Chapter 3

Indexing Method for Assessment of Air Quality:

A Case Study for Dharamshala City in India

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ABSTRACT

Rapid urbanization and globalization has led to severe degradation of existing air quality in the majority of Indian cities. In this context, the general public has been aware of their exposure to ambient air quality and the effects of such air pollutants on human health. Hence, the concept of Air quality indices (AQI) is often used by regulatory authorities in conveying the status of existing ambient air quality to the general public. The chapter presents the application of air quality indices for assessing the existing air quality standards in an Indian city, Dharamshala, a tourist location in Himachal Pradesh, for the period of 2016-2017. Two different methods of determining AQI have been used wherein one method is used as the revised Central Pollution Control Board (CPCB), India with different sub-indices for Indian conditions based on the United States Environmental Protection Agency (USEPA) methodology and another alternative method utilizes contribution from all criteria pollutants.

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INTRODUCTION

Air pollutants generated from vehicular exhausts are one of the major sources of pollution in cities of India and worldwide (Ganguly et al., 2014, 2015; Kumar et al., 2013, 2015, 2016). The important criteria air pollutants generated from traffic sources are nitrogen oxides (NO_x), carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds (VOCs), particulate matter (PM) and several metals (Ganguly and Broderick, 2008). Criteria pollutants are those pollutants whose limiting concentrations in atmosphere has been predefined as per the National Ambient Air Quality Standards (NAAQS) to minimize their effects on human health. Continuous and long-term exposure to such pollutants can lead to severe health impacts including asthma and respiratory problems (Anderson et al., 2011; Clark et al., 2010; Heal et al., 2012), inadequate development of lung functions in infants and small children (Gauderman et al., 2007), cardiovascular diseases (Lindgren et al., 2010) and may lead to cancer (Buffler et al., 2005; Langholz et al., 2002). In this context, ambient air quality standards have been fixed for these criteria pollutants in most of the developing and developed countries. In an Indian context, the Central Pollution Control Board (CPCB) has specified the NAAQS for such pollutants as shown in Table 1.

The major difficulty associated with the representation of these prescribed standards is unifying them over a reference scale for representing the health effects of air pollutants to the citizens (Nagendra et al., 2007). Further, increased air pollution concentrations and their recurrence intervals often pose challenges to general citizens of understanding of the existing ambient air quality. As such, Air Quality Index (AQI) are often used by regulatory authorities of informing the common public of the existing nature of the ambient air quality.

In principle, an AQI is a single number determined on the principle of sub-indices of different criteria pollutants and which defines the nature of the ambient air quality in the context of human health effects (Bortnick et al., 2002; Murena, 2004). The pollutants generally considered for the determination of AQI involves the monitored data of all the criteria pollutants (SO_2, NO_x, SPM and RSPM) in India. The methods of analysis of AQI using different methods primarily depend on pollutants considered, sampling period and the considered breakpoints (Monteiro et al., 2016). Different methodologies are used for determination of AQI with different categorizations and there exists no common single technique which has been universally endorsed. The determination of AQI is a simple yet an effective technique in summarizing the potential heath effects of the surrounding ambient air quality (Kowalska et al., 2009; Monteiro et al., 2016). The AQI provide the status of the ambient air quality to the general public without delving into the computational details and alerts the

Table 1. National ambient air quality standards

Pollutant	Time Weighted Average	Concentration in Ambient Air (CPCB, 2009)			European Union (EU) Air Quality Directive	World Health Organization (WHO) Guidelines
		Industrial Areas	Residential, Rural and Other Areas	Sensitive Areas		
Sulfur dioxide (SO_2) $\mu g/m^3$	Annual[a]	80	60	15		
	24 h[b]	120	80	30		
Oxides of Nitrogen (NO_2) $\mu g/m^3$	Annual[a]	80	60	15	40	40
	24 h[b]	120	80	30	200 (not to exceed 18 times in a year)	200
Suspended Particulate Matter (SPM) $\mu g/m^3$/ PM10	Annual[a]	360	140	70	40	20
	24 h[b]	500	200	100	50 (Not to be exceeded on more than 35 days per year)	50 (99th percentile, 3 days per year)
Respirable Suspended Particulate Matter (RSPM) / PM2.5$\mu g/m^3$	Annual[a]	120	60	50	25	10
	24 h[b]	150	100	75		25 (99th percentile, 3 days per year)
Lead (Pb) mg/m^3	Annual[a]	1.0	0.75	0.50		
	24 h[b]	1.5	1.00	0.75		
Ammonia (NH_4) mg/m^3	Annual[a]	0.1	0.1	0.1		
	24 h[b]	0.4	0.4	0.4		
Carbon Monoxide (CO) mg/m^3	8 h[b]	5.0	2.0	1.0		
	1 h	10.0	4.0	2.0		
Ozone $\mu g/m^3$	8 h[b]				120	100

However, 2% of the time, it may exceed but not on two consecutive days.

[a] Annual arithmetic mean of minimum 104 measurements in a year taken twice a week 24 hourly at a uniform interval.

[b] 24 hourly/8 hourly values should be met 98% of the time in a year.

citizens to take pertinent precautionary steps to prevent themselves from the harmful effects of such air pollutants (Monteiro et al., 2016). The AQI is a single number and is often associated with the preordained categorizations of air quality like *'good', 'moderate', 'poor' and 'severe'*.

In general context, about 80% of the global population living in urban areas experience high doses of pollutant concentrations exceeding the norms as prescribed by World Health Organization (WHO). The most affected population demographics are the residents living in middle to low income countries wherein about 98% of such cities having a population greater than 100000 do not meet the WHO air quality guidelines. The control of urban air pollution is often beyond the capable of the citizens and needs a concerted effort from governmental and international organizations in measures to reduce the concentrations of air pollution. In such aspects, air quality monitoring in cities is an important tool in determining the existing pollutant concentrations in the city and hence its possible health effect to the residents of the city.

As observed from the WHO report that air pollution is a serious environmental health hazard in developing countries. As per the report (CAI, 2013) more than 100 million people were exposed to contaminated air exceeding the standards. Some of the salient features of the report were that majority of Latin American countries failed in meeting the criteria of particulate pollutants whereas ozone concentrations were exceeded in in cities of Santiago (Chile), Mexico City and Quito. Another important finding was that seven of the countries failed to meet WHO's recommendation on nitrogen dioxide. Major cities in Latin America like Monterrey, Mexico City, Santiago, Lima, Bogota etc all exceeded the specified pollutant concentrations as per WHO limits. In this context, several of the Latin American countries like Chile, Mexico, Brazil are already implementing strict regulations to curb the menacing effect of air pollution. Other countries like Peru, Costa Rica, panama etc are also making holistic effects to reduce the effects of air pollutants. Similarly, the air pollutant concentrations in China are also extremely severe. In this context, Air Quality Index China (AQICN) collects data of air pollutant concentrations and maps them in real time showing the air quality concentrations in those locations. It uses a six-point classification system making easy to discern the existing air quality in the chosen location (Climate and Environment, 2016).

Several reported literature exists on the use of AQI being successfully used for signifying the state of the existent ambient air quality condition. For example, in a study carried out in Athens by Kassomenos *et al.,* (1999) classified the air quality in seven different categories based on AQI determined on the monitoring data between the periods of 1983 to 1995. Other such reported literature has been presented by Longhurst (2005), Landulfo *et al.* (2007), Mayer and Kalberlah (2008), and Elshout *et al.* (2008). Several AQI studies have been carried out in Indian cities including for Delhi (Bishoi et al., 2009; Kumar and Goyal, 2009; Kumar and Goyal, 2011), Bangalore (Nagendra et al., 2007), Kanpur (Sharma et al., 2003), Mumbai (Sharma, 1999), Coimbatore (Saravanakumar et al., 2016) and Keonjhar (Dash and Dash, 2015) using different techniques in assessing and classifying the air quality.

The main aim of the work presented in the book chapter is to determine and analyze the AQI for two newly operational monitoring stations located in Dharamshala city in Himachal Pradesh utilizing the revised CPCB and an alternative methodology for a study period of two years 2016 and 2017 and compare the efficiency of both the selected methods in categorizing the existing ambient air quality.

MATERIAL AND METHODS

Site Location

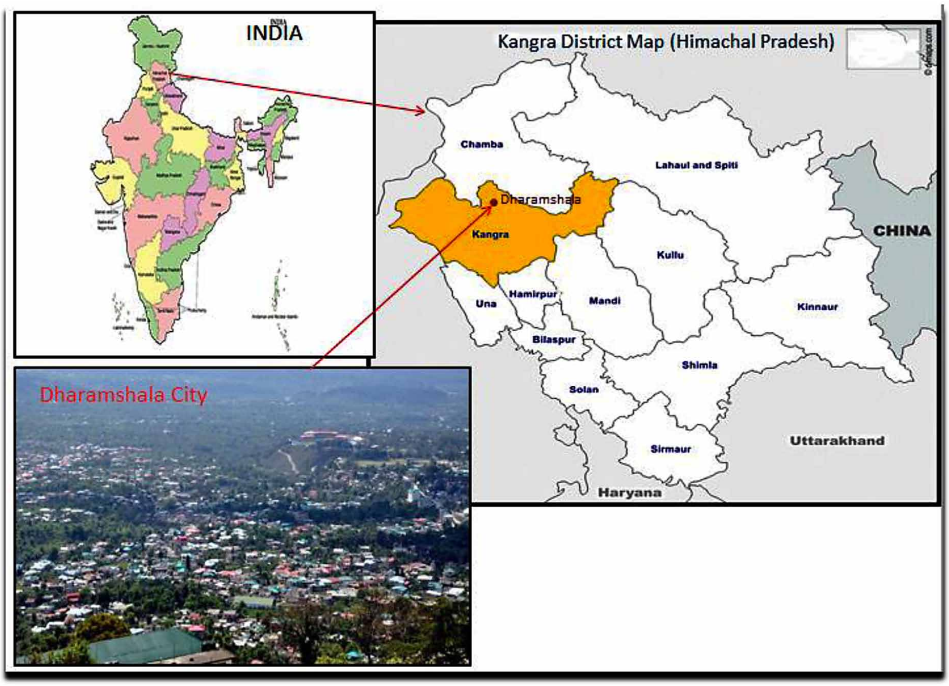
Dharamshala, one of the major cities of Himachal Pradesh lies at an elevation of 1457 m above the MSL with a population count of about 53543 as per the National Census Record of 2015. The city lies with in the latitude and longitude locations of 32.218° N to 76.320ºE covering an area of 27.6 km^2. The city can be classified as experiencing mild temperate climate (*Cwa*) as per the *Koppen climate classification.* Figure 1 shows the location of the study site.

There exist two new monitoring stations in Dharamshala namely Municipal Corporation (MC) Office (Station I) and Office Building (Station II) functioning under the National Ambient Monitoring Program (NAMP) governed by the CPCB and became operational in 2016. The monitoring data of the criteria pollutants for the study period of 2016 and 2017 were obtained from the website (http://xgn.hp.nic.in/naaqm.aspx) of Himachal Pradesh Pollution Control board (HPPCB) which is maintained in collaboration with National Ambient Air Quality Monitoring (NAAQM) of India.

Monitoring Details

The monitoring of the different pollutants at both the stations of the study location conforms to the method as prescribed by CPCB. To summarize, determination of SO_2 concentrations are carried out using the modified *West and Gaeke Method* (Ganguly and Thapa, 2016; Saravanakumar et al., 2016). The process involves passing a known volume of air in a solution of *sodium tetrachloromercurate* to form a stable compound *dichlorosulphitomercurate* which is then reacted with *formaldehyde solution*. The colour intensity of the final end product compound so formed is then determined using spectrphotometer analysis for analyzing the SO_2 concentrations.

Figure 1. Geographical location of Dharamshala City



Similarly, the pollutant NO_x is analyzed using the *modified Jacobs and Hochheiser method* (Ganguly and Thapa, 2016; Saravanakumar et al., 2016). This methodology involves passing of a fixed volume of ambient air in an initial mixture of a solution of *sodium hydroxide* and *sodium arsenite*. The resulting nitrite ion concentration is then determined on the basis of color intensity formed due to the reaction of nitrite ion with phosphoric acid, sulfanilamide, and N-(1-naphthyl)- ethylenediamine di-hydrochloride (NEDA) based on spectrophotometer analysis at 540 nm

Measurement of Respirable Suspended Particulate Matter (RSPM) are carried out using Respirable Dust sampler (RDS) which functions on the principle of air suction via cyclonic connector for collection of the suspended particulate matter (>10 µm). The average flow rate to be maintained during the collection process is 1.1 m^3/min (Ganguly and Thapa, 2016). Thereafter, the collected particulate matter on a filter paper is tested in the laboratory to determine the mass of RSPM which when divided by the air volume sampled leads to the concentration of RSPM denoted in units of µg/m^3 or ppm (Saravanakumar et al., 2016).

Air Quality Index

Air Quality Index by CPCB Method

The principle of determination of AQI by the CPCB methodology is based on the USEPA technique but using distinct breakpoint indices for Indian conditions. The methodology in principle for an AQI involves the determination of sub-indices for the criteria pollutants considered and their relative agglomeration (Kumar and Goyal, 2009; Kumar and Goyal, 2011). In contrast to the USEPA methodology the breakpoint indices for criteria pollutants for Indian conditions are based on the NAAQS standards and the potential health hazards posed by the considered criteria pollutants (Nagendra et al., 2007; Kumar and Goyal, 2009; Kumar and Goyal, 2011). Table 2 summarizes the breakpoint concentration and proposed sub-indices for Indian conditions which have already been previously reported in literature (Nagendra et al., 2007; Kumar and Goyal, 2009; Kumar and Goyal, 2011)

Table 2. Proposed sub-index and breakpoint pollutant concentration for Indian-AQI (Nagendra et al., 2007)

SI. No.	Index Values	Descriptor	SO_2 (24-h avg.) (µg/m^3)	NO_2 (24-h avg.) (µg/m^3)	SPM (24-h avg.) (µg/m^3)	RSPM (24-h avg.) (µg/m^3)
1.	0–100	Good	0–80	0–80	0–200	0–100
2.	101–200	Moderate	81–367	81–180	20–260	101–150
3.	201–300	Poor	368–786	181–564	261–400	151–350
4.	301–400	Very poor	787–1572	565–1272	401–800	351–420
5.	401–500	Severe	>1572	>1272	>800	>420

[a] Good: Air quality is acceptable; however, for some pollutants, there may be a moderate health concern for a very small number of people.

[b] Moderate: members of sensitive groups may experience health effects.

[c] Poor: Members of sensitive groups may experience more serious health effects.

[d] Very Poor: Triggers health alert, everyone may experience more serious health effects.

[e] Severe: Triggers health warnings of emergency conditions

Table 3. Air quality categories based on air quality index as per alternative methodology guidelines

SI. No.	Index Values	Descriptor
1.	0–50	Good
2.	51–100	Moderate
3.	101–150	Unhealthy for sensitive groups
4.	151–200	Unhealthy
5.	≥ 200	Hazardous

(Rao and Rao, 1986)

The formulae used for determination of AQI using the USEPA method is as follows

$$I_p = \left[\frac{(I_{HI} - I_{LO})}{(BP_{HI} - BP_{LO})}\right](C_p - BP_{LO}) + I_{LO} \tag{1}$$

Where,

I_p= the AQI for pollutant p
C_p= the actual ambient concentration of pollutant p
BP_{HI} = the breakpoint given in Table 2 that is greater than or equal to C_p
BP_{LO} = the breakpoint given in Table 2 that is less than or equal to C_p
I_{HI} = the sub-index value corresponding to BP_{HI}
I_{LO} = the sub-index value corresponding to BP_{HI}

The highest value amongst the AQI determined for the criteria pollutant is considered to be the overall AQI (Nagendra et al., 2007; Kumar and Goyal, 2009; Kumar and Goyal, 2011).

2.3.2 Air Quality Index by alternative method (AQI_{am})

The determination of AQI using the alternative methodology uses the following expression (Dash and Dash, 2015; Saravanakumar et al., 2016).

$$I_p = \frac{1}{4}\left(\frac{I_{PM10}}{S_{PM10}} + \frac{I_{PM2.5}}{S_{PM2.5}} + \frac{I_{SO2}}{S_{SO2}} + \frac{I_{NO2}}{S_{NO2}}\right) \times 100 \tag{2}$$

Where I_p is the overall AQI values. I_{values} is the actual ambient concentrations of pollutants PM_{10}, $PM_{2.5}$, SO_2 and NO_2. S_{values} is the NAAQS of pollutants PM_{10}, $PM_{2.5}$, SO_2 and NO_2 as per CPCB.

The interrelationship between the AQI determined on the alternative methodology (AQI_{am}) and the particular the air quality divisions associated with using this methodology has been summarized in Table 3 (Rao and Rao, 1986). A higher value of AQI indicates higher impacts of air pollutants on human health.

RESULTS AND DISCUSSION

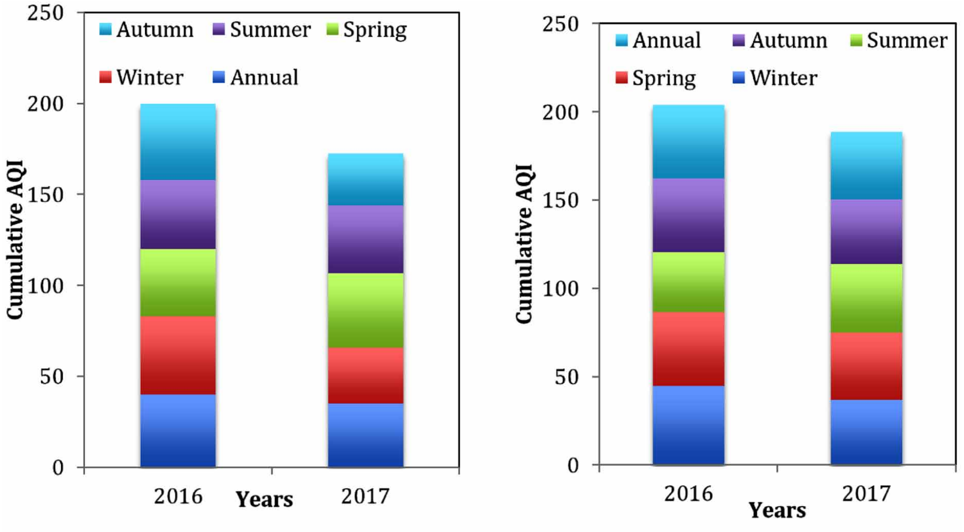
AQI Values Using CPCB Methodology

The AQI for the two monitoring stations at the study locations have been determined on the basis of monitored concentrations of the important criteria pollutants for the study period of two years of 2016 and 2017. In this context, the determined AQI parameter for both the monitoring stations using the revised CPCB methodology has been presented in Table 4. It is observed from Table 4 that the annual average AQI for monitoring station I is 40 and 35 and for monitoring station II is 42 and 38 respectively for the study years of 2016 and 2017 and hence classified as *'good'* category as per the breakpoint indices value shown in Table 2. In fact, for both the years, the annual AQI value was less than 50 at both the monitoring locations. The highest annual average AQI values for both the monitoring stations were reported in the year 2016. Further, averages of the AQI indicated that the air quality was '*good*' irrespective of seasonal variations at both the monitoring sites. The highest AQI was reported for winter in 2016 (AQI = 43) and spring in 2017 (AQI = 41) for monitoring station I and spring in 2016 (AQI = 42) and summer in 2017 (AQI = 39) for monitoring station II. The annual and seasonal variation of the AQI for the modified CPCB methodology is shown in Figure 2. The most critical pollutant for determining the AQI values at both the monitoring locations was RSPM and is identical to earlier reported literature for Delhi (Kumar and Goyal, 2011; NAMP 2016) and Bangalore (Nagendra et al., 2007). This also acts a corollary to earlier studies based on exceedence analysis wherein it has been reported that exceedence factors for NO_x and SO_2 are often low whereas it may vary from high to low for RSPM (Ganguly and Thapa, 2016). The results of the AQI analysis determined using this technique show compliance with results from other Tier-II cities in India wherein the air quality is generally classified as *good to moderate* levels. The air quality for metropolitan and Tier-I cities are generally classified as *poor to severe* levels.

Table 4. Air quality index values for both monitoring stations for the study period (2016-2017) using CPCB methodology; note that the symbol ("-" refer to the unavailability of the data)

Months	**Monitoring Station –I**		**Monitoring Station –II**	
	2016	**2017**	**2016**	**2017**
January	42	39	48	41
February	40	38	51	39
March	32	36	37	34
April	32	37	39	39
May	47	49	49	41
June	49	48	36	42
July	37	-	39	-
August	28	27	27	36
September	38	28	35	37
October	36	26	36	36
November	52	31	54	-
December	52	31	55	37
Annual Average	40	35	42	38

Figure 2. Annual and seasonal variation of AQI over the study period: (a) Monitoring Station –I; (b) Monitoring Station -II



(a) (b)

AQI Values Using Alternative Methodology

Similar to the above analysis carried out for determining the AQI using the CPCB methodology, the AQI_{am} for both the monitoring locations of the study area for the study period was determined using the alternative methodology. The results for the AQI_{am} analysis using this technique has been summarized in Table 5. It is observed from Table 5 that the annual averaged AQI values were determined to be 14 and 12 for monitoring station I and 13 and 12 for monitoring station II for the year 2016 and 2017 respectively. A comparative analysis of these AQI values with the air quality descriptors as shown in Table 3 shows that the air can be classified as *'good'* category. The highest annual averages of AQI_{am} for both the monitoring locations were observed for year 2016 similar to the AQI using the modified CPCB methodology. Further, seasonal variations of the AQI_{am} showed that the highest value was observed for winter (AQI_{am} = 14) in 2016 and summer for 2017 (AQI_{am} = 13). The AQI determined using the alternative method uses the limit values of all the criteria pollutants to determine the AQI_{am} = 14. It can be mentioned from the

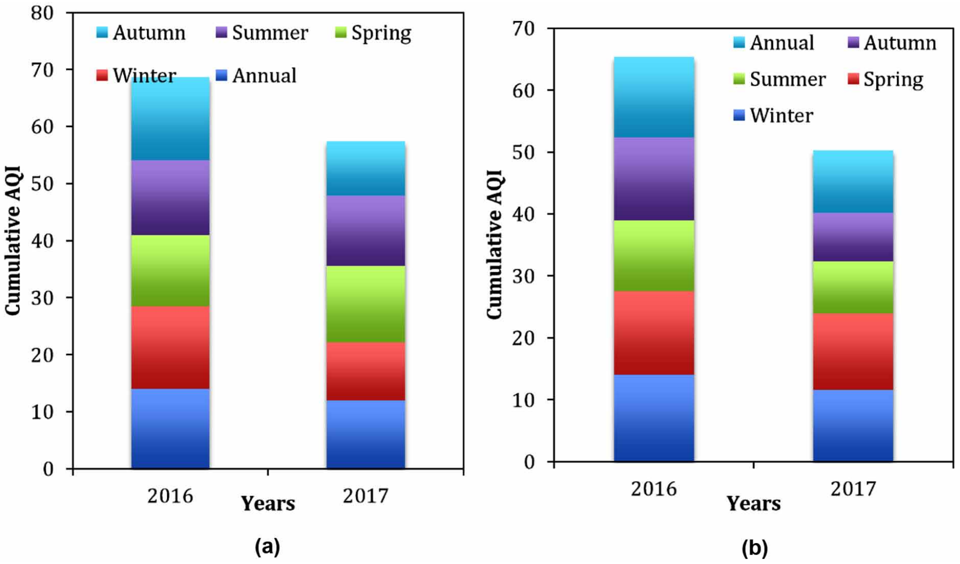
Table 5. Air quality index values for both monitoring stations for the study period (2016-2017) using alternative methodology; note that the symbol ("-"refer to the unavailability of the data)

Months	**Monitoring Station –I**		**Monitoring Station –II**	
	2016	**2017**	**2016**	**2017**
January	14	13	15	13
February	14	13	15	12
March	11	12	12	11
April	11	12	12	13
May	15	16	16	13
June	16	15	12	13
July	13	-	13	-
August	11	9	10	12
September	13	9	12	12
October	13	9	12	12
November	17	10	16	-
December	17	10	17	12
Annual Average	14	12	13	12

methodology that there is no single definitive pollutant, yet the maximal fraction for determination of AQI_{am} is from RSPM. The annual and seasonal variation of the AQI_{am} is shown in Figure 3.

Comparative analysis of AQI calculated on the alternative methodology with other Tier-II cities in India showed that the AQI_{am} was *maxim* near industrial sources and *less* in residential areas in a study conducted in Coimbatore (Saravanakumar et al., 2016). In a similar study carried out in Biliepeda (Dash and Dash, 2015) the AQI_{am} was classified as *moderate* with all major sources having relative contributions to the existing air quality. In contrast to the earlier reported literature, wherein the studies were conducted in cities having both industrial and vehicular sources affecting the air quality the monitoring stations in Dharamshala are primarily hilly location having almost no industries and comparatively less traffic flow (even though it is a tourist destination). Further, the meteorological conditions at the study location vary from previously reported literature sources which also have an influence on the existing air quality in Dharamshala.

Figure 3. Annual and seasonal variation of AQI over the study period at station I: (a) Monitoring Station –I ; (b) Monitoring Station -II



(a)

(b)

Comparison of AQI Values Using CPCB and Alternative Methodology

A detailed analysis of the methodology of determination of AQI using both the methods show that while the CPCB methodology uses the highest value of AQI determined from the concentrations of the criteria pollutants based on the sub-indices for Indian conditions the alternative methodology determines the AQI_{am} based on the contribution of all the relevant criteria pollutants. This can be noted from both *Equations 1 and 2*. In this context, the different methods have distinct and separate AQI categorizations as observed from Tables 2 and 3. Further, a review of literature shows that while the revised CPCB methodology for determination of AQI is more prevalent for metropolitan and Tier-I cities in India (Delhi, Bangalore) (Nagendra et al., 2007; Kumar and Goyal, 2011), the alternative methodology has been well used for predicting AQI for Tier-II and lower category of cities of India (Dash and Dash, 2015; Saravanakumar et al., 2016).

The output results of the comparison of the AQI values of both the monitoring locations in the study area shows that while the annual average AQI using the CPCB methodology is higher for monitoring site –II (AQI = 42 for 2016; AQI = 38 for 2017) the AQI based on the alternative methodology (AQI_{am} = 14 for 2016; AQI_{am} = 12 for 2017) is higher for monitoring site –I. Detailed information regarding the location of the actual monitoring stations are presently a little skewed but can be adjudged to be set in urban locations as per the names of the monitoring sites assigned. Evaluation of annual and seasonal variations of AQI by using both the methodologies showed similar trends for both the monitoring locations for the study period. However, most importantly the AQI values obtained using both the methods were in complete accord and surmised the air quality to be of *good quality* as per their own individual air quality categorization criteria for the entire study period.

SUMMARY AND CONCLUSION

This book chapter presents the evaluation of the existing air quality in Dharamshala city using AQI methodology at both the quality monitoring stations for the study period of 2016 and 2017. Two different methodologies were utilized for determination of AQI. The modified CPCB methodology based on the USEPA method but using different break point indices relative Indian conditions calculates the AQI based on the highest value of the AQI determined for the criteria pollutants whereas the alternative methodology determines the AQI based on the relative fractions of all the considered criteria pollutants. The computed AQI for both the methods showed that the air quality can be categorized as '*good'* irrespective of any seasonal variations. RSPM was the most significant criteria pollutant affecting the determination of AQI for both the methods. Hence, as such based on the categorizations of AQI there is no need of immediate apprehension in the context of air quality but a detailed environmental plan should be created as slight change in in the air quality can significantly affect the biodiversity of the study location. Till date, continuous monthly air quality monitoring data is available for both the sites at the study location and needs to be continued so as to develop existing baseline concentrations of criteria pollutants in Dharamshala and any significant changes in their concentrations. This is particularly important because the city has been proclaimed as the second capital of the state which could significantly increase vehicular population leading to increased pollutant concentrations. Further, it is a popular tourist spot and also being considered as smart city, regular monitoring of pollutants and computation of AQI is important to keep track of any abrupt changes in air quality in the city.

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