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Assessment of Air Quality Trends in Himachal Pradesh: A Comparative Analysis of Six Locations

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ABSTRACT: This study aimed to comprehensively analyze the Air Quality Index (AQI) trajectory across six diverse locations in Himachal Pradesh, India, by identifying primary pollutants. The investigation revealed PM10 as the predominant pollutant in these regions. To assess AQI trends, both the Mann-Kendall test and Sen's Slope were employed. The findings unveiled a consistent upward trend in Baddi, known as an industrial hub, indicating worsening air quality over the study period. In contrast, Poanta Sahib and Kala Amb showed a declining trend in AQI, suggesting potential improvements in air quality over the span of 12 months. However, the AQI fluctuations in Shimla, Parwanoo, and Damtal were characterized by a mixed trend, indicating varying patterns and potential factors influencing air quality in these locations.

Keywords: Air Quality Index, Mann-Kendall test, Sen's Slope, National Air Quality Monitoring Program.

INTRODUCTION

Air quality plays a vital role in maintaining the health of our environment and impacting both well-being and the sustainability of ecosystems. It is crucial to analyze air quality patterns in regions to effectively manage the environment and develop policies. In Himachal Pradesh, India, an examination of air quality trends across six locations provides offers valuable insights into the local mechanisms of air pollution.

The measurement of air quality becomes crucial, especially in developing nations like India, which supports extensive infrastructural and industrial activities, to understand the extent of air pollution and to take appropriate health measures. In this regard, the National Air Quality Monitoring Program (NAMP) was initiated in 1984 by the Central Pollution Control Board. National Ambient Air Quality Standards were introduced in 1994 and revised in 2009, as each country uses different air quality standards. In India, the National Air Quality Index (NAQI) measures the quality of the air in a simple way. As the level of pollutants in the air increases, so does the AQI and health risks. The index helps to compare the extent of pollution in different locations and take proper actions. It also aids the government implement policies and programs related to sustainable growth and development of the country.

In Himachal Pradesh, ambient air quality monitoring was started by the State Pollution Control Board of Himachal Pradesh (HPPCB) in 1986-87 under the National Ambient Air Quality Monitoring Program with the objective to measure the extent of pollution and study the trends. Even though there were small-scale industries based on traditional skills in the state, industrialization started in the 1980s and increased its pace since the assignment of a special package by the government of India in 2003. Moreover, the state attracts a huge number of tourists, as it is a hill station and hosts more than two thousand temples. Comparatively less rail and air networks in the hilly state result in high vehicular inflow, thereby depleting the quality of air.

A study carried out by Supriya (2020) in the low hills of Himachal Pradesh revealed that, except for NO_2, which was found maximum at agricultural sites followed by urban, peri-urban, and forest land uses, other pollutant parameters under study, such as SO_2, PM10 and Volatile Organic Compounds, were found to be maximum at urban sites followed by peri-urban and agricultural areas, and minimum at forest land uses.

Various factors such as activities, transportation systems, weather conditions, and land features have an impact on air quality trends (Rad *et al.*, 2022; Haq *et al.*, 2020). Research suggests that areas experiencing vegetation tend to have better air quality, underscoring the intricate relationship between environmental elements and pollution levels (Rad *et al.*, 2022).

Studies indicate that measures like lockdowns implemented during events such as the COVID-19 pandemic have resulted in improved air quality in urban settings (Mahato *et al.*, 2020; Singh & Chauhan 2020). When studying air quality trends in Himachal Pradesh, it is essential to consider not only pollutant levels but also factors like temperature variations, snow coverage, and how vegetation is spread throughout the region (Haq *et al.*, 2020; Arundhati & Bhagat 2023).

Assessment utilizing cutting-edge technologies, like machine learning and remote sensing, can improve the assessment and analysis of air quality factors (Rad *et al.*, 2022; Hoffman *et al.*, 2022). Moreover, research centered on areas in Himachal Pradesh, such as Prashar Lake, highlights the importance of environmental factors in influencing air quality patterns (Brar *et al.*, 2023; Jindal *et al.*, 2014).

Keeping the above facts as base, present work aims to find out the major pollutants and to analyze the trend of air quality index over the years in Himachal Pradesh.

MATERIAL AND METHODS

A. Choice of Locations

Himachal Pradesh, a cool hilly state, located in northern part of India, has 12 districts. The HPPCB currently monitors the ambident air quality at 25 monitoring stations in 12 cities namely Shimla, Parwanoo, Damtal, Manali, Una, Dharamshala, Sundar Nagar, Poanta Sahib, Kala Amb, Baddi, Nalagarh and Rhotang. Out of these 12 cities, 6 cities were chosen based on availability of data.

B. Collection of Data

The data of concentration of pollutants required for the present work has been acquired from the website Himachal Pradesh Pollution Control Board (CPPCB). Pollutants concentration data of 15 years, from 2004 – 05 to 2019 – 20, was available for Damtal, Kala Amb, Parwanoo, Poanta Sahib and Shimla locations whereas 9 years data, from 2007 – 08 to 2019 – 20, was available for Baddi location. Since, Baddi is an industrial location, it was felt that the study had to be carried in that location with the available 10 years of data. So, the study has been carried out for the above 6 locations considering the pollutant concentration of PM10, NO_2 and SO_2, as these are the only common pollutants (based on data available) in selected locations.

C. National Air Quality Index

National Air Quality Index, used in India, was developed by IIT Kanpur and recommended by the expert group, was implemented in 2014 under Swachh Bharat Abhiyan. The index measures eight pollutants namely PM10, PM2.5, NO_2, SO_2, CO, O_3, NH_3 and Pb, while the index which had been in use earlier measured only three parameters. Apart from CO, which is measured in mg/m³, all other pollutant concentrations are measured in µg/m³. Since Pb can't be measured in real time it is not the part of 'Real time AQI'. While calculating 'I_{si}', 8 hourly average concentration is used only for CO and O_3 and for other pollutants 24 hourly averages are used.

The index is divided into 6 categories, which are coded with different colors. The importance was given to lower-level categories, hence 2 categories below 100 and the next four categories for successive hundreds. Each pollutants have the sub-indices, based on dose response relation and National Ambident Air Quality Standard, and the worst sub-indices reflects the overall AQI.

The sub-index value is calculated by using the formula,

$$I_{si} = \left(\frac{(C_{obs} - C_{min})((I_{max} - I_{min}))}{(C_{max} - C_{min})}\right) + I_{min}$$

where,

I_{si} - Sub-index value of the observed pollutant
C_{obs} - Observed Pollutant concentration
C_{max} - Maximum concentration of AQI color category that contains $\leq C_{obs}$
C_{min} - Minimum concentration of AQI color category that contains C_{obs}
I_{max} - Maximum AQI value corresponding to $\leq C_{max}$
I_{min} - Minimum AQI value corresponding to C_{min}

Once the sub-index value for each pollutant is calculated, overall index value can be calculated different methods such as simple or weighted average method, summation or multiplication operation and maximum or minimum operator method. Here, maximum operator method was used as it is free from eclipsing, ambiguity and synergistic effects of combination of pollutants are not known. The same is being used to calculate NAQI by pollution control boards.

$$AQI = Max(I_{si1}, I_{si2,} \dots\dots\dots, I_{si8})$$

AQI Categories	AQI Range ($I_{min} - I_{max}$)	Concentration Range (24 hr average in µg/m³) ($C_{min} - C_{max}$)		
		PM10	NO_2	SO_2
National Standards		**100**	**80**	**80**
Good	**0- 50**	0-50	0-40	0-40
Satisfactory	**51-100**	51-100	41-80	41-80
Moderately Polluted	**101-200**	101-250	81-180	81-380
Poor	**201-300**	251-350	181-280	381-800
Very Poor	**301-400**	351-430	281-400	801-1600
Severe	**401-500**	430+	400+	1600+

For calculating the Air Quality Index from available data, Microsoft Excel soft-ware was employed. Here, taking into consideration that, minimum of 3 pollutant concentrations are essential for estimating the index value out of which one of the PM10 and PM2.5 is compulsory, in this analysis, due lack of availability of data only 3 pollutant concentrations, *i.e.*, PM10, NO_2 and SO_2, were used.

D. Statistical Analysis

(i) *Mann-Kendall test (MK test).* MK trend (non-parametric trend) test has been employed in the analysis to detect monotonic trends in the data series. The testing of trend by normal approximation test is test carried out by Kendall (1975). The test developed by Kendall in 1975 makes the assumption that the data set contains few tied values. MK test analyses the trend of given data in the study area with respect to study variable and determines whether it is statistically significant for the purpose of the test. Among the results of MK test, the *S*-statistics of the test are used when the number of data available are less than 10 and Z-statistics are employed when more than 10 data values are available (Kendall, 1975).

The Mann-Kendall statistics (S) is given as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sign(X_j - X_i)$$

where,

$$Sign(X_j - X_i) = \begin{cases} -1, & if(X_j - X_i) < 0 \\ 0, & if(X_j - X_i) = 0 \\ 1, & if(X_j - X_i) > 0 \end{cases}$$

An upward trend is indicated by a positive value of S, while the downward trend is indicated by a negative value of S. It is also necessary to test the statistical significance of the trend. The variance of S is given by:

$$V(S) = \frac{m(m-1)(2m+5) - \sum_{j=1}^{p} l_j(l_j - 1)(2l_j + 5)}{18},$$

where m, is the number of observations, p is the number of tied groups and l_j is the number of observations in j^{th} group.

Z-statistic is given as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{V(S)}}, & if S > 0 \\ 0, & if S = 0 \\ \frac{S+1}{\sqrt{V(S)}}, & if S < 0. \end{cases}$$

If the resultant Z statistic is negative and is less than tabulated value of Z then there is decreasing trend, if it is positive and is greater than tabulated value of Z then there is increasing trend and if it is zero and is less than tabulated value of Z then there is no trend.

(ii) *Sen's Slope estimator (SSE).* Since the trend of the AQI data found to be linear in nature, Sen's nonparametric approach (1968) was employed to forecast the true slope of a time series. A set of N data pairs can use this method to determine the slope. We use:

$$Q_i = \frac{x_k - x_j}{k - j},$$

where, i varies from 1 to $n-1$ and j varies from 2 to n. x_k and x_j are data values at time k and j respectively.

If there are n observations of x_k in the time series, there will be $N = n(n-1)/2$ slope estimates. This median slope of N values of slopes is called Sen's slope. The Sen's slope is:

$Q = Q_{\frac{n+1}{2}}$, if n is odd

and

$Q = Q_{\left(\frac{n+2}{2}+\frac{n}{2}\right)}$, if n is even.

An increasing trend is indicated by a positive Sen's slope, while a decreasing trend is indicated by a negative Sen's slope.

RESULTS AND DISCUSSION

Results and discussed are described under three categories as under:

A. Pollutant concentrations

The initial finding about have shown that PM10 is the major pollutant in all the six selected locations. As a result, PM10 concentration was significantly dictating the value of air quality index in maximum operator method, which was used to find the overall AQI value. Table 1 shows the maximum and minimum concertation (μg/m³) of PM10 in different location, along with month and year, under study. Among the six locations, the highest concentration of PM10 was found in Kala Amb in October, 2007-08 and minimum was found in Shimla in January, 2015-16.

Table 1.

Sr. No.	Location	Maximum		Minimum	
		Concentration (μg/m³)	Month and year	Concentration (μg/m³)	Month and year
1.	Baddi	286.30	Jun, 2018-19	43.00	May, 2009-10
2.	Damtal	315.80	Dec, 2014-15	30.90	Aug, 2011-12
3.	Kala	375.00	Oct, 2007-08	43.58	Sept, 2006-07
4.	Parwanoo	174.83	Oct, 2006-07	28.66	Mar, 2004-05
5.	Shimla	145.00	May, 2009-10	08.30	Jan, 2015-16
6.	Poanta	435.38	Jun, 2005-06	33.00	Jul, 2008-09

B. Air Quality Indices

Fig. 1-18 shows the month wise and year wise air quality indices for all the six locations calculated by using maximum operator formula. The analysis revealed that maximum and minimum AQI for the locations Baddi were 224 (May, 2009-10) and 43 (June, 2018-19), for Damtal 316 (Dec, 2014-15) and 31 (Aug, 2011-12) for Kala Amb375 (Oct 2007-08) and 44 (Sept, 2006-07), for Ponta Sahib 435 (Jun 2005-06) and 33 (Jul 2008-09), Shimla 130 (May, 2009-10) and 8 (Aug 2005-06) and for Parwanoo it was found to be 150 (Oct, 2006-07) and 32 (Mar, 2004-05) respectively. The monthly average of AQI, in most of the cases, disclosed that in the locations Baddi, Kala Amb and Ponta the AQI was over 100 in the months of winter and summer (October to May) indicating poor air quality and the same ranged between 50 and 100 in the months of July to September indicating good air quality. But, in case of Damtal, Parwanoo and Shimla the air quality found out to be good throughout the year ranging between 50 and 100.

C. Trends of air quality index

Further, in Table 1, positive 'Sen's slope' reveals that, there is increasing trend of AQI in all the months in Baddi, which has been represented graphically in Fig. 1-3, whereas in Damtal, there is decreasing trend in all the months except December (Fig. 4-6). Also, in case of Parwanoo there is increasing trend in June, July, August and October, while the trend is decreasing in all other months (Fig. 7-9).

The Table 2 shows that there is downward trend in all the months for location Kala Amb, the same can be observed in the Fig. 10-12. In Shimla, the trend decreasing in February and March months and for the remaining months the trend is increasing. At last, in Ponta Sahib, downward trends for all the months were observed. In both the Tables 1 and 2, it was found that 'trends' either increasing with positive sign or decreasing with negative sign shown by the 'Sen's slope' have been supported by the positive and negative 'z' and 'tau' values respectively. Among the six locations under study, Shimla was found to be least polluted.

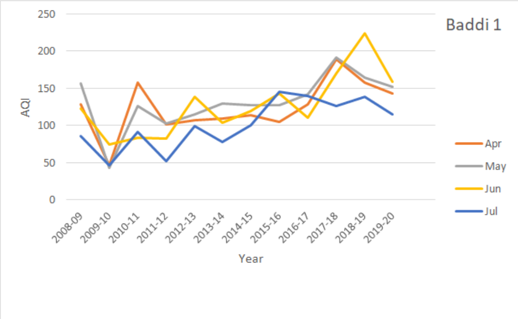
During the study, it was observed that the maximum operator for the calculation of overall AQI, which is used by the Central Air Pollution Control Board, isn't efficient as the overall AQI depends on only one the pollutants.

Table 2.

Months	Baddi				Damtal				Parwanoo			
	z	tau	Sen's slope	trend	z	Tau	Sen's slope	trend	z	tau	Sen's slope	trend
Apr	1.7224	0.4000	5.2500	+	-1.5323	-0.2929	-2.4416	-	-1.0355	-0.2000	-0.6548	-
May	2.1995	0.5038	6.0625	+	-1.2181	-0.2353	-2.0000	-	-1.0376	-0.2017	-0.5774	-
Jun	2.5372	0.5758	9.0000	+	-0.9014	-0.1757	-1.6333	-	1.6258	0.3123	1.1825	+
Jul	2.4000	0.5455	6.6250	+	-0.6310	-0.1255	-1.2381	-	1.1742	0.2279	0.5857	+
Aug	3.1004	0.7078	6.1736	+	-0.8595	-0.1695	-0.7071	-	0.5865	0.1177	0.4773	+
Sep	3.2382	0.0012	7.3810	+	-0.9935	-0.1941	-0.9000	-	-0.0451	-0.0168	-0.0714	-
Oct	2.3370	0.5344	7.2500	+	-1.2181	-0.2353	-1.0000	-	0.0901	0.0251	0.1964	+
Nov	3.3601	0.7576	5.9167	+	-0.4052	-0.0833	-0.7172	-	-2.7464	0.0060	-2.8000	-
Dec	2.8868	0.6565	6.4500	+	0.0901	0.0251	0.3357	+	-1.4990	-0.2907	-1.4500	-
Jan	2.4744	0.5649	6.2500	+	-1.2181	-0.2353	-2.0000	-	-2.0830	-0.4001	-1.2792	-
Feb	2.8115	0.6364	7.9286	+	-0.4052	-0.0833	-0.7841	-	-0.8613	-0.1710	-0.5357	-
Mar	2.8868	0.6565	7.3333	+	-1.9830	-0.3766	-2.5000	-	-0.6322	-0.1266	-0.7211	-

Table 3.

Months	Kala				Shimla				Paonta			
	z	tau	Sen's slope	trend	z	tau	Sen's slope	trend	z	tau	Sen's slope	trend
Apr	-0.9014	-0.1757	-2.0000	-	1.6336	0.3177	0.6389	+	-2.2961	-0.4333	-3.6111	-
May	-0.8572	-0.1681	-1.7917	-	0.9915	0.1925	3.0000	+	-1.9399	-0.3698	-3.8776	-
Jun	-0.6767	-0.1345	-2.0000	-	1.5931	0.3105	1.8333	+	-1.9399	-0.3698	-2.4167	-
Jul	-0.7669	-0.1513	-0.7625	-	1.6738	0.3221	1.6026	+	-1.3520	-0.2594	-2.8833	-
Aug	-0.7669	-0.1513	-2.2679	-	0.9032	0.1772	1.0714	+	-2.5238	-0.4770	-3.2143	-
Sep	-1.2181	-0.2353	-2.5357	-	2.4453	0.4682	1.5417	+	-1.9830	-0.3766	-2.1385	-
Oct	-0.2256	-0.0504	-0.2556	-	2.2166	0.4238	2.3667	+	-1.5323	-0.2929	-2.5000	-
Nov	-1.3520	-0.2594	-3.1667	-	0.2260	0.0509	0.1548	+	-2.1161	-0.4000	2.7639	-
Dec	-0.9915	-0.1925	-3.2083	-	0.0453	0.0171	0.0001	+	-3.4252	-0.6444	-3.1667	-
Jan	-0.8554	-0.1667	-1.8750	-	0.9032	0.1772	0.6905	+	-2.7096	-0.5148	-3.5833	-
Feb	-0.4060	-0.0840	-0.5357	-	-0.2260	-0.0509	-0.0955	-	-1.1718	-0.2259	-2.0000	-
Mar	-0.8554	-0.1667	-1.5903	-	-0.2710	-0.0591	-0.1288	-	-2.3008	-0.4370	-4.1389	-



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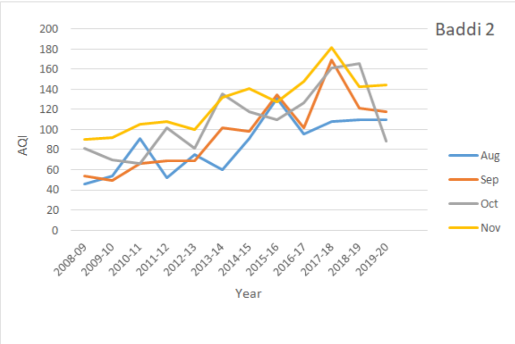

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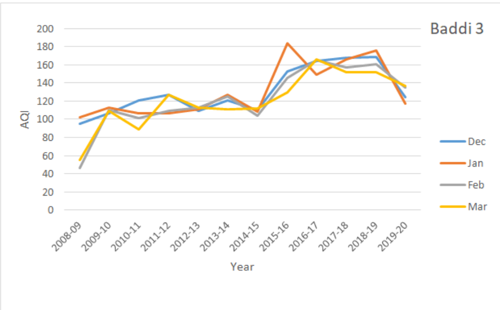

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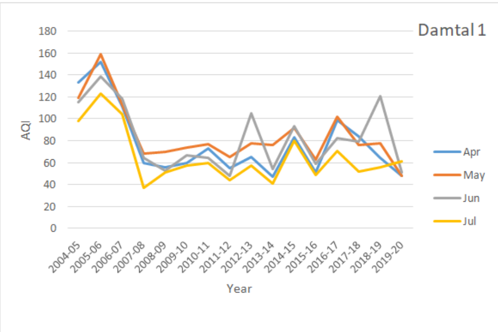

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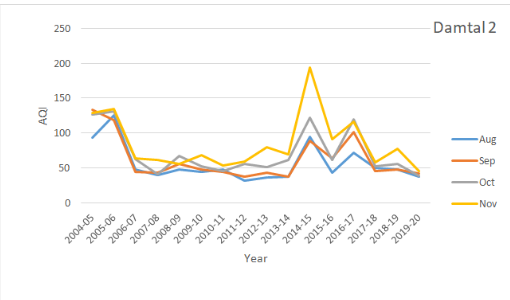

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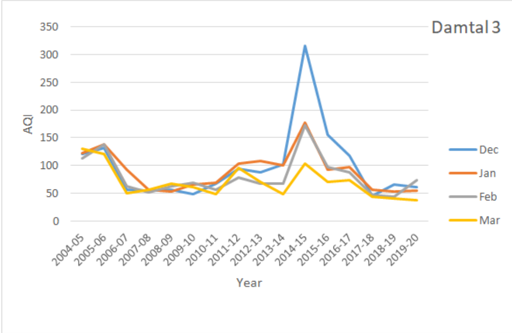

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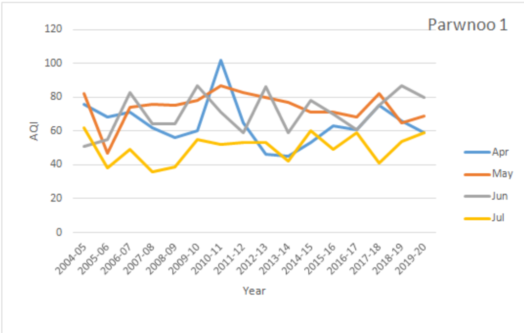

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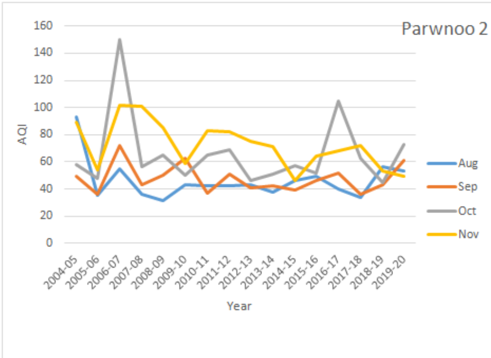

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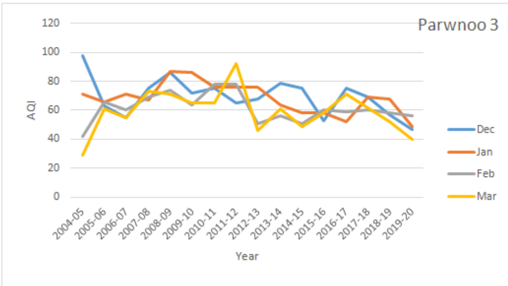

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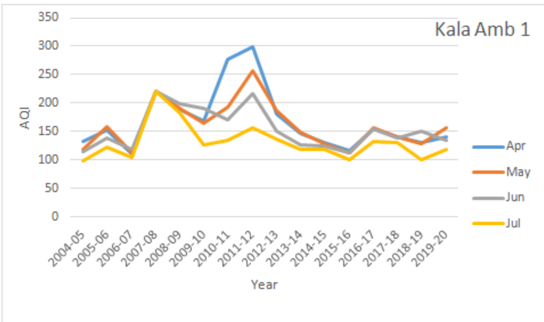

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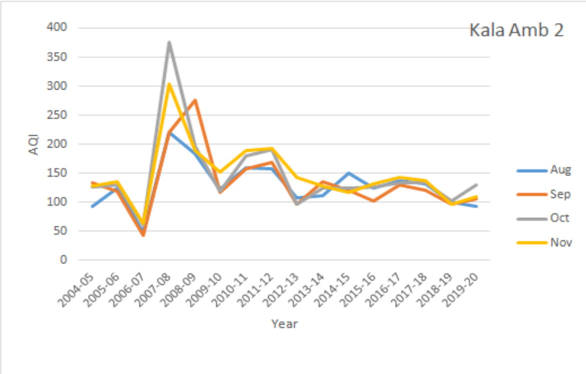

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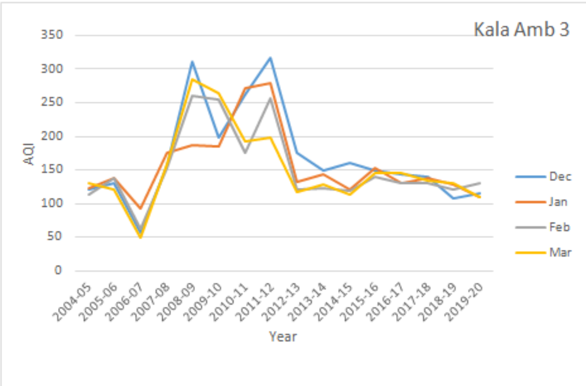

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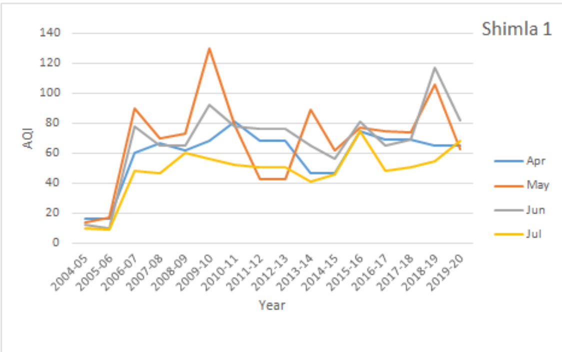

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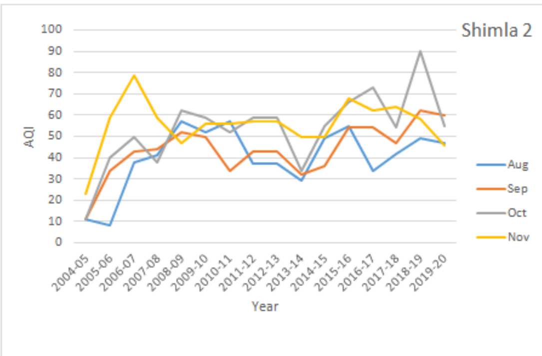

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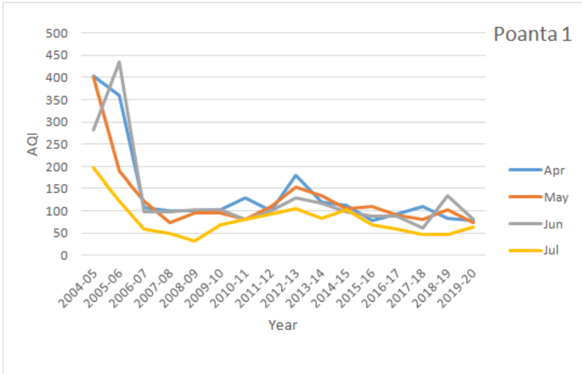
Fig. 15.



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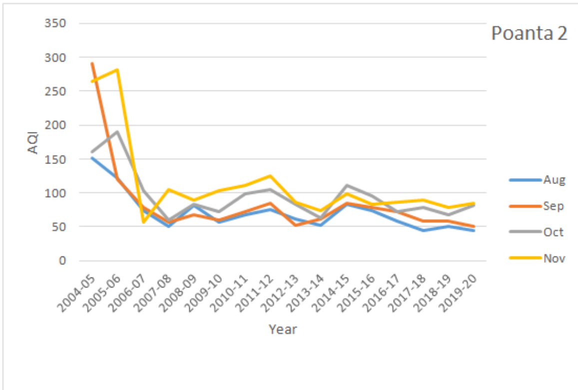

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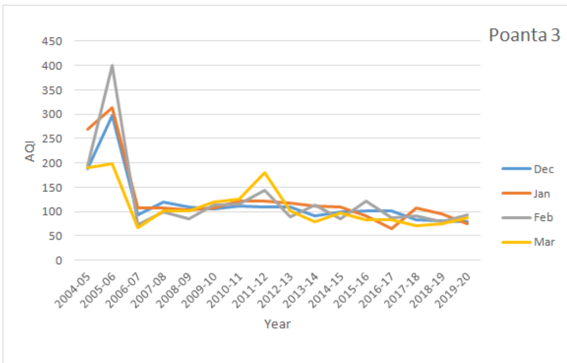

Fig. 18.

CONCLUSIONS

The results of the study showed that there were various trends among sites under investigation. Baddi, an industrial hub, showed a consistent upward trend in AQI; hence it indicated worsening air quality as time went on. In contrast, Poanta Sahib and Kala Amb demonstrated declining trends in AQI suggesting possible improvements in air quality over a 12 month-period. However, Shimla, Parwanoo and Damtal presented mixed trends thus signifying varying patterns and likely factors affecting air quality. Most importantly, Baddi, Kala Amb and Ponta consistently revealed winter (October to May) and summer values for AQI above 100 implying poor air quality while showing figures below 50 but above 100 ranging between July and September which implied good air quality. Damtal, Parwanoo and Shimla had good air quality round the year whereby their AQIs stood at between 50-100 throughout the year. The least polluted area is Shimla among all other locations assessed herein. Furthermore, maximum operator method used to calculate overall AQI has been observed to contain certain limitations since it only relies on a single pollutant. Therefore, this wide-ranging analysis emphasizes the significance of continued monitoring as well as assessment regarding observable tendencies involving atmospheric conditions meant to facilitate ecological governance together with policy development in Himachal Pradesh.

FUTURE SCOPE

Future research should focus on year-round, multi-pollutant AQI assessments to overcome the limitations of the maximum operator method. Continuous monitoring and advanced modeling can help identify sources of pollution and seasonal trends more accurately. Policymakers should utilize this data for targeted interventions, especially in industrial areas like Baddi. Additionally, expanding monitoring networks in semi-urban and rural areas can support better ecological governance and contribute to sustainable environmental policies in Himachal Pradesh.

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