 and exceeds gradually above 1 at the 675nm up to starting of March.

Pokhara has dominant level of submicron aerosols in atmosphere. On 29th of March the aerosol loading is very high over the site Pokhara with the value above 1.5. This type of condition results haze formation in atmosphere affecting visibility to some extent.

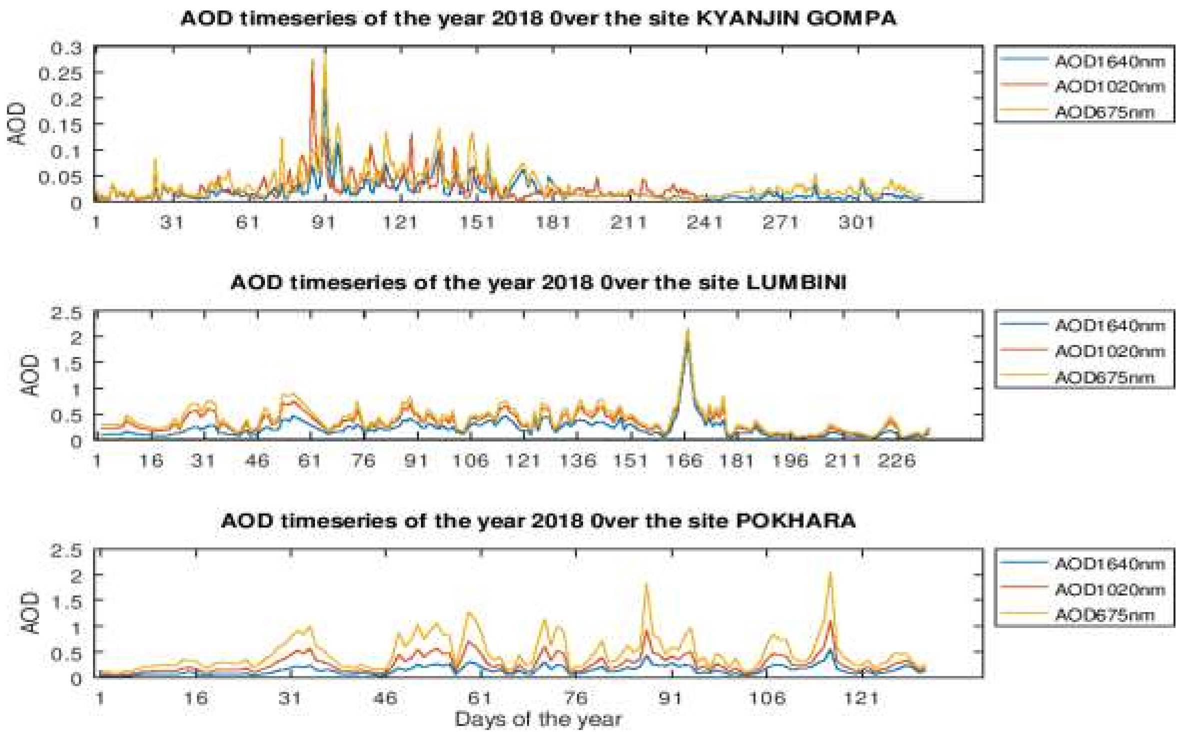

Fig. 1: AOD of different wavelength from Kyanjin_Gompa (top), Lumbini (middle) and Pokhara (bottom) of the year 2018.

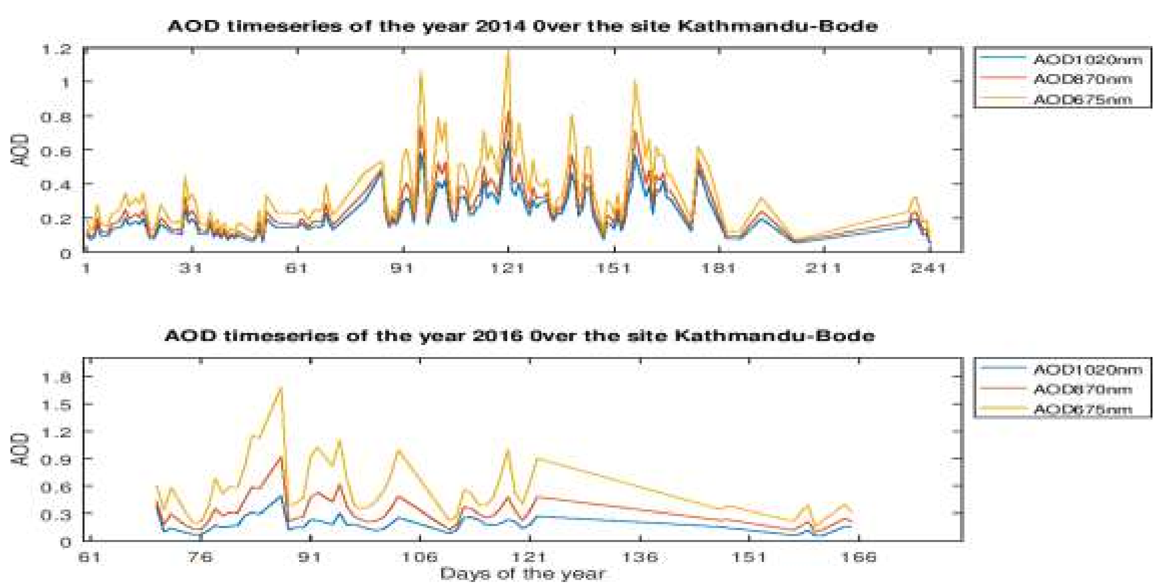

Fig. 2: AOD of different wavelength from Kathmandu_Bode of the year 2014 (top) and 2016 (bottom).

Figure 2 represent the time series of AOD at three different wavelengths 1020nm, 870nm and 675nm from Kathmandu-Bode of the year 2014 (top) and 2016 (bottom). The wavelength 1020nm belongs to IR spectrum and the spectral channel of 870nm and 675nm belongs to red band of visible spectrum. The study of the AOD over the AERONET-site Kathmandu-bode exhibits dominance of aerosol particle that are detected by channel with wavelength of 675nm which signifies sub-micron aerosol particles. For the red channel, the AOD above 0.02 signifies hazy condition of atmosphere and extremely hazy at AOD value above 0.4. The variation of AOD in the year 2014 also exhibits cyclic variation i.e. secondary maximum during the summer (April-May) season reaching primary maximum during pre-monsoon (June) and decreasing with approaching monsoon (July).

The AOD value reaches 1 with the approaching midsummer which is harmful state of atmosphere with hazy condition. With the start of May AOD values exceeds 1 reaching 1.2. The time series of Kathmandu exhibit high AOD variation with maximum aerosol loading starting from the end of March up to June and then there is sharp decrease with start of the monsoon. On comparing the time series of 2014 with the time series of 2016 over Kathmandu, it is observed that the maximum aerosol loading occurs during summer which implies that AOD value shows sharp increment from the mid of March till end of the month. During this period the AOD values ranged 0.4 to 0.6 in the year 2014 but in the year 2016 the AOD reached 1.5 during the same period of the year. The AOD value ranges 0.9 to 1.2 during 91st – 106th day of the year 2016. During the same period the AOD value ranges from 0.7 to 1 for the year 2014. There is drastic decrease of AOD with the start of May in the year 2016. The variation is similar for other two wavelengths.

The time series analysis for the Aerosol optical depth solely is unable to provide the information about the frequency spectrum. With the aim to extract dominant periodicities, Morlet CWT analysis is applied on the AOD value retrieved from visible spectral channel (675nm) and scalograms are presented in Figure 3-7.

As mentioned earlier, the continuous wavelet analysis was used to analyze the AOD of daily averages data of 4 stations of Nepal. The time period from 76th day to 201st (March-July) day over the site Kyanjin-Gompa (Figure 3) shows high atmospheric modulation. We can observe presence of three dominant accumulations during this period. The variation during the 80th to 91stday of the year shows very high variation relatively than other. Localized wavelet spectrum in the scalogram exhibits wave dominance over the period around 4 to 6 days. Most of the power is concentrated during the period 5 to 4 days. Some spectrum of 5 to 4 days is observed however its strength is lower compared to dominance period. Another wavelet spectrum is obtained at about 27th to 30th day of the year 2018 with periodicity of 2 to 4 days, however, has lower strength than other.

Wavelet spectra as determined from the time series of the radiometer retrieved AOD measurements obtained at three wavelengths for the daily averages AOD values of station Lumbini is shown above in Figure 4. About 176th day of the year the periodicity of around 8 to 9 days is predominant. Another periodicity is also present around 8th to 48th day of the year with period of around 15 days but of less intensity. Similarly, Figure 5 shows the periodicities observed on AOD at Pokhara in which dominance periodicities (scales) exhibits around 7 to 9 days during 110th to 120th day of the year. By comparing the global wavelets spectra corresponding to AOD, representing Kyanjin-Gompa, Lumbini and Pokhara, it is found that the periodicity of 15 days of Lumbini is maximum among all. It should be noted that this wavelength 675nm lie in the spectral region where the submicron aerosol particles in their accumulation regime contribute to the AOD. These particles are believed to be mainly originated from secondary production mechanisms making them highly susceptible to anthropogenic activities (Stone et al., 2010). Periodicities are highly influenced by the local factors and the spatial variability of periodic features in the AODs obtained [15]. Thus, the results of the present study are in good agreement with the aforementioned studies.

In figure 5, periodicity around 5 to 6 days is predominant during 115th day of the year with higher intensity of accumulation. Another wave spectrum also shows dominance with periodicity of around 16 days. The 141st day also shows 3 to 5 days periodicities, however with the lower intensities. Similarly, the 121st day of the year 2014 shows periodicity of 5 to 4 days.

Figure 6(a) and 6(b) represent the scalogram of AOD of the site Kathmandu-Bode of the year 2014 and 2016 respectively. The dominant periodicity is at 6 to 4 days during 80th to 110th day of the year 2014. Other spectra are also present but of lower intensities with much higher periodicity. Comparing CWT analysis for the site Kathmandu between 2014 and 2016 there is higher periodicity present during the year of 2016. This is an obvious result as the pollution is increasing every year and there is more accumulation of aerosol in the atmosphere.

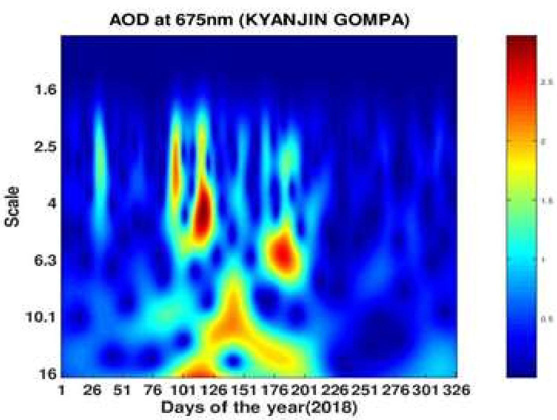

Fig. 3: CWT analysis of AOD from Kyanjin Gompa of the Year 2018.

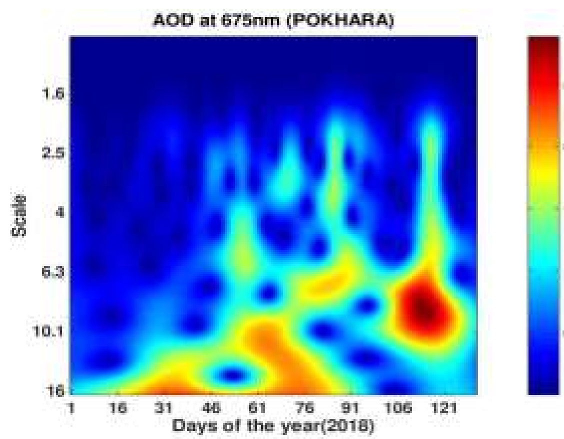

Fig. 5: CWT analysis of AOD from Pokhara of the year 2018.

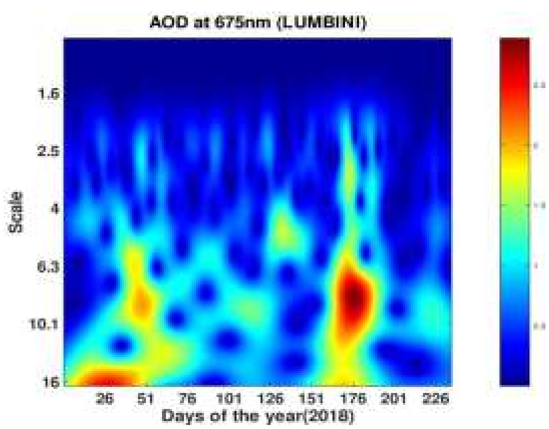

Fig. 4: CWT analysis of AOD from Lumbini of the year 2018.

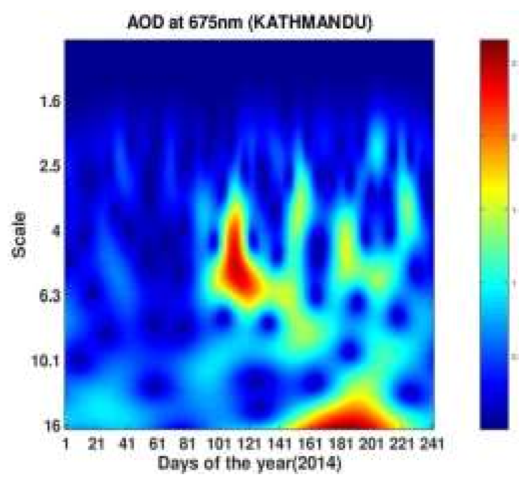

Fig. 6(a): CWT analysis of AOD from Kathmandu of the year 2014.

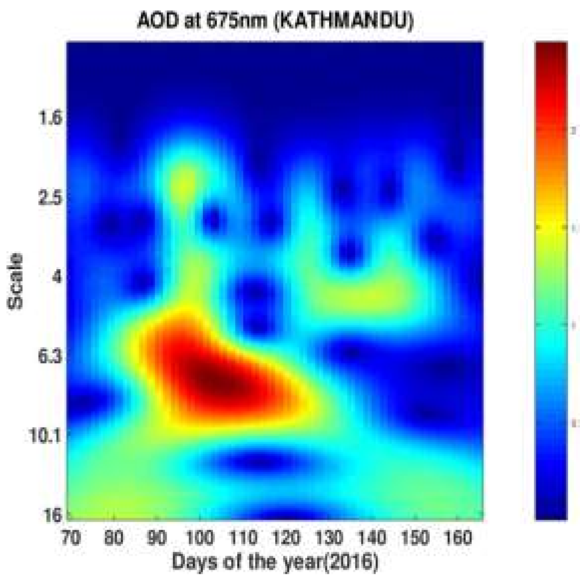

Fig. 6(b): CWT analysis of AOD from Kathmandu of the year 2016.

5. Conclusion

Analysis of aerosol records of 4 stations with geographical variability has been carried out with the aim to extract spatial and temporal variability of AOD and with the application of the continuous wavelet analysis; Periodicity possessed by AOD is extracted. We have represented scalogram alone for CWT analysis for qualitative glimpse rather to show statistically what can happen. We detailed unique dataset of the year 2018 for the urban site Lumbini and Pokhara along with the central Himalayan valley Kyanjin-Gompa to study the variation of aerosl loading among these areas. Along this location we took recent available data of Kathmandu valley of the year 2016 and 2014 as a rapid urban representation. This study investigated that among three site study of 2018, Lumbini has the highest AOD value. This result agrees with the previous studies result that IGP are the most polluted area with high aerosol loading. The site Lumbini shows maximum periodicity of aerosol loading with period of 7 to 10 days. This behavior of aerosol variability is seen during pre-monsoon (around June 15) over the site Lumbini and during April (around 26 April) with AOD value more than 2 and 2 respectively. This is the toxic hazy condition of the atmosphere where visibility within the atmosphere decreases.

The periodicity seen in Kyanjin_Gompa around April is of 2 to 3 days. This means Aerosol loading in atmosphere of the with particular AOD value up to 3 days. This study showed pre-monsoon is most polluted time of the year with primary maximum AOD exhibiting higher days periodicity i.e. there is presence of higher intensity of aerosol for longer period during pre-monsoon. By investigating the dataset for Kathmandu-Bode it is found that the AOD value of the year 2016 has increased from 1.2 to 1.6 which is obviously because of urban aerosol accumulation. Studies have shown that urban cities like Kathmandu have accumulation of aerosol resulting from fuel burning and construction dust. It is clear from our study that there is dominance of submicron particle in atmosphere of this site. Comparing the primary maxima of the year 2016 with 2014 the periodicity has increased in 2016 from 5 days in 2014 to 6 days period in 2016. This shows accumulation of higher intense aerosol loading for longer periods. The decline in AOD from early May_ June is due to early start of rainfall during the year 2016. Rainfall washes out large amount of atmospheric aerosol which is also one of the factors for variation in AOD. The Himalayan valley according to previous studies shows aerosol loading during summer is due to transport of the pollution from the foothills and mostly due to biomass burning. Although the periodicity is lower than other sites, it is clear from study that Kyanjin_Gompa which is a central Himalayan valley has considerable presence of both the coarse mode aerosol and the submicron aerosols. This means it shows higher AOD up to 0.25 in all wavelengths but at various days of the year. This study concludes that IG plains have the most polluted atmosphere, and then the Himalayan foothills are the next one which includes valley like Pokhara and Kathmandu.

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