The air quality assessment of northern hilly city in India

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ABSTRACT (375 words)

The last decade in India has seen a rapid deterioration in the air quality in its major cities. This has led to increased interest from the general public to their exposure to ambient air quality primarily because of effects of such air pollutants on human health. In this context, the Air Quality Indices (AQI) is often used by the local authorities to signify the levels of the seriousness of air pollution to the common public. The use of air quality indexing for assessment of existing air quality standards has been widely used for different cities in India and the world. The paper presents the application of air quality indices for assessing the existing air quality standards in an Indian city, Shimla. The indices have been calculated using the methodology described by the US Environmental Protection Agency (USEPA), which is adopted by the Central Pollution Control Board (CPCB) in India. An alternative method for determination of AQI is also utilized (referred as AQI_{am}) for Indian context. The estimates AQIs are applied to two monitoring sites (Tekka Bench, Ridge and ISBT Bus stand) in Shimla city over the study period (2004-2015) on the pollutants: sulfur dioxide (SO_2), oxides of nitrogen (NO_x), suspended particulate matter (SPM) and respirable suspended particulate matter (RSPM). The annual AQI results for the study period showed that the air quality was *'good'* for Tekka Bench monitoring station for the entire study period and for the ISBT Bus stand for all the years, except 2011 when it was in *'moderate'* category. The annual AQI predicted using the alternative methodology indicated the level of air quality to be *'good'* for the entire study period, except 2013 when it was classified as *'satisfactory'* for the monitoring site at Tekka Bench. Similarly, the annual air quality was classified as *'moderate'* for the years 2011, 2013-2015 for the monitoring station at ISBT Bus stand site with the remaining years of the study period being classified as *'good'*. These categorizations of existing air quality interpret the expected health effects of exposure to

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surrounding ambient air. Higher the value of AQI more severe is the categorization and thereby more harmful are the human health effects being exposed to ambient air conditions. Similar such seasonal variations of AQI were also observed during the study period at both the monitoring sites.

Keywords: Air Quality Index, vehicular pollution, Health effects, Ambient Air quality; Shimla

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1. Introduction

Traffic-generated air pollution is a major source of air pollution in urban areas and an important contribution to pollution in rural areas (Ganguly et al., 2014, 2015; Kumar et al., 2013, 2015, 2016). Vehicle emissions include nitrogen oxides (NO_x), carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds (VOCs), particulate matter (PM) and several metals. Exposure to traffic-generated pollutants, which include oxides of nitrogen (NO_x), carbon monoxide (CO), volatile organic carbon (VOC) and particulate matter (PM) can cause adverse health effects such as impaired lung function and asthma (Anderson et al., 2011; Clark et al., 2010; Heal et al., 2012), deficits in the growth of lung functions (Gauderman et al., 2007), and cancer (Buffler et al., 2005; Langholz et al., 2002). Vulnerable groups include individuals with existing respiratory and cardiovascular disease such as the children with asthma (Gasana et al., 2012;Lindgren et al., 2010). The CPCB has set the National Ambient Air Quality Standards (NAAQS) for criteria pollutants in India, as summarized in Table 1.

Table 1: Indian National Ambient Air Quality Standards (CPCB, 2009).

Pollutant	Time Weighted Average	Concentration in Ambient Air		
		Industrial Areas	Residential, rural and other areas	Sensitive Areas
Sulfur dioxide (SO_2) µg/m^3	Annual[a]	80	60	15
	24 h[b]	120	80	30
Oxides of Nitrogen (NO_2) µg/m^3	Annual[a]	80	60	15
	24 h[b]	120	80	30
Suspended Particulate Matter (SPM) µg/m^3	Annual[a]	360	140	70
	24 h[b]	500	200	100
Respirable Suspended Particulate Matter (RSPM) µg/m^3	Annual[a]	120	60	50
	24 h[b]	150	100	75
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

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.

However, the major difficulty lies in consolidating these standards in a reference scale (Nagendra et al., 2007). The problem is further compounded as such high air pollution concentrations and its frequency makes it difficult for citizens to appraise the existing air quality (Nagendra et al., 2007). In this context, AQI is generally used by local environmental authorities to indicate the status of the existing air quality.

An AQI is defined a definitive number stating the air quality in respect of its human health impacts (Bortnick et al., 2002; Murena, 2004). It is an informative tool wherein it summarizes the measured ambient air quality in expressing the potential health impacts of the emitted air pollutants in a simplified manner (Kowalska et al., 2009; Monteiro et al., 2016). These indices provide the citizens in informative data on the existing air quality without the details on which they are computed so that the citizens can take appropriate preventive measures from adverse health effects of air pollution (Monteiro et al., 2016). The AQI is a definitive number which is often correlated with predefined air quality classifications like *'good', 'moderate', 'poor' and 'severe'*. An AQI is determined as the function of different sub-indices for criteria pollutants. The pollutants generally considered are the ones that are continuously monitored in urban locations and the pollutants SO_2, NO_x, SPM and RSPM are considered for Indian conditions. There exist different methodologies for development of AQI but there exists no universally accepted method. The methods of analysis of AQI using different methods primarily depend on pollutants considered, sampling period and the considered breakpoints (Monteiro et al., 2016).

Air Quality indices have been used widely used for reporting existing air quality status. Several reported literature mention the use of AQI in global cities across the world. For example, Kassomenos *et al.*, (1999) used an AQI varying from 1-7 designated as good to the extreme to evaluate the air quality in the metropolitan area of Athens for the study period 1983-1995. Similar such studies have been reported by Longhurst (2005), Landulfo *et al.* (2007), Mayer and Kalberlah (2008), and Elshout *et al.* (2008). In Indian context AQI studies have been carried out 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 methodologies to calculate AQI for categorizing the air quality.

Statistical distribution fits are often performed on monitored air quality data to analyze the stochastic randomness in the data as the concentrations depend on varied factors including different meteorological and emission factors (Sharma et al., 2013). The probability density function (*pdf*) is the most widely utilized statistical parameter and is often incorporated in regulatory policies for control of air pollution to check for exceedences (Chu et al., 2012). Reported scientific literature includes fitting of different statistical variations for air quality data including lognormal (Burkhardt et al., 1998; Gokhale and Patil, 2003), Weibull (Genikhovich et al., 2005; Ganguly and Broderick, 2008) and other statistical distributions. These distribution-fits are the most widely used to fit the air quality monitored data.

The main objective of work is to present the AQI for both the monitoring sites in Shimla using the CPCB and the alternative method for a period of 2004-2015 and analyse the inter-comparability of obtained results. Further, statistical distribution best fits for the different AQI values for different pollutants have been analyzed and reported for all the pollutants at both the monitoring stations.

2. Material and Methods

2.1 Site Location

Shimla, the capital of Himachal Pradesh is located at 2000 m above the MSL and has a population of about 1,70, 000 as per the National Census Record of 2011. The city lies on UTM coordinates of (707284.74, 3443226.52) and within the UTM zone 43R. The city lies within the cold and cloudy climatic zone in Shimla city (Figure 1).

There are two monitoring stations in Shimla namely Tekka Bench on the Ridge (Station I) and the ISBT Bus stand (Station II) functioning under the National Ambient Monitoring Program (NAMP) governed by the CPCB. Station I has been classified as a background site by the CPCB whereas station II has been classified as an urban site (Ganguly and Thapa, 2016).

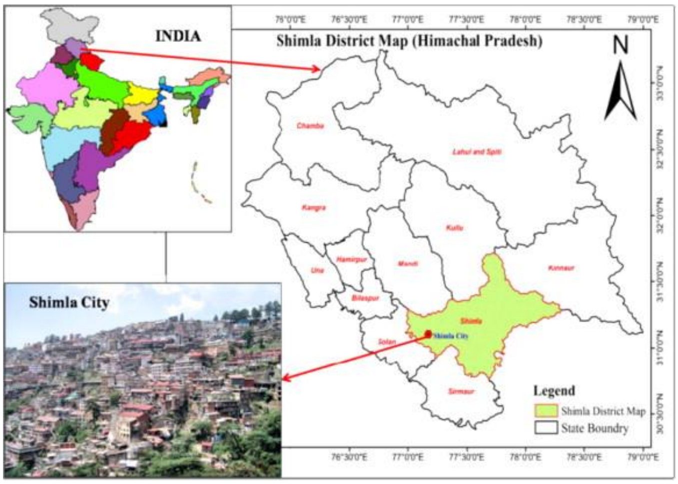


Fig 1: Geographical Location of Shimla City.

2.2 Monitoring Details

The monitoring of the different pollutants at both the monitoring sites in Shimla were carried out as per the CPCB guidelines. In particular, SO_2 is determined using the modified West and Gaeke Method (Ganguly and Thapa, 2016; Saravanakumar et al., 2016). In this method, SO_2 is absorbed from a known volume of air in a solution of sodium tetrachloromercurate to form a stable compound dichlorosulphitomercurate. The resulting stable compound dichlorosulphitomercurate is then reacted with formaldehyde solution and the color intensity so produced during the reaction process is determined using a spectrophotometer.

NO_x is determined using the modified Jacobs and Hochheiser method (Ganguly and Thapa, 2016; Saravanakumar et al., 2016). The principle involves the collection of ambient NO_2 by passing the ambient air through a mixture of a solution of sodium hydroxide and sodium arsenite. The nitrite ion concentration is then determined by measuring the absorbance of the dye produced using a spectrophotometer (540 nm) during the reaction of nitrite ion with phosphoric acid, sulfanilamide, and N-(1-naphthyl)- ethylenediamine di-hydrochloride (NEDA)

A respirable dust sampler (RDS) using a cyclonic connector is used to measure the suspended particulate matter (>10 μm) with the average flow rate being maintained at 1.1 m^3/min. (Ganguly and Thapa, 2016). The particulate matter is collected on a filter paper and is weighed in the laboratory to obtain the mass of particulate matter over the volume of air sampled with the resulting concentration being reported in μg/m^3 (Saravanakumar et al., 2016).

2.3 Air Quality Index

2.3.1 Air Quality Index by CPCB method

The CPCB method for determination of the AQI utilizes the use of USEPA methodology with different breakpoint indices for Indian conditions. The determination of AQI using this methodology involves the formation of sub-indices of the concerned pollutants followed by the agglomeration of the sub-indices (Kumar and Goyal, 2009; Kumar and Goyal, 2011). For the application of USEPA method for Indian conditions, the breakpoint concentrations for different pollutants are based on the Indian NAAQS standards and the potential health impacts of the criteria pollutants (Nagendra et al., 2007; Kumar and Goyal, 2009; Kumar and Goyal, 2011). The proposed sub-index values and the breakpoint pollutant concentrations have already been reported by previous studies (Nagendra et al., 2007; Kumar and Goyal, 2009; Kumar and Goyal, 2011) for Indian conditions and have now been summarised in Table 2.

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

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

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

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 AQI is determined for all of the considered pollutants and the highest value 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 AQI is calculated using the following expression using the alternative method is as follows (Dash and Dash, 2015; Saravanakumar et al., 2016).

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

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 correlation between AQI_{am} and the different air quality categories using this methodology has been summarized in Table 3 (Rao and Rao, 1986). It is observed from Table 3 that higher the value of AQI, greater the impact of air pollutants on human health.

Table 3. Air quality categories based on Air Quality Index as per Alternative Methodology guidelines (Rao and Rao, 1986)

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.	$\geq$ 200	Hazardous

2.4 Statistical Variations of the predicted AQI

Identification of 'best fit' distributions for air quality datasets involves either use of graphical analysis techniques (Gokhale and Khare, 2007), quantitative methods like Kolmogorov-Smirnov (KS) test, Anderson–Darling (AD) and chi-square tests (Gokhale and Patil, 2004) or using visual inspection method (Kottegoda and Rosso, 2008). The fundamental difference in computing the 'goodness of fit' using KS or chi-square method and the AD test is that the former fails to capture the tail end of the distribution (Ganguly and Broderick et al., 2008; Sharma et al., 2013). The AD test was carried out on hourly monitored data for the pollutants over the period 2011-2013 for both the monitoring sites to fit the AQI data and to determine the parametric constants of the best-fit curves.

3. Results and Discussion

3.1 AQI values using CPCB methodology

The AQI values obtained using the CPCB methodology for the entire study period of 2004 - 2015 has been summarized in Table 4 for Station I. The annual average AQI values lie within the *'good'* category as per the classification of CPCB. It was observed that for the entire study period of 2004-2015, the annual AQI values less than 50 occurred in almost 60% of the study period. The maximum annual AQI value was obtained to be 79 for the year 2013. Seasonal analysis of the AQI calculated also showed that majority of the times the AQI belonged in *'good'* category with the exception of the spring season in 2013 when it was in the '*moderate'* category (AQI = 104). The SPM was the most decisive pollutant contributing to the AQI values for 93% of the study period. This is similar to earlier reported results for Delhi (Kumar and Goyal, 2011) and Bangalore (Nagendra et al., 2007).

A similar analysis of AQI values computed for the entire study period for Monitoring station II has been summarized in Table 5. The annual AQI values lie in the *'good'* category for all years of the study period with the exception of the year 2011 wherein the annual AQI was classified as '*moderate'* (AQI = 108). However, in contrast to monitoring station I, only 25% of the annual AQI values was less than 50. Seasonal analysis of the AQI over the study period showed that for winter and summer seasons the air quality was generally *'good'* in classification, however, the AQI was classified as *'moderate'* for winter 2011 and spring for years 2009, 2011 and 2013. Annual and Seasonal variations of the AQI for both these monitoring stations for the entire study period has been represented in Figure 2

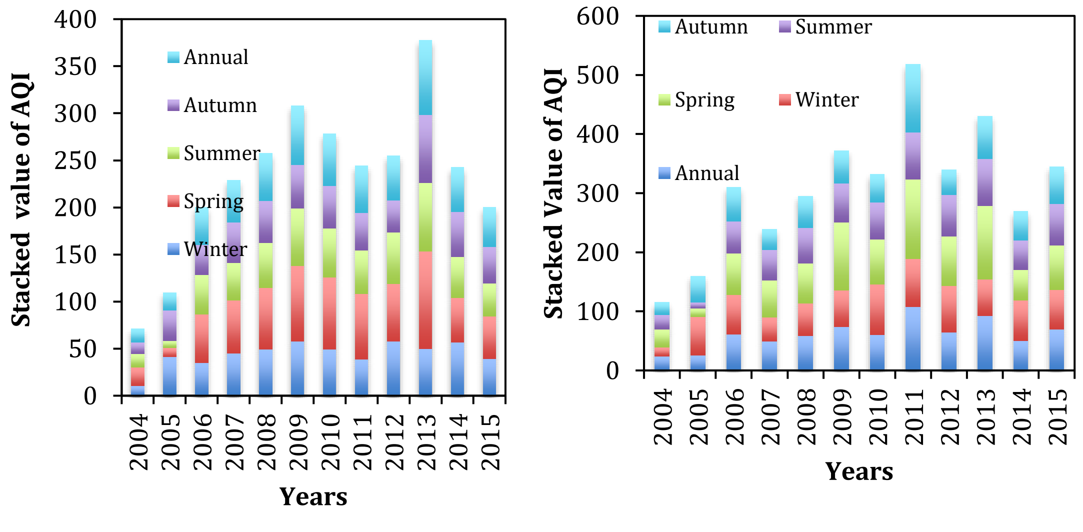
Table 4. Air Quality Index values for Station I for the entire study period (2004-2015) using CPCB methodology; note that the symbol ("-" refer to the unavailability of the data)

Months	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
January	-	11	31	41	34	51	41	46	36	69	40	59
February	-	10	34	29	52	56	50	52	47	69	40	43
March	-	6	29	41	61	83	67	60	61	95	37	40
April	19	11	59	62	62	78	80	78	55	82	43	44
May	21	12	68	67	73	79	82	71	67	134	62	52
June	19	7	68	60	45	90	82	69	84	96	46	50
July	12	7	33	31	40	49	41	38	47	72	46	31
August	11	8	25	28	57	45	33	31	33	50	37	23
September	13	33	27	32	52	39	28	31	24	61	34	41
October	12	32	30	43	47	48	55	44	39	84	49	39
November	12	31	39	53	37	51	53	45	39	71	62	38
Decemeber	10	59	34	49	42	83	50	33	36	70	68	39

Similar, to results seen in monitoring station I, SPM was the most decisive pollutant contributing to the AQI values for 93% of the study period. The results are similar and can be compared to exceedance factor reported in an earlier study that the exceedance factor for SO_2 and NO_x were found to be relatively low but for particulate matter, it varied from low to high (Ganguly and Thapa, 2016). Hence from both exceedance factors and AQI calculated, particulate matter is the most dominating pollutant governing the air quality in Shimla city. This is similar to other reported literature for Bangalore and Delhi (Nagendra et al., 2007; Kumar and Goyal, 2011; NAMP 2016). Comparison of AQI calculated using this methodology with other similar tier-II cities in India show that the results are in agreement, and that in majority of tier-II cities in India the air quality lies in the *good to moderate* category. However, for majority of metropolitan cities and tier-I cities in India, the AQI was found to be in *poor to severe* category.

Table 5. Air Quality Index values for Station II for the entire study period (2004-2015) using CPCB methodology; note that the symbol ("-" refer to the unavailability of the data)

Months	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
January	-	12	44	68	18	53	57	103	65	98	45	69
February	-	15	78	59	89	60	60	109	79	90	47	71
March	-	10	59	53	68	87	68	125	105	105	45	76
April	30	16	60	67	62	68	81	114	59	106	47	75
May	30	17	90	70	73	190	79	164	87	161	62	77
June	29	10	78	65	65	92	78	110	107	109	56	81
July	26	9	48	47	60	56	52	68	71	76	46	75
August	19	12	38	41	57	52	57	60	32	55	49	55
September	22	34	43	44	52	50	34	86	32	60	41	54
October	17	40	50	38	62	59	52	131	41	66	55	66
November	23	59	79	23	47	56	56	127	54	90	50	68
Decemeber	19	73	73	15	51	67	46	100	48	94	65	67



(a) Monitoring Station –I

(b) Monitoring Station -II

Figure 2. Annual and Seasonal Variation of AQI over the study period

3.2 AQI values using alternative methodology

The AQI were also calculated using the alternative methodology (AQI_{am}) for the study period and the results have been summarised in Table 6 for Station I for the entire study period. The annual averaged AQI_{am} values are classified as *'good'* for the entire study period excepting for the year 2013 wherein it was classified as *'moderate'* (AQI_{am} =26) as per the methodology. Seasonal variation of the AQI_{am} was also categorized as 'good' excepting spring 2013 wherein it was classified as *'moderate'* (AQI =33). The annual AQI values occurring less than 20 accounted for 93% of the study period. As observed from Eq. (2), the alternative methodology utilizes all the pollutant concentrations and their limit values to obtain the AQI_{am} values and as such, there is no decisive pollutant, however, the maximum contribution to the computation of AQI_{am} is derived from SPM contribution.

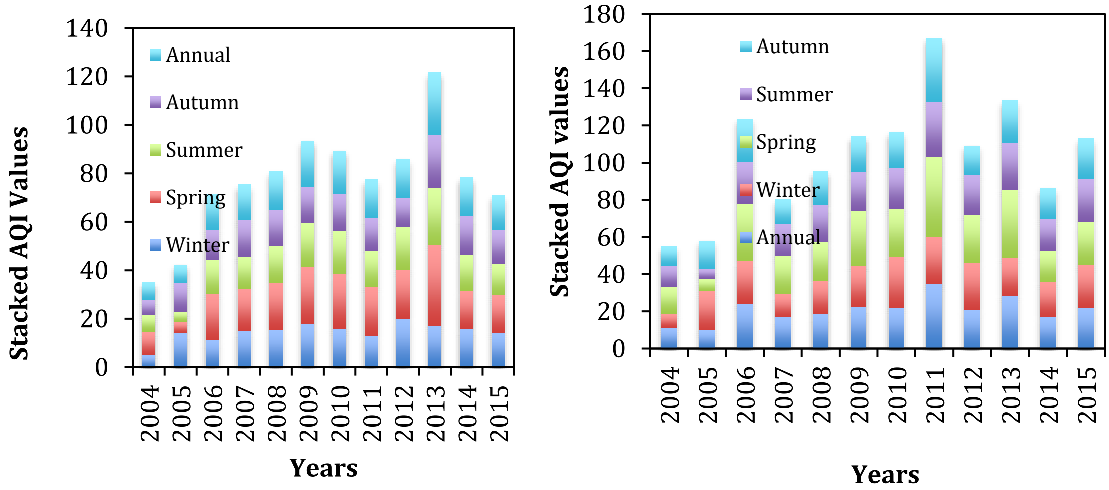
Table 6. Air Quality Index values for Station I for the entire study period (2004-2015) using Alternative Methodology; note that the symbol ("-" refer to the unavailability of the data)

Months	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
January	-	5	10	13	12	16	13	15	12	24	14	15
February	-	5	15	10	17	17	16	17	16	23	14	12
March	-	3	13	13	19	24	20	18	21	27	13	14
April	10	5	21	19	18	24	24	22	18	26	15	15
May	10	5	23	20	21	23	24	20	22	47	19	17
June	9	4	22	18	14	26	25	21	25	31	16	17
July	7	4	11	11	13	15	15	13	16	24	15	12
August	5	5	9	11	18	14	13	11	12	16	13	10
September	6	11	11	11	17	13	11	12	9	20	12	15
October	6	11	14	15	15	15	18	15	14	24	16	14
November	7	13	13	19	12	17	18	14	13	22	19	14
Decemeber	5	18	11	16	13	25	16	11	13	23	21	14

The AQI_{am} values computed for monitoring station II has been summarized in Table 7. The annual AQI_{am} for monitoring station II is categorized *'good'* for all the years with the exception of the year 2011 (AQI_{am} = 35) and 2013 (AQI_{am} = 29) wherein they are classified as *'moderate'*. However, in comparison to monitoring station I only 40% of annual AQI_{am} values was less than 20. Seasonal analysis showed a number of variations in the categorisation of AQI_{am}. For example winter of 2010 (AQI_{am} = 28) and 2011 (AQI_{am} = 26); spring 2009-2013 (AQI_{am} of 30, 26, 43, 26, 37 respectively); summer and autumn of 2011 (AQI_{am} of 29 and 34 respectively) were classified as *'moderate'*. Annual and seasonal variations of the AQI have been illustrated in Figure 3 for the entire study duration for both the monitoring stations using this methodology.

Table 7. Air Quality Index values for Station II for the entire study period (2004-2015) using alternative methodology; note that the symbol ("-" refer to the unavailability of the data).

Months	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
January	-	7	14	25	6	17	20	32	22	32	15	17
February	-	7	26	20	27	20	21	33	24	27	16	18
March	-	5	33	18	21	26	23	38	30	31	16	21
April	14	7	25	21	20	21	27	36	20	30	17	24
May	14	8	35	22	22	42	27	55	27	50	19	25
June	13	4	33	20	21	28	26	38	30	34	18	26
July	12	5	17	17	20	18	20	27	21	24	16	25
August	10	6	16	15	18	18	21	23	13	18	17	19
September	10	13	18	16	17	17	15	28	13	19	14	19
October	9	14	24	16	21	20	20	39	15	21	18	23
November	11	18	28	8	16	20	22	36	19	28	18	22
December	9	23	24	5	16	24	19	31	17	29	21	23



(a) Monitoring Station –I (b) Monitoring Station -II

Figure 3. Annual and Seasonal Variation of AQI over the study period at Station I.

The results obtained using this methodology for Shimla was compared with other reported literature using this methodology for other tier-II cities. In a similar study conducted in Coimbatore (Saravanakumar et al., 2016) it was reported that AQI_{am} was maximum at industrial areas but least in the residential areas. This is similar to the AQI_{am} results observed in Shimla with the exception that there exists no industrial areas in Shimla and the primary source of pollutants in Shimla is vehicular traffic (Ganguly and Thapa, 2016) For a similar AQI_{am} analysis carried out in Biliepeda (Dash and Dash, 2015), it was reported that the AQI_{am} values were primarily categorized as 'moderate' with major sources of pollutants being industrial, mining and mineral related transportation activities whereas in Shimla the AQI_{am} was mostly classified as good to moderate category.

3.3 Comparison of AQI values using CPCB and alternative methodology

The principal difference in calculation of AQI values using the CPCB and the alternative methodology (AQI_{am}) is that while the CPCB method utilizes the greatest values of AQI obtained for each of the pollutants calculated using the proposed sub-indices, the alternative method uses all of the pollutants to determine the AQI_{am} as observed from equations 1 and 2. Hence, as a result of which, they have different index values categorization (described earlier in Tables 2 and 3). Further, it has been observed that while the CPCB method has been widely used for metropolitan and Tier –I cities in India like Delhi and Bangalore for determination of AQI (Nagendra et al., 2007; Kumar and Goyal, 2011), the alternative methodology has been successfully applied for smaller and Tier-III cities in India (Dash and Dash, 2015; Saravanakumar et al., 2016).

A comparison of AQI values of monitoring station I and II using *both the methods* show that higher AQI values are obtained for monitoring site II in comparison to monitoring site I. This is because monitoring site I is classified as a background site whereas monitoring site II is located near an ISBT bus station wherein there exists heavy traffic flow during peak times (primarily diesel buses) and *'start-stop'* action of diesel buses leading to emission of high concentrations of particulate matter thereby making it the most dominating pollutant in determination of AQI. Particulate matter concentration fluctuated over the study period albeit different intervention measures being introduced including improvement of vehicle technology and other vehicular pollution control measures. As per Supreme Court directives, while older vehicles were scrapped, thereby reducing vehicular emissions, its beneficial effects were offset by increased flow of vehicular traffic (including recently introduced large public transport diesel vehicle buses).

The annual and seasonal variation of AQI obtained using both the methodologies seems to follow the same trend for both the monitoring locations (Figures 2a and 4a for monitoring station I and Figures 2b and 4b for monitoring station II). The AQI values obtained using both the methods showed agreement in air quality categorization majority of the times over the study period. However, certain significant differences in the categorization of the air quality were observed depending on the breakpoint classification of the AQI obtained using both the methods. These have been summarized in Table 8.

Table 8. The difference in Air Quality Characterization for both the monitoring sites for the entire study period using the two different methodologies.

Monitoring Station	Year	Classification	AQI (USEPA)	Categorization (USEPA)	AQI (CPCB)	Categorization (CPCB)
I	2013	Annual	79	Good	26	Moderate
II	2013	Annual	93	Good	29	Moderate
II	2011	Winter	81	Good	26	Moderate
II	2010	Winter	76	Good	26	Moderate
II	2012	Spring	84	Good	26	Moderate
II	2010	Spring	76	Good	26	Moderate
II	2012	Summer	79	Good	29	Moderate

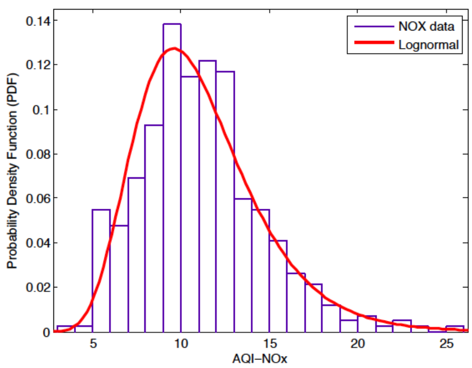
From the different categorization values obtained using the calculated AQI using both the methods, it is observed that the change occurs from *'good'* to *'moderate'* using the alternate method. The breakpoint value for categorization from *'good'* to *'moderate'* is **25** (Table 3) using the alternate methodology and it is observed from Table 8 that most of the *'moderate'* values using this method are a ***'spillover'*** effect from *'good'* categorization (AQI = 26, breakpoint value is 25).

Finally, the application of two different methods for computation of AQI and thereby categorization of existing air quality in Shimla city over an extensive study period (2004-2015) shows no remarkable differences. Though there are certain differences for certain times in categorization of air quality in the study period (as observed from Table 8), the overall existing air quality in Shimla city can be categorized as ***'good' to 'moderate' or 'satisfactory'***.

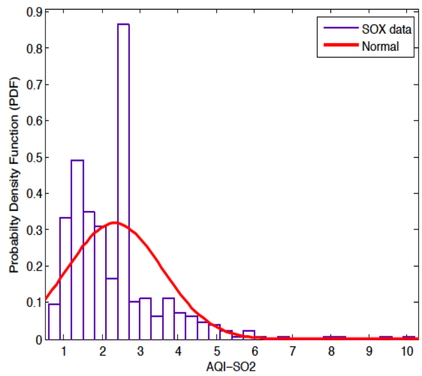
3.3 Statistical Variations of the AQI

The AQI values were fitted to probability distribution function based upon the results of the AD tests. For monitoring site I (*n*=419) for the period of 2011-2013, the best-fit distribution curve for SO_2 was found to be normal distribution (μ=2.33, σ = 1.25), for NO_x lognormal distribution (μ= 2.36, σ = 0.311)and log-logistic distribution for SPM (μ= 3.96, σ = 0.33). The *pdf* histogram plots with the best-fit curves have been shown in Figures 4(a-c). Similarly, the AQI values at the monitoring station II were best fitted by a log-logistic distribution for SO_2 (μ= 0.99, σ = 0.26) and NO_x (μ=2.74, σ = 0.17) and a normal distribution for SPM (μ= 87.72, σ = 40.88). This has now been shown in Figures 4(e-g). Table 9 highlights the parametric values for the different distribution fits for different pollutants at both the monitoring sites. The distribution plots show that the selected distributions well fit the calculated AQI values for all the pollutants at both the monitoring stations. However, certain outliers were observed for all the conditions. For both monitoring stations, outliers were observed for SO_2 and SPM. These AQI outliers were observed primarily during the winter periods wherein inversion conditions are most predominant.

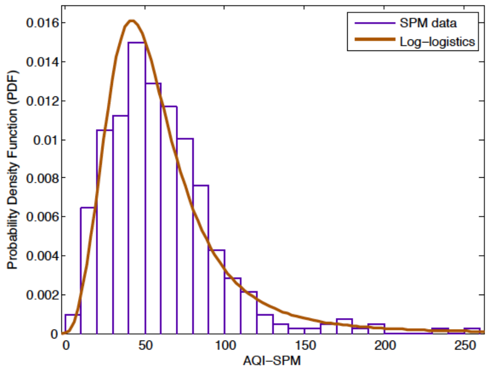
It is observed from the above statistical distributions that different AQI values for different pollutants show different statistical distributions from the monitoring locations indicating different statistical variations for different pollutants. These can be attributed to the individual pollutant characteristic and thereby their different diffusion characteristics in the atmosphere (NO_x and SO_2 are gaseous pollutants; SPM is particulate matter), further influenced by terrain and meteorological conditions (Morel et al., 1999; Kan and Chen, 2004).



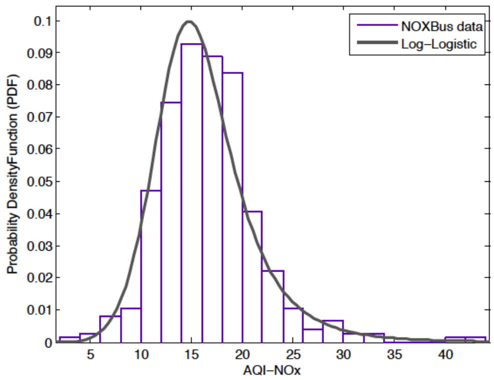
(a)



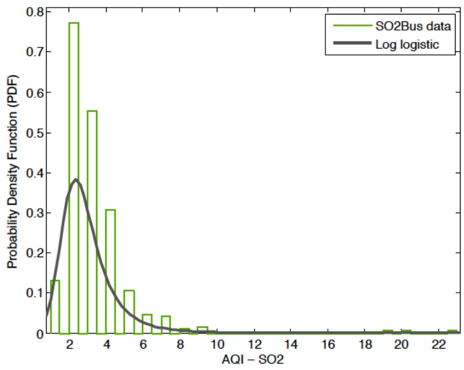
(b)



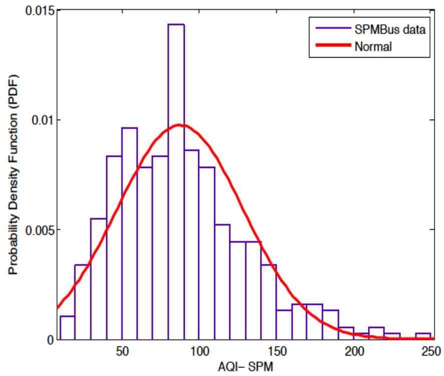
(c)



(d)



(e)



(f)

Figure 4. Probability Distribution Function plots for different pollutants at both the monitoring stations.

Table 9. Parametric values for different distribution fit for pollutants at different monitoring sites.

Distribution Fits	Monitoring Station -I						Monitoring Station -II					
	SO_2		NO_x		SPM		SO_2		NO_x		SPM	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
Normal	2.34	1.25	11.08	3.43	59.58	34.31	3.11	2.11	16.13	4.89	87.72	40.89
Lognormal	0.73	0.47	2.36	0.31	3.92	0.61	3.06	2.43	2.73	0.31	4.35	0.50
Weibull	2.64	1.99	12.32	3.35	67.27	1.84	3.50	1.69	17.86	3.26	99.22	2.28
Gamma	4.49	0.52	10.73	1.03	3.23	18.47	3.11	2.40	11.01	1.47	4.47	19.59
Log-logistic	0.73	0.27	2.37	0.18	3.96	0.33	0.99	0.26	2.74	0.17	4.39	0.28
Extreme Value	3.06	1.99	12.91	4.14	78.98	58.69	4.52	4.77	18.79	7.04	109.48	48.00

It is observed from the best-fit distributions of AQI that for NO_x (from both monitoring stations) and SPM from monitoring station I and SO_2 from monitoring station II predominantly shows lognormal or log-logistic distributions. Log-logistic distributions are similar to lognormal distributions with heavier tails. Lognormal distribution usually represents successive dilution of the generated pollutant from source to receptor and can be potential identifier for health risk. A larger standard deviation value of the lognormal distribution signifies sufficient intersection of the concentration curve and the frequency distribution resulting a in a relatively flat distribution (Kan and Chen, 2004).

4. Summary and conclusions

This work discusses the existing air quality in Shimla city using Air Quality Indices (AQI) at both of its air quality monitoring sites. The AQI were computed using both the CPCB method which utilizes using proposed sub-indices for Indian conditions and an alternative method for an extensive study period from 2004-2015. The computed AQI using the two methods showed similar categorisation of existing air quality for major durations of the study period with certain discrepancies at certain time periods at the two sites which could be attributed to the ***'spillover'*** effect. Based on the AQI calculated using the two methods, the air quality for the studied period in Shimla can be categorised as '*good' to 'satisfactory'* levels. Further, based on the computed AQI values and thereby the air quality categorization the present situation is not alarming in Shimla city but it is necessary to develop a detailed environmental policy for hilly terrains for the preservation of biodiversity, wildlife, existing flora and fauna which are highly susceptible to slight changes in air quality. Continuation of monitoring of all the criteria pollutants at both the monitoring stations in Shimla needs to be continued to observe any potential changes to the existing baseline data which will then be utilized for future air quality policies in the city and thereby in the state of Himachal Pradesh. Further, the monitored data can be used for modeling different scenarios of pollutant behavior in the context of a change of air quality policies or pollution generation patterns.The goodness of fit analysis of the calculated AQI values was carried out to determine the pdfs. The distribution fits showed that the AQI values varied for different pollutants at both the monitoring sites and could not be represented by a single distribution pattern. The statistical distribution of the AQI show different statistical variations for different pollutants due to the pollutant characterestics. Computation of AQI using the above two described methods showed that SPM was the most dominant pollutant. Further studies including trend analysis of the pollutants and source apportionment studies are curently in progress to determine the effects of the pollutant in greater details.

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