Global J. Environ. Sci. Manage.,4(4): 483-492, Autumn 2018
DOI: 10.22034/gjesm.2018.04.008

CASE STUDY

Seasonal variation of air quality index and assessment

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Received 1 April 2018; revised 30 July 2018; accepted 30 September 2018; available online 1 October 2018

ABSTRACT: Different methods have been designed to calculate the air quality index in form of mathematical formula. But the formula designed by Central Pollution Control Board in 2014 is more robust to find out the air quality category. The index has been calculated based upon four parameters like particulate matters (PM10, PM2.5), sulfur oxide and nitrogen oxide. The study area has affected by different sources like point, line and volume. Presence of different industries and mining activities polluting the natural environment of nearby areas more, although the industries taking mitigative measures proactively. In the present research, monitoring of ambient air quality has been carried out for a period from March 2013 to February 2016 for three years. It has been revealed from the study that the air quality status of the area has been declining from 2013 to 2016 i.e. 78.9 to 157.8 in summer, 49.4 to 84.3 in monsoon and 86.9 to 183.9 in winter season. It has also been found that, PM_{10} and $PM_{2.5}$ were responsible for maximum sub-index as well as air quality index. During the study period 2015-16, out of the eight stations most comes under moderately polluted category especially in winter season followed by summer season. Statistical and Duncan's multiple range test has been applied to the results with two-way and one-way analysis of variance based on different seasons and stations. In two-way analysis of variance, F-value was computed to be 30.105 based on seasons and stations and one-way analysis of variance test shows the F-values as 186.07 and 18.97 based on seasons and stations respectively which is found to be significant ($P<0.01$).The present research is important to assess the environmental quality of a mining- industrial complex area and can be a reference for similar study in other areas.

KEYWORDS: *Air quality index (AQI); Duncan's multiple range test (DMRT); Nitrogen oxide (NO_2); Particulate matters (PM_{10}; $PM_{2.5}$); Sulfur oxide (SO_2).*

INTRODUCTION

Air pollution and its impact to the nearby habitation are the most challenging issues which have to be addressed on top most priority. Air pollutants are generated from different sources including both natural and manmade polluting the atmosphere in a greater extent (Gupta and Ghose 1986; Al-salem, 2006). A number of research has been carried out and the findings has been implemented worldwide (Yang *et al.* 2004; Samoli *et al.,* 2005; Analitis *et al.,* 2006; Dash and Dash 2015). More focused research has been undertaken based on regional differences with respect to different air pollutants , their characteristics and their role in the air pollution(Samoli, 2001, 2005; Aga, 2003; Zeka, 2005; Mamta and Bassin, 2010; Balashanmugam *et al.*, 2012). The concentrations of air pollutants and its magnitude varies across different areas which depends upon the types of industrial and other activities which at the end leads to various types of health related hazards (Samet, 2000; Katsouyanni, 2001; Analitis, 2006; Rai, 2011; Meena *et al.*, 2012;

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Note: Discussion period for this manuscript open until January 1, 2019 on GJESM website at the "Show Article".

Yadav *et al.*, 2012). For a full proofed solution, a comprehensive monitoring should be carried out as per the national and international guidelines (Dash and Dash, 2015).Air quality dispersion modeling has also a great role to predict the impact of different air pollutants to the nearby areas (Katara *et al.* 2017; Dash *et al.* 2017, Kumar *et al*. 2018). Many researches has been carried out by using the mathematical tool to find out the Air Quality Index (AQI) which is very easy to understand and converts different air pollutants concentrations to a single number of an area (Ott, 1978; Bortnick *et al.*, 2002; Murena, 2004; Zlauddin and Siddiqui, 2006; Joshi and Semwal, 2011). On the basis of AQI, an area can be categories as good, satisfactory, moderately polluted, poor, very poor, and severe (Lahani, 1984; Inhaber, 1974). AQI has been developed and used in many developed countries since last three since last three decades (Shenfeld, 1970; Ontario, 2013) based on which the ambient atmosphere can be categorized (Inhaber, 1974; Dash and Dash, 2017). AQI is used for reporting daily air quality of how clean or polluted the air is and its associated health effects in the area (EPA, 2014**).** National Air Quality Index to strengthen air quality information dissemination system for larger public awareness and their participation on air quality management have been initiated by the Ministry of Environment and Forests (MoEF) Government of India and Central Pollution Control Board (CPCB). CPCB proposed the breakpoint concentration method for measurement of AQI for individual pollutants is very much robust way to find out the status of air quality. This was also adopted by China and is USEPA concept of break point concentration level which they have adopted since last decade for their development. In the current study, air quality index has been calculated for a period of three years starting from March' 2013 to ending with February' 2016 based for four ambient air pollutants PM_{10}, $PM_{2.5}$, SO_2 and NO_2 at eight different locations covering all the three seasons (summer, monsoon and winter). The study has been carried out near Bileipada, Joda of Keonjhar district of Odisha during the period March 2013 to February 2016.

MATERIALS AND METHODS

Study area

Fig. 1 shows the study area near Bileipada (22° 3' 43.2216" latitude and 85° 28' 31.0368" longitude), Keonjhar of Odisha state is covered with various industrial and mining activities because of the availability of raw materials in the close proximity. In view of the current air pollution scenario, eight numbers of ambient air quality monitoring stations

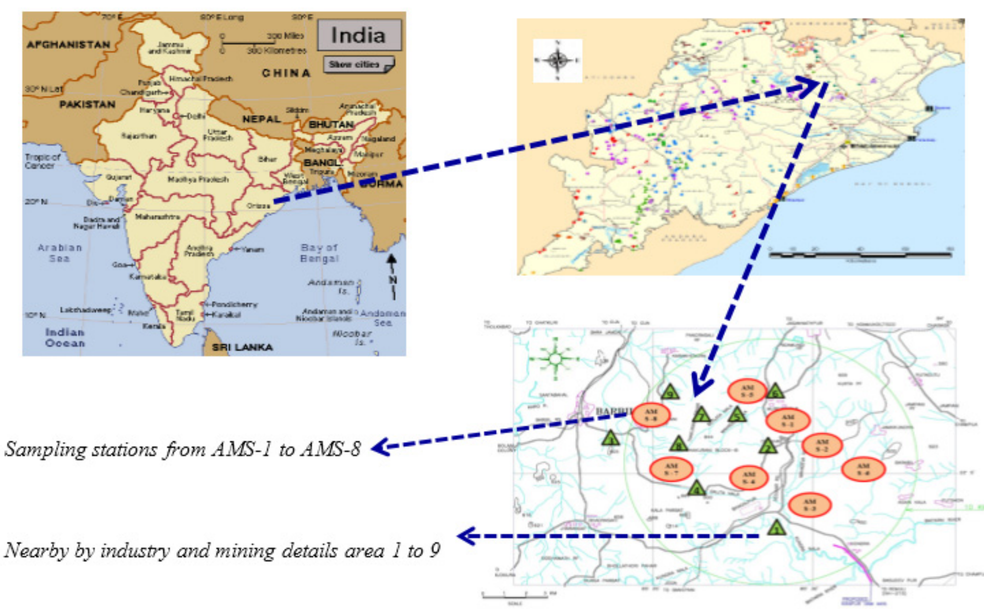

Fig. 1: The geographic location of stations in the study area

(Table 1) were selected based upon CPCB, Government of India guideline based on nearby emission sources, information about meteorological conditions and past air quality report. It has been observed that, east to south east is the predominant wind direction in the study area. Based on the atmospheric conditions, stations were selected in upwind (east) and downwind direction (west) to access the impact due to industrial activities and transportation movement in the study area. The authors have already studied on the ambient air quality modeling at the current study area taking the common sampling locations (Kumar *et al.* 2018). In addition, in the current study, an attempt has been made to calculate the Air Quality Index (AQI) of the study area in order to categories it on the basis of its pollution potential as per the norms of government of India.

Sampling methodology

Ambient air pollutants were monitored for a period of three year as per the standard methods prescribed by CPCB as given in Table 2 (CPCB, 2009). Then AQI was calculated with the help of monitored results during the study period to find out the status of ambient air quality.

Air quality index

Air Quality Index was calculated using the standard formula (USEPA, 2006, CPCB 2014). The monitored ambient air pollutant's concentration as converted to a sub-index and the worst one is reflects over all AQI. The sub-index (Ip) for a given pollutant concentration (Cp), as based on 'linear segmented principle' is calculated as Eq. 1.

$$I_p = [\{(I_{HI} - I_{LO})/ (B_{HI}-B_{LO})\} * (C_p-B_{LO})] + I_{LO} \quad (1)$$

I_p = Sub-index

B_{HI}= Breakpoint concentration greater or equal to given conc.

B_{LO}= Breakpoint concentration smaller or equal to given conc.

Table 1. Sampling station details

Station Name	Latitude	Longitude
AMS-1	22.093694	85.478722
AMS-2	22.085722	85.480638
AMS-3	22.079527	85.478583
AMS-4	22.084944	85.469944
AMS-5	22.116555	85.468611
AMS-6	22.078083	85.497416
AMS-7	22.073000	85.455638
AMS-8	22.086944	85.473333

Table 2: Experimental methods of different parameters

Sl. No.	Parameter	Experimental method	Equipment used	BIS reference
1	PM_{10}	Gravimetric	APM 460, DXNL	IS:5281 (Part-23)-2006
2	$PM_{2.5}$	Gravimetric	APM 550 with Impactor Design	USEPA 40CFR Part-50 appendix -L
3	SO_2	Impinger collection, West and Gaeke 1956	APM 433	IS: 11255 (Part-2) – 1985
4	NO_2	Impinger collection, Jacobs and Hochheiser 1958	APM 433	IS: 11255 (Part-7) – 2005

Table 3: Breakpoint of AQI Scale (0 -500) **(μg/m³)**

AQI category (range)	PM_{10} 24 h	$PM_{2.5}$ 24 h	NO_2 24 h	SO_2 24 h
Good (0-50)	0-50	0-30	0-40	0-40
Satisfactory (51-100)	51-100	31-60	41-80	41-80
Moderately polluted (101-200)	101-250	61-90	81-180	81-380
Poor (201-300)	251-350	91-120	181-280	381-800
Very Poor (301-400)	351-430	121-250	281-400	801-1600
Severe (401-500)	430 +	250 +	400 +	1600 +

Table 4: Mean and standard deviation of monitored values of different parameters based on season and station

Station Code	with period	Summer Season								Monsoon Season								Winter Season							
		PM_{10}		$PM_{2.5}$		SO_2		NO_2		PM_{10}		$PM_{2.5}$		SO_2		NO_2		PM_{10}		$PM_{2.5}$		SO_2		NO_2	
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
AMS - 1	2013-14	72.4	7.3	31.9	4.7	10.7	1.1	12.9	1.5	43.6	14.4	19.2	6.9	8.1	2.0	10.6	2.0	85.2	4.4	38.4	3.7	13.8	1.6	12.9	2.0
	2014-15	79.7	11.6	41.1	2.5	14.7	2.9	18.8	2.3	47.4	16.2	20.9	7.9	8.4	2.4	12.6	3.2	88.1	4.2	43.8	2.8	18.2	2.1	16.8	3.8
	2015-16	138.8	17.2	69.5	8.7	17.8	1.9	21.1	1.9	66.7	26.9	33.3	13.5	13.5	3.4	15.9	3.5	145.3	27.6	70.4	16.0	18.8	1.7	17.6	4.1
AMS - 2	2013-14	78.9	6.9	37.2	3.2	11.3	1.5	13.8	1.7	49.4	16.0	23.1	8.1	8.4	2.3	11.2	2.4	86.9	2.9	42.2	2.5	14.6	1.4	13.5	3.1
	2014-15	102.6	11.3	48.7	8.2	18.6	2.0	22.8	2.7	56.6	21.2	29.5	13.9	10.1	4.0	14.3	4.8	99.9	7.5	50.2	3.6	20.6	3.4	18.8	2.8
	2015-16	156.5	11.0	77.6	5.8	22.7	2.0	25.5	1.9	69.5	37.6	34.1	18.7	13.4	3.4	15.8	3.5	164.5	19.7	82.5	12.2	22.3	2.1	21.7	3.6
AMS - 3	2013-14	73.1	8.4	34.4	6.7	10.9	1.6	13.5	1.9	40.6	13.3	18.7	6.3	8.6	2.3	11.6	1.9	80.4	8.7	37.1	5.8	14.4	1.3	13.2	3.6
	2014-15	98.7	4.1	47.2	4.6	16.1	2.2	21.2	2.0	52.8	16.8	22.5	10.0	8.9	2.2	12.9	3.6	94.5	9.4	50.2	3.6	18.8	4.7	17.9	5.9
	2015-16	154.6	13.7	76.4	6.0	21.3	2.2	23.7	1.8	82.6	26.0	45.2	11.3	14.2	2.9	16.5	3.1	166.6	29.6	84.3	17.0	21.1	2.3	20.3	3.8
AMS - 4	2013-14	64.6	4.7	29.3	2.4	9.8	1.3	11.8	1.2	37.5	12.0	18.4	6.1	7.9	2.3	10.8	2.4	66.1	6.4	29.3	4.6	11.6	1.5	10.5	2.0
	2014-15	72.4	6.8	35.8	3.4	12.2	1.6	16.4	1.7	48.8	13.0	24.0	9.1	8.4	2.2	11.8	3.1	74.0	3.7	37.7	2.8	13.6	3.1	12.1	2.9
	2015-16	111.4	22.5	54.1	10.6	16.1	3.0	18.3	3.0	57.1	10.5	27.1	6.0	10.8	1.4	12.9	1.5	112.7	17.3	56.1	8.9	17.6	2.1	15.9	3.2
AMS - 5	2013-14	66.7	9.1	32.5	5.4	11.4	1.6	13.7	1.4	35.8	7.7	15.6	3.5	7.5	2.1	10.2	2.1	69.9	6.8	30.7	4.7	12.9	2.8	11.4	3.6
	2014-15	78.8	5.6	36.2	7.0	12.7	2.0	17.3	1.5	41.4	13.2	21.5	8.4	8.9	2.7	12.3	2.9	86.7	4.4	44.3	2.8	18.2	3.4	16.3	4.4
	2015-16	130.6	27.9	68.2	16.0	17.9	1.7	20.2	1.4	72.2	26.0	37.4	13.8	11.8	3.1	14.2	2.9	152.8	39.2	75.3	19.0	20.3	2.5	19.5	4.9
AMS - 6	2013-14	58.3	7.8	23.3	3.6	9.9	0.9	12.4	1.3	33.1	15.8	15.5	6.6	6.4	1.8	8.9	2.1	64.4	4.8	27.1	3.3	13.1	2.3	11.8	2.9
	2014-15	67.8	3.5	33.5	2.6	11.8	1.5	18.5	2.0	40.4	13.3	18.3	6.6	8.1	3.2	11.9	3.5	79.9	5.5	40.3	4.6	18.5	3.8	16.0	3.1
	2015-16	104.7	8.5	51.3	4.2	15.8	2.2	19.1	2.2	62.1	11.6	29.9	6.7	11.1	1.5	13.3	1.6	110.2	10.4	54.5	5.2	17.7	3.7	16.4	5.4
AMS - 7	2013-14	55.9	6.1	19.6	2.5	8.2	1.3	11.1	1.0	31.5	11.3	14.7	4.6	7.1	2.3	9.7	2.0	59.8	4.7	18.9	4.3	10.4	1.3	9.7	2.8
	2014-15	60.8	6.9	30.0	4.4	9.3	2.0	13.2	1.7	42.3	12.9	17.3	7.9	8.1	2.6	12.0	3.7	66.5	5.4	32.5	3.3	12.7	3.5	11.4	2.4
	2015-16	63.5	6.7	29.5	3.3	9.9	1.8	11.8	1.6	45.9	14.6	21.3	6.9	9.5	2.1	12.2	2.4	67.7	5.2	31.7	3.2	11.6	1.7	10.8	2.9
AMS - 8	2013-14	68.6	4.7	31.9	1.6	12.6	1.2	14.9	1.4	42.9	15.2	19.9	6.1	7.6	2.2	10.1	2.3	74.7	5.2	32.8	3.1	11.9	1.4	10.9	3.4
	2014-15	61.3	7.3	32.8	2.3	11.0	2.0	17.2	2.5	39.3	9.7	18.7	5.8	7.9	2.5	11.6	3.2	68.9	7.6	35.3	4.3	14.9	5.0	13.1	4.4
	2015-16	64.8	5.8	30.1	3.0	10.8	1.6	12.8	1.6	41.4	13.2	20.1	6.1	8.8	2.1	10.8	2.0	69.6	3.4	32.1	2.4	12.4	2.1	11.7	2.5

I_{HI} = AQI value corresponding to B_{HI}
I_{LO}= AQI value corresponding to B_{LO}
C_p = Pollutant Concentration
Finally;
AQI = Max (I_p) (where; p= 1, 2,...., n; denotes n pollutants)

The result is a set of rules (i.e. set of equations) that translate parameter values into a more simple form by means of numerical manipulation as shown in Fig. 2 (CPCB, 2014).

The AQI is divided into six groups with specified range and color scheme of AQI band given in Table 3.

RESULTS AND DISCUSSION

The mean and standard deviation (SD) of monitored results of the four ambient air quality parameters with respect to station and season are shown in Table 4.

Table 5 shows the AQI result during the summer season of the study area. It has been observed that, in summer season the air quality status is found to be satisfactory to moderately polluted on year wise. This is because of the vehicular movement, industrial and mining activities. But some of the stations such as AMS – 7 and 8 comes under satisfactory category, because of absence of any developmental activity near the monitoring sites.

During monsoon season it has been experimented that, there is no such impact of air pollutants to the nearby areas. The air quality status also found under good and satisfactory category in terms of AQI as given in Table 6. This might be due to the heavy precipitation during the season. During the study period 2013-14, the air quality status of all the stations comes under good category which continues to the study period 2014-15 except some of the stations i.e. AMS-2, AMS-3 and AMS-4 which comes under satisfactory category.

The ambient atmosphere in the study period is found to be affected more during winter season of the study period 2015-16 in maximum stations except some stations i.e. AMS-7 and AMS-8, which comes under satisfactory category. It might be due to the heavy movement of raw materials through vehicular. During the study period maximum mines are not in operation. Hence most of the industries depend upon nearby mines for raw materials. The AQI value varies from satisfactory to moderately polluted category which covered maximum monitoring sites shown in Table 7.

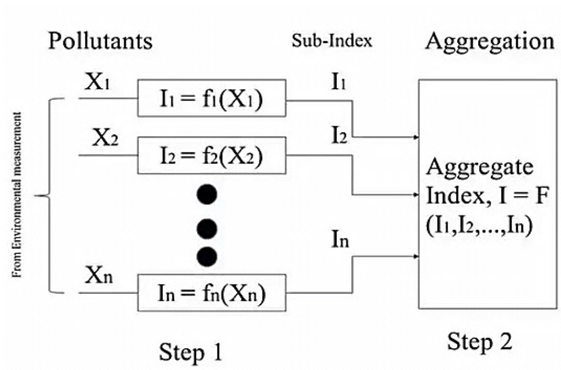

Fig. 2: Aggregated AQI formation

Table 5: AQI of different station bases on summer season

Station	Summer (13-14)	Summer (14-15)	Summer (15-16)
AMS-1	72.4	80.8	136.8
AMS-2	78.9	100.9	157.6
AMS-3	73.1	98.4	154.5
AMS-4	64.6	73.2	136.4
AMS-5	66.7	78.8	137.1
AMS-6	58.3	67.8	102.9
AMS-7	55.9	63.0	63.5
AMS-8	68.6	62.3	64.8

The result after application of two-way analysis of variance is shown in Table 8 based on different monitoring stations and seasons. The F value was found to be highly significant (30.105; P<0.01) which shows that due to the different atmospheric conditions in all stations, there is a significant variation in AQI. Variations in seasons are also found highly significant where the F-values (236.809; P<0.01) which indicates that variation in AQI was due to variation in season.

After application of one way analysis of variance (ANOVA) test on AQI due to the variations in seasons the F values were found to be significant (186.07; P<0.01) as shown in Table 9. Application of DMRT test for season wise mean with standard deviation is given in Fig. 3.

The highest AQI was observed during winter season followed by summer season then monsoon season. Due to lower mixing height and formation of inversion layer the AQI values obtained high in winter season i.e. 94.17. Then in summer season the values observed is 88.22 higher than monsoon due to maximum dispersion and turbulence of wind. In both the season the air quality status comes under satisfactory to moderately polluted category. AQI value during monsoon is comparatively lowest than other two seasons might be due to the rainfall and other meteorological conditions in the study area which was 49.59 and it comes under good to satisfactory category. Due to variation in stations after application of one-way ANOVA on AQI, the F values was computed to be significant (18.97; P<0.01) as given in Table 10.

One-way ANOVA with DMRT for homogenous mean was applied to find out more accurate results with respect to different stations. The station wise average with standard deviation is given in Fig. 4. The Monitoring stations AMS – 7, 8 and 6 with AQI value 53.39, 57.20 and 65.85 respectively indicates that they

Table 6: AQI of different station bases on monsoon season

Station	Monsoon (13-14)	Monsoon (14-15)	Monsoon (15-16)
AMS-1	43.6	47.4	66.2
AMS-2	49.4	58.4	68.4
AMS-3	40.6	52.8	84.3
AMS-4	37.5	50.7	57.1
AMS-5	35.8	43.4	75.6
AMS-6	33.1	40.5	62.1
AMS-7	31.5	42.3	45.9
AMS-8	42.9	39.5	41.4

Table 7: AQI of different station bases on winter season

Station	Winter (13-14)	Winter (14-15)	Winter (15-16)
AMS-1	85.2	88.1	146.2
AMS-2	86.9	99.0	176.9
AMS-3	80.4	95.1	183.9
AMS-4	66.2	74.0	108.3
AMS-5	69.9	86.7	154.8
AMS-6	64.4	79.9	106.9
AMS-7	59.8	66.5	67.7
AMS-8	74.7	68.9	69.6

Table 8: Two-way ANOVA test for AQI based on stations and seasons

Parameter	Source	Sum of squares	Degree of freedom	Mean squares	F-values
AQI	Station	167008.50	7	23858.357	30.105**
	Season	375346.14	2	187673.072	236.809**
	Station x Season	35726.442	14	2551.889	3.220**
	Error	665705.744	840	792.507	
	Total	1243786.83	863		

** "F" Significant at P<0.01

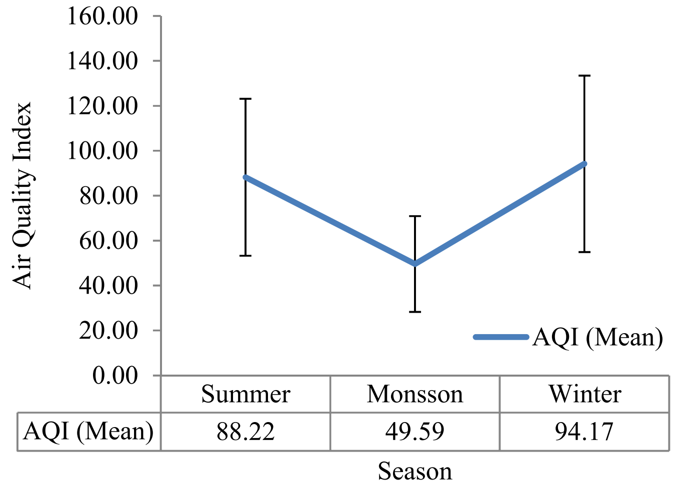

Fig. 3: Mean with standard deviation of AQI (Season Wise)

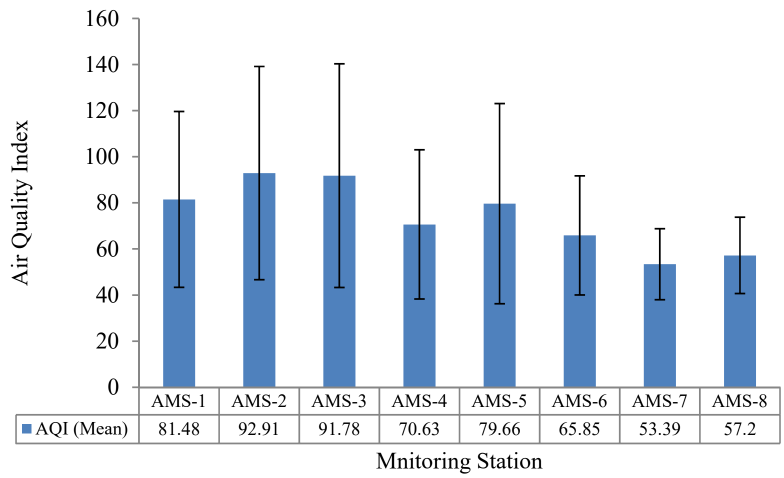

Fig. 4: Mean with standard deviation of AQI (Station Wise)

Table 9: One- way ANOVA test for AQI based on seasons

Parameter	Source	Sum of squares	Degree of freedom	Mean Square	F-values
AQI	Between Seasons	375346.14	2	187673.07	186.07**
	Within Seasons	868440.69	861	1008.64	
	Total	1243786.83	863		

** "F" Significant at P<0.01

Table 10: One-way ANOVA test for AQI based on stations

Parameter	Source	Sum of squares	Degree of freedom	Mean square	F-values
AQI	Between stations	167008.50	7	23858.36	18.97**
	Within stations	1076778.33	856	1257.92	
	Total	1243786.83	863		

** "F" Significant at P<0.01

are similar, because all three stations were situated in the low pollution impact zone where the maximum area is covered with forest. Further, in stations AMS-2, 3 and 1 the AQI values were 92.91, 91.78 and 81.48 respectively (good to moderately polluted category) which are found to be higher than other stations. This is might be due to nearby industrial activities and transportation activities in mining sites.

Similar type of studies has also been carried out in different areas to find out an overall idea about the air quality status which helps to take immediate corrective measures to control over emissions in the area (Nigam *et al.,* 2016; Mamta and Basin, 2010).

CONCLUSION

From the current study it has been revealed that the level of pollution in the study area has been increased year after year. During 2013-14 the maximum AQI found in AMS-2 and 3 in summer season are 78.9 and 73.1 which increased to 100.9 and 98.4 during 2014-15 and then 157.6 and 154.5 in 2015-16 respectively. The AQI value found satisfactory to moderately polluted due to higher concentration of pollutants as a resultant of developmental and transportation activities in the study area. Similarly the AQI values were found to be higher in winter as compared to summer on year wise in the same stations AMS-2 and 3 i.e. 86.9 and 80.4 (2013-14), then 99.0 and 95.1 (2014-15) and 176.9 and 183.9 (2015-16) respectively. In winter season also the study area comes under satisfactory to moderately polluted category, but the observed values are higher than summer season. From 2013-14 to 2015-16. In all the three seasons there is an increase in the level of pollution from 2013-14 to 2015-16. This is because in 2015-16, most of the mines in the study area have been closed, as a result of which materials from other area are transported to industries of the study area and local meteorological conditions which results in an increasing pollution load in the study area. In monsoon season the values was good to satisfactory i.e. 49.4 and 40.4 in 2013-14, then 58.4 and 52.8 in 2014-15 and 68.4 and 84.3 in 2015-16 in AMS-2 and 3 respectively. After doing statistical analysis with the application of one-way ANOVA test based on seasons and stations, it has been computed that in winter season (94.17 $\pm$ 39.28) the AQI values found higher than the summer (88.22 $\pm$ 34.95) followed by monsoon (49.59 $\pm$ 21.31). This study can be referred for any planning related to environmental management system by both government and private bodies to initiate necessary proactive action which leads to protect our natural environment. The same research may be applied to other similar types of areas in order to take appropriate preventive measures to protect natural environment of the area.

ACKNOWLEDGEMENT

The authors are thankful to the authority of the Institute of Technical Education and Research (ITER), Siksha 'O' Anusandhan (Deemed to be University) for providing necessary laboratory facilities to carry out the present research work.

CONFLICT OF INTEREST

There is no conflict of interests regarding the publication of this manuscript as declared by authors.

ABBREVIATIONS

ANOVA	Analysis of variance
AMS-1 to 8	Ambient Monitoring station 1 to 8
APM	Air pollution monitor
AQI	Air quality index
Avg.	Average
BIS	Bureau of Indian standards
CO	Carbon monoxide
C_p	Pollutant concentration
CPCB	Central Pollution Control Board
DMRT	Duncan's Multiple Range Test
DXNL	Model deluxe noise less
EPA	Environmental Protection Agency
F Value	Statistical Test
Fig.	Figure
IND-AQI	Indian – air quality index
IS	International standards
ITER	Institute of Technical Education and Research
m	Meter
m/s	Meter per second
m^3	Meter cube
mg.	Milligram
MoEF	Ministry of Environment and Forest
NH_3	Ammonia
NO_2	Nitrogen dioxide
O3	Ozone

P	Probability Value
Pb	Lead
PM_{10}	Particulate matter less than or equal 10 micron
$PM_{2.5}$	Particulate matter less than or equal 2.5 micron
SD	Standard deviation
Sl. No.	Serial number
SO_2	Sulfur dioxide
T_p	Sub index
USEPA	United states environmental protection agency
USEPA 40CFR	U.S. Code of Federal Regulations
$\bar{x}$	Mean
µg/m^3	Microgram per meter cube

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HOW TO CITE THIS ARTICLE

Kumar, S.D.; Dash, A., (2018). Seasonal variation of air quality index and assessment. Global. J. Environ. Sci. Manage., 4(4): 483-492.

DOI: 10.22034/gjesm.2018.04.008

url: http://www.gjesm.net/article_32678.html