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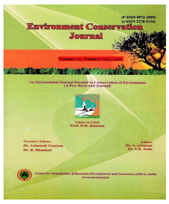

Detecting air pollutants trends using Mann-Kendall tests and Sen's slope estimates

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ABSTRACT

Recently, trend detection in ambient air pollutants has received a lot of interest, particularly in relation to climatic changes. Air pollutants data that were acquired from monitoring stations from 2015 to 2021 were used in the current investigation. The direction and size of the monotonic trend were determined using the Mann-Kendall test and Sen's slope estimator. The findings showed that there was significant fluctuation in different parameters over time. According to the study, SO_2 and NO_2 indicate a slightly increasing tendency with approximate annual concentrations of 6µg/m^3 and 40µg/m^3, respectively, whereas PM2.5 shows a decreasing trend with an approximate annual concentration of 130µg/m^3. For all of Odisha's districts, PM10 exhibits no trend, with annual concentrations of about 90µg/m^3. The study found that while NO_2, PM2.5, and PM10 concentrations were significantly over the standard allowed limits while SO_2 concentrations were significantly below them. Specific actions are needed to reduce these pollutants' emissions in Odisha.

Introduction

Environmental deterioration now largely depends on air pollution. The main causes of air pollution today are rising industrialization and the use of automobiles for transportation to meet the demands of an expanding human population (Sharma *et al.*, 2018; Bhutiani*et al.,* 2021). The most significant pollutant in terms of phytotoxicity is air particulate matter, which is one of the criterion pollutants. Air pollution in cities and peri-urban areas is a major global environmental concern (Gupta *et al.,* 2016; Ruhela *et al.,* 2022a). The main causes of particulate matter (PM) pollution are activities related to agriculture, road dust, power plants powered by vehicle emissions, construction activities, etc. (Kumar *et al.,* 2018; Ruhela *et al.,* 2022b). In general, atmospheric aerosols are dominated by crustal components in the Indian region mainly because of their origin from suspended soil-dust and road dust (Bhaskar and Sharma, 2008). Because of this, ambient suspended particulate matter levels have frequently been found to be above National Ambient Air Quality Standards (NAAQS) guidelines (CPCB, 2012).

In the fields of climatology, water quality, air quality, and other time series, trend detection is an important topic. A statistical test is used to determine whether there is a trend in a time series of air quality measurements; the test's power is the likelihood that it would reject the null hypothesis in the presence of a trend or fail to do so in the absence of a significant trend (Karpouzos *et al.,* 2010). Because most projects are planned, developed, and operated based on the historical pattern of environmental behaviour, detection of temporal trend is one of the most crucial environmental monitoring goals (Abdul *et al.,* 2006).In its annual report, India's Central Pollution Control Board (CPCB) stated that 67 monitoring stations for NO_2 and 295 stations for PM10 exceeded national ambient air quality limits. The

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concentration of SO_2 has been reported to be below acceptable limits (NAQ, 2010). Air pollution in a city demands rapid attention because the city has a huge population, and so air pollution may affect more individuals. A fundamental component of an air pollution management system is strict rules, ongoing monitoring of air pollutants, and trend analysis (Chelini *et al.,* 2010: Box *et al.,* 2015).
Odisha is fortunate to have a wealth of mineral resources, including 24% of India's coal reserves, 17% of iron ore, 98% of chromite, 51% of bauxite, 35% of manganese, and 92% of nickel ore (Odisha Economic Survey 2014–15). The coal belts of the state have been deemed the most hazardous for human health and living circumstances, according to a State of Environment study from 2008. The coal belt's surrounding areas experience shockingly high concentrations of suspended particulate matter (SPM) and respirable particle matter (RPM), which are many times higher than the national acceptable threshold. Furthermore, according to WHO (2010), harmful chemicals released during the coal mining process may have a negative impact on the air quality in the area. Because coal is a significant source of energy and fuel, it is crucial for the expansion and development of a transitional economy like Odisha. In addition, coal has the strongest forward connections with other industries.
Human population increase is becoming a contentious problem, and this overpopulation has had numerous negative repercussions on the ecosystem. Numerous social and economic issues negatively impact the environment. As a result of this negative influence, dangerous pollutants like SO_2, NO_2, RSPM, SPM, etc. are released into the atmosphere (Ahamad *et al.,* 2022; Ruela *et al.,* 2022b). The amount of suspended particle matter (SPM) in the air in Bhubaneswar is alarming, according to a report from the Odisha State Pollution Control Board. It increases the chance of premature death and causes substantial deterioration of heart and lung conditions. In addition, cardio-respiratory problems may result. In order to assess the health effects of pollutants, health care data for Odisha was analysed, and it was shown that respiratory disorders were responsible for 4.80 percent of deaths per 100,000 people in Odisha in 2014 (Samal *et al.,* 2019).
The environmental time-series data can be analysed using a variety of statistical approaches to find trends and seasonal variations. There are two mathematical methods for calculating trend analysis: parametric methods, which are more efficient but they require the data be in depended and normally distributed, and non-parametric methods, which presuppose dependent observations. One of the often employed non-parametric techniques to identify significant trends in time series data is the Mann-Kendall test. It is feasible to detect if a rising or decreasing trend exists using the Mann-Kendall test (Jaiswal *et al.,* 2018).
The present study's objective is to use the Mann-Kendall test and Sen's slope estimator (1968) to identify and quantify the trend in air quality in five districts of Odisha. The objective is to have a deeper understanding of the air quality trend from 2015 to 2021.

Material and Methods

Study area and data collection

Odisha State comprises 30 districts and a geographical area of roughly 156,077 km^2. About 1438 mm of rain falls on the state each year. The weather in Odisha State is generally tropical, brief winter with mild temperatures, and highly humid with medium-to-high rainfall. In the majority of the districts, cyclones, droughts, and floods of varied intensities happen virtually annually. In western areas, the summertime maximum temperature rises beyond 40°C and fluctuates between 40°C and 46°C.
Through the National Ambient Air Quality Monitoring Program (NAMP) and State Ambient Air Quality Monitoring Program (SAMP), which are both supported by the CPCB, the Central Pollution Control Board monitors ambient air quality at 38 stations in seventeen different areas of the State. At all monitoring stations, variables including respirable suspended particulate matter (PM10 and PM2.5), SO_2, NO_2, NH_3, O_3, CO, Pb & Ni are routinely analysed. Except for Brahamanagar in Berhampur and Konark Police Station in Konark, all 10 monitoring locations consistently had Respirable Suspended Particulate Matter (RSPM or PM2.5) concentrations above the prescribed limit of 60 g/m^3, while at 21 locations, the average annual value of PM remained 2.5 g/m^3 below the limit (out of 30 locations monitored). The 102 most polluted cities in India include six in the state of Odisha. The

national ambient air quality requirements established by the Central Pollution Control Board (CPCB) have not been met by Cuttack, Bhubaneswar, Balasore, Angul, Talcher, or Rourkela (Anonymous, 2019). The study areas that selected for trend analysis is shown in the figure 1.
The Odisha State Pollution Control Board in Bhubaneswar provided the monthly air quality statistics for five districts over a six-year period (2015–2021). Data was retrieved for Angul, Bhubaneswar, Cuttack, Talcher, and Rourkela in the state of Odisha. The air quality indices used in the study include Sulphur dioxide (SO_2), Nitrogen dioxide (NO_2), Particulate matter 2.5 (PM2.5), and Particulate matter 10 (PM10).

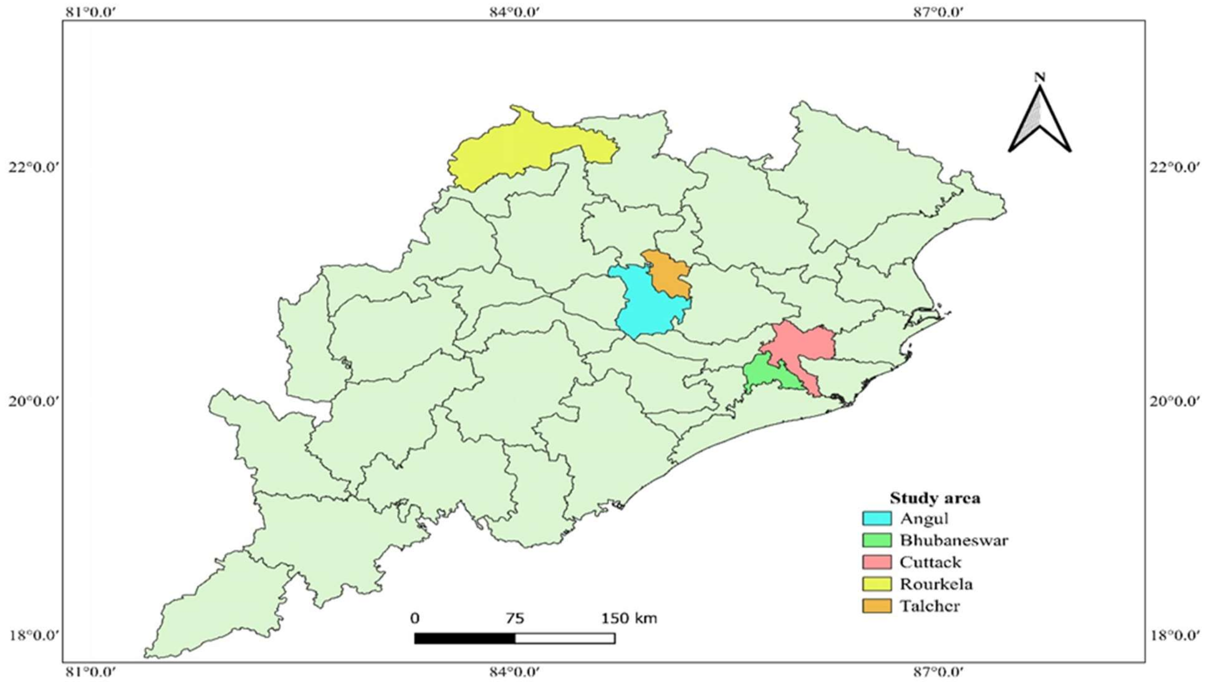

Figure 1: Study areas of Air pollutants in Odisha state

Shaprio-Wilk test

The Shaprio Wilk test is used to determine the normality of a data. Null Hypothesis(H_0) of the test is that the data follows a normal distribution and alternative hypothesis(H_1) is the data does not follow normal distribution.
The Shaprio-Wilk test statistics,

$$W = \frac{(\sum_{i=1}^{n} a_i x_{(i)})^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

Where, $x_{(i)}$ are the ordered of the sample values and a_i is the constant

Mann-Kendall Test

The Mann-Kendall (MK) test is a non-parametric trend analysis for locating the increasing and decreasing pattern in time series of the data. Instead than comparing the actual values of the sampled data, it compares the relative magnitudes of the data. Introduced by Mann (1945) and reworked by Kendell (1975) and The MK test is initially applied using the null hypothesis (H_0) of trend testing against the alternative hypothesis (H_1) of a monotonically increasing or decreasing trend, in which the observations x_i is arranged in time randomly. All following data values are contrasted with the data values evaluated as ordered time series. The statistic S is increased by one if a data value from a later period is higher than a data value from an earlier period. However, S is decreased by one if the data value from a later period is lower than a data value sampled earlier. (Da silva *et al.,* 2015). The final value of S is the sum of all these increments and decrements. Calculated as follows is the MK test statistic S:

$$S = \sum_{k=1}^{n=1} \sum_{j=k+1}^{n} sgn\,(x_j - x_k) \quad (1)$$

$$Sgn(x_j - x_k) = \begin{cases} -1 & if\ (x_j - x_k) < 0 \\ 0 & if\ (x_j - x_k) = 0 \\ +1 & if\ (x_j - x_k) > 0 \end{cases} \quad (2)$$

Where x_j and x_k are, respectively, the annual values in the years' j and k, j>k. If n 10, the Mann-Kendall test is used to compare the value of |S| directly to the theoretical distribution of S. If the absolute value of S equals or exceeds a given value $S_{\alpha/2}$, where $S_{\alpha/2}$ is the smallest S having the probability smaller than $\alpha/2$, H_0 is, at some level of probability, discarded in favour of H_1. S values that are positive or negative suggest an upward or downward trend. (Chaudhuri and Dutta, 2014). For n≥10, the statistic S is approximately normally distributed with the mean and variance as follows:

$$E(S) = 0$$

$$Var\,(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)\,(2t_p + 2)\right] \quad (3)$$

t_p is the total amount of data values in the p^{th} group, and q is the total number of tied groups. Calculating the standard test statistic Z is as follows:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(s)}} & ; if\ S > 0 \\ 0 & ; if\ S = 0 \\ \dfrac{S+1}{\sqrt{Var(s)}} & ; if\ S < 0 \end{cases} \quad (4)$$

The Z value is used to assess if a statistically significant trend exists. An upward (downward) trend is indicated by a positive (negative) Z value. H_0 is rejected if $|Z|>Z_{1-\alpha/2}$ when testing for either an upward or downward monotonic trend (a two-tailed test) at level of significance, where $Z_{1-\alpha/2}$ is derived from the common normal cumulative distribution tables. Equation 5 is used to calculate the Kendall's values.

$$\tau = 2\frac{S^*}{z(z-1)} \quad (5)$$

S* stands for Kendall's sum, which is calculated as S* = A-B, where A is the number of chances that the difference between x_b and x_a will be larger than zero and B is the number of chances that it will be less than zero. (Chattopadhyay *et al.,* 2012; Gowthaman *et al.,* 2022).

Sen's slope estimator test

In non-parametric data, this test, also known as the Theil-Sen slope test, is frequently used to calculate the strength of a trend that was discovered using the M-K test (Eymen and Köylü, 2018). This method, which is median-based and uses a linear model to assess the trend's slope, was created by Theil and Sen in (1950) and (1968), respectively. The variance of the residual is calculated using Equations 6 and 7 if there are m pollutant data points in the time series (X_1, X_2, X_3,... X_m) and X_a and X_b are the pollutant values at time instance a and b such that b > a.

$$T_i = \frac{X_b - X_a}{b-a} \quad for\ i = 1, 2, 3, \ldots \ldots \ldots m \quad (6)$$

Equation 7 is used to calculate the Sen's slope estimator, which is the median of all T_i values and is indicated as T_{med}. The sign of T_{med} indicates whether the data are trending upward or downward, and its numeral indicates how steep the trend is.

$$T_{med} = \begin{cases} T_{\frac{m+1}{2}} & if\ m = odd \\ \dfrac{T_{\frac{m}{2}} + T_{\frac{(m+2)}{2}}}{2} & if\ m = even \end{cases} \quad (7)$$

The M-K test's ability to predict pollution trends is dependent on the significance level α, and other significant levels may also indicate the presence of trends. Sen's slope estimator can therefore be used to determine the changing rates for contaminants that display no trend in the M-K Test.

Results and Discussion

The descriptive statistics for the variables under consideration are shown in Table 1. Prior to analysis, the data must undergo quality check because incorrect outliers can have a significant impact on trends. The measured variables, the limit of detection, the mean, and the standard deviations are all summarised in Table 1. If the data are from a normal distribution, it can be determined using the standardised skewness and kurtosis. The data demonstrated that skewness values varied from -

0.17 to 2.98 and kurtosis values ranged from -0.49 to 10.87, indicating data were from a population with a non-normal distribution (Brown, 2006).Both the Mann-Kendall test and the Sen's slope test are non-parametric tests. Shaprio Wilks test was applied to determine whether the data were normal. The findings are shown in Table 2, and the test shows that none of the time series data for air pollutants follow a normal distribution. As a result, the methodology used for the study is suitable.

Trend analysis using Mann-Kendall test

In this section of the study, time series data on pollutants from several districts of Odisha are estimated using the Mann-Kendall test and Sen's slope estimator, and its findings are examined. The six-year monthly data were used to calculate the Mann-Kendal S and Z statistics (2015-2021). Table 3 includes a Mann Kendall's test statistics and associated p-value are listed next to each test name and figure 2 shows the trend graph of different air pollutants for selected locations. P-values less than 0.05 are considered significant, and at these levels, the null hypothesis would be proven incorrect. The null hypothesis for this investigation is that there is no trend in the data that is currently available.The p-value is below the significant level for the obtained data of sulphur dioxide (SO_2) in the districts of Angul and Bhubaneswar, with positive (0.270) and negative (-0.224) Kendall's Tau values, respectively. This values indicates that increasing trend for Angul and decreasing trend for Bhubaneswar. The equivalent p-values for the remaining districts, Cuttack, Talcher, and Rourkela, are 0.280, 0.228, and 0.962, respectively, which are more than the significant valueof 0.05 and indicate that there is no trend in the data. The table 3 for the pollutant NO_2 indicates a trend with a positive orientation for the districts of Angul and Talcher

Table 1: Descriptive statistics of air pollutants

Variables	Locations	Min	Max	Mean	Variance	SD	Skewness	Kurtosis
SO2 (µg/m3)	Angul	7	23	11.7	4.62	2.15	1.54	7.93
	Bhubaneswar	2	7	3.21	1.01	1.00	1.43	2.76
	Cuttack	2	8	3.98	1.93	1.39	1.03	0.41
	Talcher	10	15	12.3	1.01	1.00	-0.078	0.267
	Rourkela	3	20	10.75	10.79	3.28	0.621	0.415
NO2 (µg/m3)	Angul	21	36	31.14	7.13	2.67	-0.92	1.35
	Bhubaneswar	13	40	22.55	31.91	5.64	1.27	1.12
	Cuttack	19	45	32.11	60.90	7.80	-0.21	-1.59
	Talcher	26	42	34	10.72	3.27	-0.183	-0.082
	Rourkela	6	24	16.13	9.58	3.09	-0.25	1.83
PM2.5 (µg/m3)	Angul	45	143	76.01	450.97	21.2	1.10	1.32
	Bhubaneswar	28	133	55.40	426.36	20.6	1.25	1.82
	Cuttack	26	207	70.82	816.84	28.5	2.19	-0.49
	Talcher	30	173	77.3	978.81	31.2	1.052	0.924
	Rourkela	40	223	80.25	897.61	29.9	2.98	10.87
PM10 (µg/m3)	Angul	57	124	93.71	285.50	16.8	-0.17	-0.99
	Bhubaneswar	45	137	90.10	632.94	25.1	0.06	-1.10
	Cuttack	49	167	88.29	694.62	26.3	0.55	7.44
	Talcher	45	153	98.6	562.02	23.7	-0.191	0.740
	Rourkela	51	158	106.2	526.30	22.9	-0.17	-0.01

Table 2: Results of Shaprio-Wilks test for normality

Locations	Angul		Cuttack		Bhubaneswar		Talcher		Rourkela	
Pollutants	Statistic	P	Statistic	P	Statistic	P	Statistic	P	Statistic	P
SO_2	0.87	<0.001	0.84	<0.001	0.79	<0.001	0.90	<0.001	0.95	0.008
NO_2	0.93	<0.001	0.87	<0.001	0.85	<0.001	0.96	0.02	0.94	0.002
PM10	0.96	0.025	0.94	0.001	0.96	0.012	0.97	0.012	0.97	0.02
PM2.5	0.91	<0.001	0.83	<0.001	0.84	<0.001	0.91	<0.001	0.67	<0.001

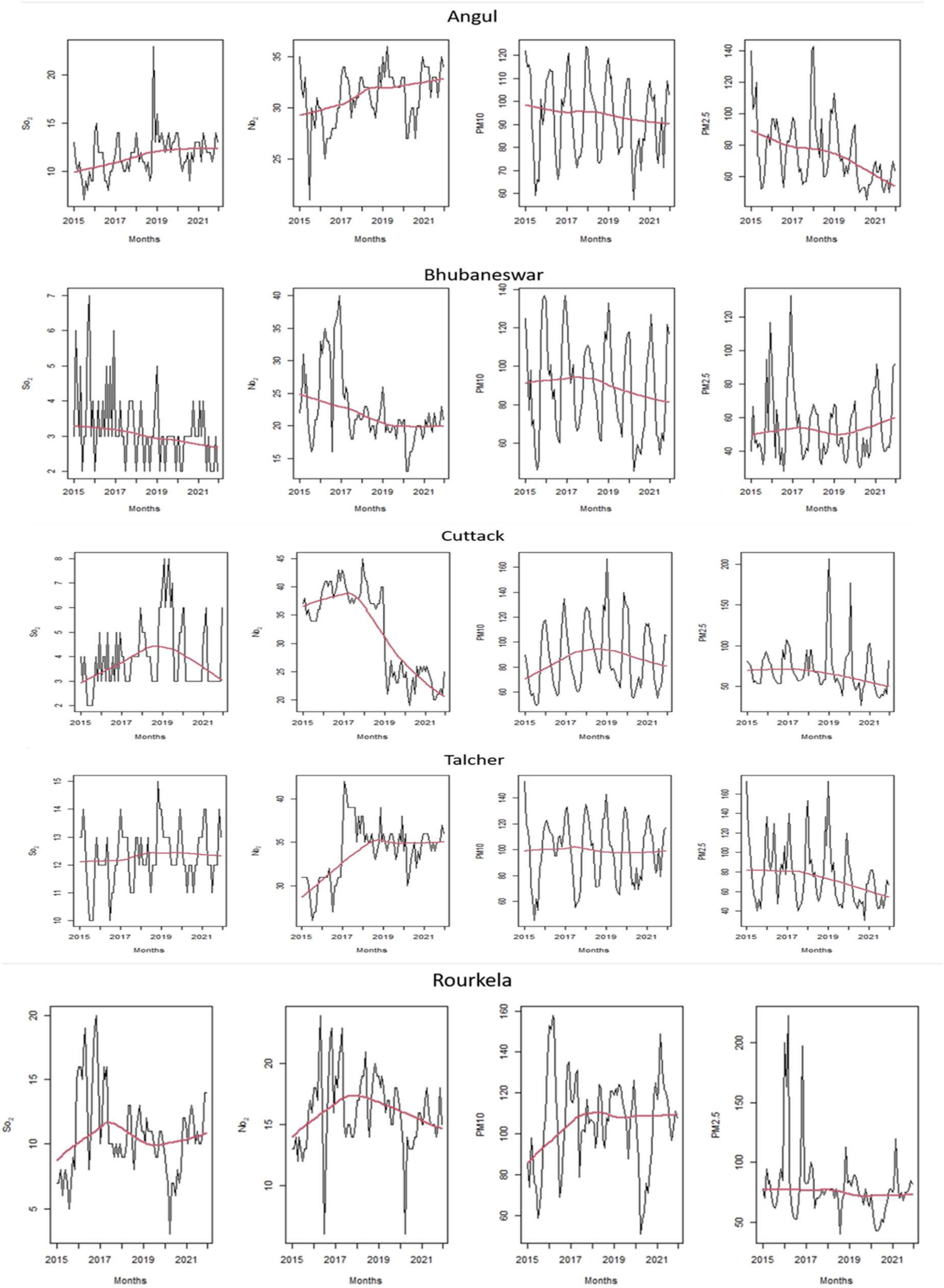

Figure 2: Trend graph of different air pollutants for the period from 2015 to 2021

and a trend with a negative orientation for the districts of Bhubaneswar and Cuttack. No trend is predicted for Rourkela due to the higher p value of 0.697. H_0 is rejected for the districts of Angul, Cuttack, and Talcher for particulate matter particle size up to 2.5 (PM2.5), demonstrating the existence of a trend with a negative orientation in the pollutant data. Due to higher p values of 0.232 and 0.062, no trend is estimated in the other two districts. Table 3's findings for PM10 show that for every district, p values are closer to the significant level of 0.05, and H_0 is accepted, demonstrating that there is no trend in the data.

Sen's slope estimation

The results of the Sen's slope test validate the M-K test findings, and the values of the Sen's Slope estimator are also reported in Table 3. Sen's slope values are also obtained for pollution data in which no trend exists. This is because the hypothesis in the M-K test is formed above the significant level, and there is a chance that a trend may exist and, therefore, that a trend slope may exist beyond. In the proposed study, significant level is kept at 5% for the findings calculation. The M-K test findings can be explained by the Sen's slope data shown in Table 3 that also show similar slope orientations. For the trends, the Sen's slope value of SO_2 for Angul displays a positive slope (0.02) and a negative slope (-0.01) for Bhubaneswar. The NO_2 slope estimator results for Bhubaneswar and Cuttack (-0.068 and -0.235) show a negative slope for the trends, whereas those for Angul and Talcher show positive slopes for the trends (0.04 and 0.053). In prior years, the Angul, Cuttack, and Talcher districts' PM2.5 slope estimate data showed a negative slope. The Mann-Kendall test for the PM10 data reveals no trend, and the Sen's slope estimator values predicted a positive slope for the districts of Cuttack and Rourkela with 0.083 and 0.100 respectively, and a negative slope for the districts of Angul, Bhubaneswar, and Talcher with -0.086, -0.154, and -0.027 respectively.

Table 3: Results of M-K and Sen's slope estimator test on different pollutants

Variables	Locations	Kendall's Tau	S	Z	Sen's Slope	Trend	P Value
SO_2 (µg/m^3)	Angul	0.270	943	3.69	0.02	↑ Trend	0.002
	Bhubaneswar	-0.224	-782	-3.35	-0.01	↓ Trend	<0.008
	Cuttack	0.075	264	1.078	0.001	No Trend	0.280
	Talcher	0.084	295	1.204	0.001	No Trend	0.228
	Rourkela	0.03	13	0.04	0.001	No Trend	0.962
NO_2 (µg/m^3)	Angul	0.288	1006	3.92	0.04	↑ Trend	<0.001
	Bhubaneswar	-0.304	-1062	-4.128	-0.068	↓ Trend	<0.001
	Cuttack	-0.479	-1671	-6.468	-0.235	↓ Trend	<0.009
	Talcher	0.251	878	3.424	0.053	↑ Trend	<0.001
	Rourkela	-0.02	-101	-0.38	0.001	No Trend	0.697
PM2.5 (µg/m^3)	Angul	-0.331	-1155	-4.46	-0.37	↓ Trend	<0.001
	Bhubaneswar	0.010	-310	0.139	0.001	No Trend	0.232
	Cuttack	-0.193	-676	-2.609	-0.230	↓ Trend	0.009
	Talcher	-0.225	-785	-3.03	-0.385	↓ Trend	0.002
	Rourkela	-0.138	-482	-1.861	-0.11	No Trend	0.062
PM10 (µg/m^3)	Angul	-0.089	-311	-1.198	-0.086	No Trend	0.231
	Bhubaneswar	-0.088	-310	-1.193	-0.154	No Trend	0.889
	Cuttack	0.057	199	0.765	0.083	No Trend	0.444
	Talcher	-0.021	-75	-0.285	-0.027	No Trend	0.774
	Rourkela	0.069	243	0.93	0.100	No Trend	0.349

The study's findings help in evaluating the levels of various pollutants in various districts of Odisha during the previous few years. In this period, the lower concentration values of SO_2& NO_2 are

2μg/m^3 and 6μg/m^3& the higher concentration values are 23μg/m^3& 45μg/m^3 respectively. Similarly, SO_2 and NO_2 concentration were found to be little higher in the township areas and industrial areas (Mohapatra and Biswal, 2014). The PM2.5 value ranged from 26μg/m^3 to 223μg/m^3 and PM10 value ranged from 45μg/m^3 to 158μg/m^3. Both PM2.5 and PM10 values were higher in Rourkela district followed by Cuttack. In all the other sampling station it was found that PM2.5 and PM10 values were nearly close or slightly exceeding the standard values set by the CPCB. But the SO_2 and NO_2 concentration were not in the permissible limit as stated by CPCB (NAAQS-2004) for the district of Angul, Bhubaneswar and Cuttack. The average AQI value gives us an idea that selected stations are moderately polluted but it is nearer to the range of heavy air polluted region. The SO_2 and NO_2 concentration for the district of Angul shows increasing trend and for the district of Bhubaneswar shows decreasing trend over the years. The concentration of PM2.5 shows decreasing trend for Angul, Cuttack and Talcher, and for remaining district it shows no trend. Similarly, PM10 values are shows no trend but still are very close to permissible limits. More control measures are needed for pollutants, especially for PM2.5 and nitrogen dioxide, according to the M-K test and Sen's slope estimator test shown in the table 3 (Pal *et al.,* 2018). Results indicate that nitrogen oxide levels in Talcher and Angul have

been rising in recent years. Odisha's PM2.5 and PM10 concentrations are above the annual permissible limits 40μg/m^{3}and 60μg/m^3, respectively (National Air Quality Index, 2014; Permissible threshold for pollutants, 2017). Since these are the primary pollutants, new restrictions are required, including improving road traffic conditions and limiting vehicular pollution through better vehicle types (Lenschow *et al.,* 2001). The studies mentioned above showed that there was no trend or a negative trend in the levels of PM10 and PM2.5 for any of the cities. The global lockdown brought on by COVID-19 has reduced air pollution and raised the Air Quality Index. One of the biggest issues in Cuttack and Bhubaneswar is the traffic. There are thousands of moving automobiles every day. Traffic is under tremendous pressure as a result. However, because of lockdown, this problem has been somewhat under control (Das *et al.,*2021). While ambient aerosol, including PM10, has a lowering trend globally, it has a significant negative impact in India (Dey *et al.,* 2012). Since the introduction of BSES VI environment standard automobiles, the Indian government has somewhat restrained the rise of traffic-related NO_2 and PM10 emissions (Bansal and Bandivadekar, 2013: Hilboll *et al.,* 2017), but the positive trend in the data still refers to the need for better strategies to combat such pollutants.

Conclusion

The present study used the Mann-Kendall test and Sen's Slope estimates methodologies to identify the monotonic trends in air quality variables between 2015 and 2021. The M-K test results show a trend in some pollution data across districts, and the Sen's Slope estimator test result determined the strength of the trends. It may be concluded that SO_2 and NO_2 were under the permissible limit for some districts, however PM2.5 and PM10 throughout the entire research area are close to or above the CPCB's permissible limit. In most places, PM2.5 and PM10 concentrations are observed to be greater in μg/m^3. Due to industrial activity, rising urbanisation, and vehicular traffic, Odisha's air quality has substantially declined. The air quality is significantly worsened by an excessive amount of pollution, which has detrimental effects on the exposed population.

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Conflict of interest

The authors declare that they have no conflict of interest.

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