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Air Pollution Trend Analysis Using Sen Estimator Method

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Abstract— Air pollution has been a serious and heavy environmental downside everywhere; thus several air quality management systems were initiated to watch and manage pollution rates around cities. The aim of this work is to give a statistical method for trend detection of air pollution data. In this paper some of the pollutants such as SO_2, NO_2, Suspended Particulate Matter (SPM) and Respirable Suspended Particulate Matter (RSPM) that causes pollution are discussed and statistical method to find their trends or pattern is proposed. For trend analysis air pollution data of Durg district for year 2010-2012 are taken. Trend analysis is divided into two phase : trend detection and trend estimation. Trend detection done using Mann-Kendall method and trend estimation is done using Sen estimator method. The proposed method is compared with Linear Regression method. Comparison is done on three basis . First comparison is done on basis of slope and intercept obtained by both methods second error and accuracy percentage for both methods are checked using Mean Absolute percentage Error (MAPE) and at last how both methods perform if outliers are present and absent in data . From this we conclude that Sen estimator gives same accuracy as Linear regression gives but Sen estimator method performs better even in presence of outliers. From result based on Sen estimator method we conclude that pollutants SO2 and Respirable Suspended Particulate Matter (RSPM) increases from year 2010-2012. Therefore, corrective measures should be taken to decrease their adverse effect.

Keywords— Mann-Kendall, MAPE(Mean Absolute Percentage Error), Sen estimator, SO_2 ,NO_2, Suspended particulate Matter (SPM), Respirable Suspended Particulate Matter(RSPM).

I. INTRODUCTION

Trend detection is a lively space of interest in air pollution and alternative natural statistic for quite three decades. It has been found that harmful emission of various pollutants in air affects seriously human health, agriculture and natural life. Inhaling such impure air also leads to or causes several chronic disorders and respiration related problems. For this purpose trend analysis of air pollution has been done. Trend detection in pollution time series is of sensible importance in analyzing the impacts of amendment numerous of varied pollutants within the various ecosystems of the earth. In this paper statistical method is adopted for detecting gradual trends in air pollution series over time. The aim of trend testing is to see if the values of a random variable is usually increasing or decreasing over a period of time.

Aim of identifying trend analysis of various pollutants is to decrease the adverse affect of pollution. In this paper a statistical method is used for identifying air pollution trend.

A. Time Series Data

A time series is an ordered set of real values that is defined as $X=[x_1,x_2,\ldots..,x_N]$ of N values where X_i denotes the value related to time slot i, $i<-T=\{t_1,t_2,\ldots.,t_N\}$ where T is domain of time [5]. Time series are series of observations of random variable that have been collected over some period of time.

Trend is a regular change in data over time and is one of the component of time series data In other words trend is finding the changes in time series data i.e. identifying whether time series data is increasing or decreasing. This amount of change or trend is usually calculated around some central value such as mean or median.

Air Pollution and Pollutants

Air pollution is introduction of unwanted particulates or other harmful materials in atmosphere either from anthropogenic or natural source that may cause diseases, other chronic diseases and damage human health, food crops or vegetation. Air pollution occurs when gases, dust particles, fumes or odors are introduced into atmosphere and distort the natural balance.

Pollutant is defined as unwanted substances that get mixed with land, air and water makes them dirty or not safe or suitable to use. Pollutants are components of pollution that can be either natural occurring contaminants or foreign contaminants. In simple words things that pollute the air are called as air pollutants

- **Sulphur Dioxide (SO_2) :** Sulphur dioxide is a highly reactive and colorless gas and is produced during combustion processes that took place at various industrial power plants. It also causes respiration disease when inhaled by human.
- **Nitrogen Dioxide (NO_2) :** Nitrogen dioxide is the most prominent air pollutant . It is a very reactive gas and are emitted from high temperature combustion, vehicle and industrial combustion.
- **Particulate Matter (PM):** Particulate matters (PM) also called as particle pollution are fine particles of solid or liquid suspended in gas. Particulate Matter (PM) whose aerodynamic diameter are larger than 2.5 micrometer but less than or equal to 10 micrometers are called as inhalable coarse particles or respirable suspended particulate matter (RSPM).

Various methods are given for finding trends. The simplest method of finding trend is called as moving average or simple moving average [14]. A number of moving average methods around 19 are given to smooth the data [14]. The simple moving average technique is further improved by introducing a new method called as Exponential Weighted moving average.

Mustapha.A (2013) does surface water quality trend detection of Jakara basin in Nigeria using non parametric test called as Sen's slope and Mann-Kendall test .Monthly Rainfall data from 2001-2010 are collected .This contains data about water quality parameter such as: dissolved oxygen (DO) , 5 day bio-chemical oxygen demand (BOD_5), chemical oxygen demand (COD) , ammonia-nitrogen (NH_3-NL) , nitrite (NO_3),dissolve solids (DS) and total solids (TS).[27]

Jain.S (2012) gives methods for trend analysis of rainfall and temperature data for India. According to this paper trend or temporal variation of annual rainfall, rainy days and temperature for basins of India is detected using Mann-Kendall, Regression and sen slope method. [4] He.Y et.al (2013) analyze the trend of natural illuminance levels in 14 Chinese cities by Mann-Kendall trend analysis method.[30] . Kurt.A et.al (2008) proposed an online neural network based forecasting system. This is a real time based forecasting method that forecasts the level of pollutants for next 3 days. In this a feed forward network is implemented with 7 input layers and 10 hidden layer and uses Levenberg–Marquardt optimization training function to update weights and bias values [8] . Olaniyi.S (2011) proposed a method for stock trend prediction using moving average and regression analysis. This paper predicts financial market prices in the banking sector of Nigerian economy using three banks as a case study.

II. DATA AND METHODOLOGY

A. Data collection

Air pollution data is collected from isbeid.gov.in. Data used in this paper is of Durg district of Chhattisgarh, consisting of year 2010-2012 on month basis. Data is from a station named Laghu udyog located in Durg district.

Air pollution data set contains 10 attributes namely year, state district, month, SO_2, NO_2, Suspended Particulate Matter (SPM), Respirable Suspended Particulate Matter (RSPM), location and source.

B. Data Preprocessing

Data preprocessing is a data mining technique that processes raw data into useable or understandable format by removing unused data. Data preprocessing includes data cleaning as a task.

Air pollution preprocessing is done by eliminating unused attributes such as district, location and source. Therefore, resulting database consist of year ,month,attributes , SO2, NO2, Suspended Particulate Matter (SPM), Respirable Suspended Particulate Matter (RSPM) attributes.

Next step in data preprocessing is that data is then grouped into Excel format.

Once data format is changed then statistical properties of air pollution data such as mean, median, maximum, and minimum values for each pollutant are calculated.

Outliers present in data is also identified or detected . Table 1 shows statistical properties of air pollution time series data .in this outlier is detected at year 2011 for NO2 pollutant. This outlier affects result of linear regression.

C. Trend Analysis.

In this paper trend analysis is conducted in 3 phase:

First phase is trend detection. Trend detection is conducted using Mann-Kendall Tau test. This test detects or checks presence of any increasing or decreasing trend in data set.

Second phase of trend analysis is called as trend estimation. Trend estimation is conducted using Sen Estimator method. Sen Estimator method estimates the magnitude of increasing or decreasing trend.

Third phase of trend detection method is called as trend representation. Trend representation is done using graphical form.

Phase 1: Trend Detection

Trend detection in time series is of great importance because using this test one can determine the values of random variables or time series values are generally increasing or decreasing.

In this paper for trend detection Mann-Kendall tau test is used.

Mann-Kendall Tau (τ) Test

Mann-Kendall test is a non-parametric statistical method that is applied on data set to determine if a series of observation of random variable is increasing or decreasing. This will detect presence of negative or positive trends in time series data set. This method is based on sign difference of random variables rather than their direct values therefore this method is less affected by outliers.

This method is also called as Kendall's Tau .Tau measures the strength of relationship between variable X and Y. In other words, Tau value tells about how X and Y are correlated.

Mann-Kendall Tau is calculated as:

$$\tau = \frac{S}{n(n-1)/2} \quad \text{.....(1)}$$

Where,

S=Mann- Kendall principle of statistic

n=No. of data pairs

Let $X_1, X_2, \ldots\ldots, X_n$ represents n data points and X_i, X_j represents data points at time i and j respectively such that (j>i) .Then Mann-Kendall principle of statistic (S) is calculated as:

$$S = \sum_{i=1}^{n-1} \sum_{j=k+1}^{n} sign(X_j - X_i) \quad (2)$$

Where,

$$sign(X_j - X_i) = \begin{cases} 1 & \text{if } (X_j - X_i) > 0 \\ 0 & \text{if } (X_j - X_i) = 0 \\ -1 & \text{if } (X_i - X_j) < 0 \end{cases} \quad (3)$$

If $\tau = 0$ Then no trend exist. Whereas,

If $\tau \neq 0$ Then trend exist.

If value of τ is negative then X and Y are negatively correlated and Y decreases more than increasing.

Similarly, if τ is positive then X and Y are positively correlated and Y increases more.[25]

Phase 2: Trend Estimation

Mann-Kendall method used for trend detection only give information about increasing or decreasing trend but does not give magnitude of that positive (negative) trend.

Therefore, for trend estimation sen slope estimator method is used.

Sen Estimator method

Sen Estimator is a simple method to find true slope (change per unit time) of Mann-Kendall's tau test. This will give magnitude of increasing or decreasing trend. This method is applied when there exist linear relationship.

Let $X_1, X_2, \ldots\ldots, X_n$ represents n data points and X_i, X_j represents data points at time I and j respectively such that (j>i)

The slopes (Ti) for all data pairs are calculated as

$$T_i = \frac{(x_j - x_k)}{(j-k)} \quad (4)$$

Where,

i=1, 2…..n

The median of these n values of Ti gives Sen Slope which is calculated as:

$$Q = \begin{cases} T_{\frac{N+1}{2}} & \text{If N is Odd} \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}} \right) & \text{If N is Even} \end{cases} \quad (5)$$

Where Q is median value of T_i and is called as Sen slope.

Equation for linear trend is of the form

$$Y = Q*t + B \quad (6)$$

Where,

Q is Sen slope ,B is the intercept and T is time.

The intercept (constant) value is calculated as

$$B = Median\left[X_i - (Q \times t_i)\right] \quad (7)$$

Phase 3: Trend Representation

Once trend is detected and estimated the next step is representing this trend. Trend line along with actual pollutant data is represented graphically in GUI form using software MatlabR2012a.

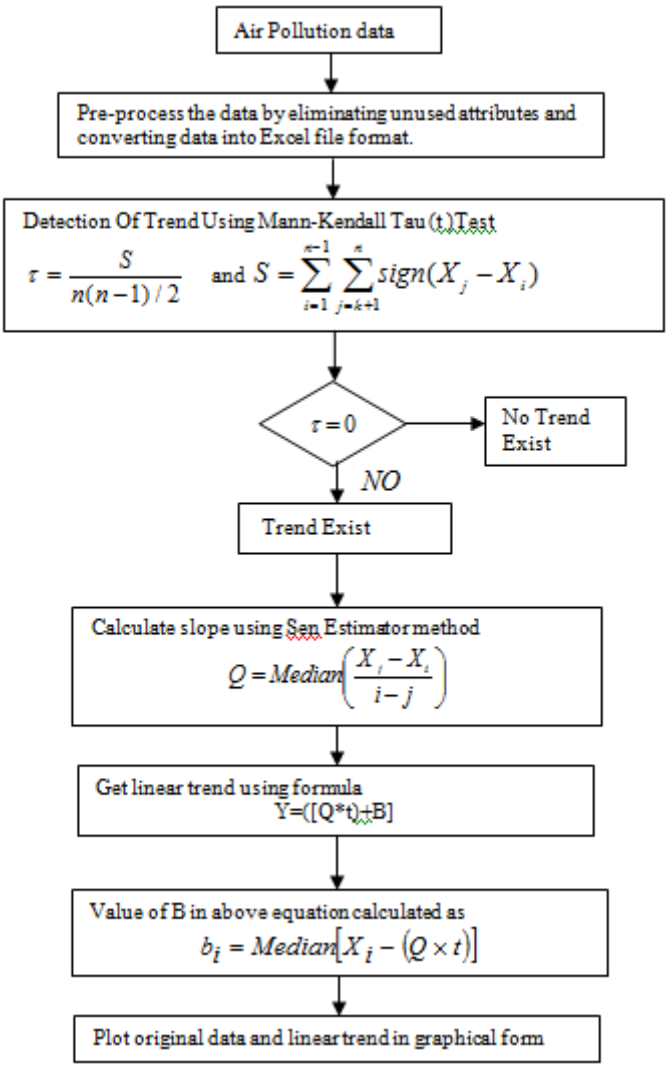

Fig 1 Flow Chart for Proposed Methodology

Table 1: Descriptive Statistic of Variable Under Study

YEAR	POLLUTANT	MAX	MIN	MEAN	MEDIAN	OUTLIERS
2010	SO_2 $(\mu g/m^3)$	13.41	10.48	11.795	11.81	0
2010	NO_2 $(\mu g/m^3)$	31.880	30.43	30.9892	30.8850	0
2010	SPM $(\mu g/m^3)$	293.19	247.86	278.4325	285.54	0
2010	RSPM $(\mu g/m^3)$	170.12	144.66	161.4767	162.1250	0
2011	SO_2 $(\mu g/m^3)$	13.15	10.58	11.5717	11.535	0
2011	NO_2 $(\mu g/m^3)$	32.52	30	30.8117	30.75	1
2011	SPM $(\mu g/m^3)$	291.86	251.3	276.337	277.885	0
2011	RSPM $(\mu g/m^3)$	166	148.17	156.995	157.47	0
2012	SO_2 $(\mu g/m^3)$	11.79	10.57	11.1325	11.01	0
2012	NO_2 $(\mu g/m^3)$	31.8	29.63	30.7167	30.77	0
2012	SPM $(\mu g/m^3)$	292.3	267.15	281.818	285.24	0
2012	RSPM $(\mu g/m^3)$	170.31	142.16	159.446	159.275	0

Table 2: Result of Mann-Kendall and Sen Slope Estimator for Year 2010-2012

YEAR	POLLUTANT	MANN-KENDALL'S TEST		SEN ESTIMATOR METHOD	
		S- VALUE	TAU VALUE	Q VALUE	INTERCEPT VALUE
2010	SO_2	-27	-0.412226	-0.2094	13.2231
2010	NO_2	-10	-0.1515	-0.0351	30.9934
2010	SPM	-38	-0.5757	-2.0670	295.997
2010	RSPM	4	0.0606	0.0876	164.862
2011	SO_2	-28	-0.42424	-0.164375	12.6741
2011	NO_2	-2	-0.0303	-0.00933	30.7873
2011	SPM	-16	-0.2424	-1.48167	286.398
2011	RSPM	10	0.15151	0.428667	155.112
2012	SO_2	-24	-0.36364	-0.0735	11.491
2012	NO_2	-12	-0.184637	-0.06667	31.1233
2012	SPM	-32	-0.48485	-1.73167	293.905
2012	RSPM	10	0.15151	0.655139	156.851

III. RESULT AND DISCUSSION

Table 1 represents the statistical properties of air pollution data from 2010-2012. It contains the minimum, maximum, mean, median value for each pollutant. Detection of outliers is also important as these outliers seriously affect trends.

Table 2 summarizes result of Mann-Kendall and sen slope estimator. The Mann-Kendall method computes Mann-Kendall tau value and Mann-Kendall principle Statistic (S) value. Sen Estimator method computes slope and intercept value for the linear equation for different pollutants from year 2010-2012.

In Figure:2 trend for 4 pollutant namely SO_2, NO_2, SPM, RSPM are shown for year 2010.From statistic shown in table II and Fig 1 SO_2 shows a decreasing (negative) trend (S = -27 and Tau = -0.412226).Sen slope also shows decreasing trend (Q= -0.2094 ,B =13.2231) .

For NO_2 also a negative trend is shown(S=-10 ,tau=-0.1515).Sen slope shows decrease in magnitude of Q(Q=-0.0351, B=30.9934) .

For SPM a downward trend is shown(S=-38 ,tau= -0.5757).Sen slope shows decrease in magnitude of Q(Q= -2.0670, B=295.997) .

For pollutant RSPM the principle of statistic (S) value is 4 tau value is 0.0606 and Sen slope method gives 0.0876 as slope and 164.862 as intercept.

Figure:3 gives trend for 4 pollutant namely SO_2, NO_2, SPM, RSPM are shown for year 2011.

For pollutant SO2 both Mann-Kendall and Sen estimator both shows negative trend (S=-28,tau=-0.42424, Q=-0.164375,B=12.6741).

Pollutant NO_2 also shows negative trend (S=--2 ,tau= -0.0303).Sen slope shows decrease in magnitude of Q(Q=-0.0351, B=30.9934) .

For SPM a downward trend is shown(S=--16 ,tau= -0.2424).Sen slope shows decrease in magnitude of Q(Q= -1.48167, B=286.398) .

For pollutant RSPM the principle of statistic (S) value is 10 tau value is 0.15151 and Sen slope method gives 0.428667 as slope and 155.112 as intercept.

Figure: 4 Shows trend for year 2012 of 4 different pollutants. In this pollutant SO_2, NO_2, SPM shows decreasing trend both by Mann-Kendall and Sen Estimator method and increasing trend in RSPM pollutant. For pollutant SO2 (S=-24, tau=-0.36364, Q=-0.0735, B=11.491). For NO2 (S=-12, tau= -0.18 4637, Q=-0.06667, B=31.1233). For SPM (S=-32, tau= -0.48485, Q= -1.73167, B= 293.905).

Whereas, pollutant RSPM signifies increasing trend both by Mann-Kendall and Sen Estimator method (S= 10, tau= 0.15151, Q= 0.655139, B= 156.851).

IV. PRECSENCE OF OUTLIERS

This section shows how both models perform in presence and in absence of outliers. Outliers are data are the observation points that are distant from other observation.

From table 1 an outlier is detected for pollutant NO_2 for year 2011.

Table 3 Slope and Intercept Value in Presence of Outliers

YEAR	POLLUTANT	SEN ESTIMATOR METHOD		LINEAR REGRESSION	
		SLOPE	INTERCEPT	SLOPE	INTERCEPT
2011	NO_2	-0.00933	30.7873	0.0684	30.671

Table 4 Slope and Intercept in Absence of Outliers

YEAR	POLLUTANT	SEN ESTIMATOR METHOD		LINEAR REGRESSION	
		SLOPE	INTERCEPT	SLOPE	INTERCEPT
2011	NO_2	-0.035	30.885	-0.004273	30.682

Table 3 and table 4 shows how trend in proposed method and linear regression varies in presence and in absence of outliers.

From above two tables we can conclude that Sen Estimator estimates negative trend in both case i.e. in presence and in absence of outliers. Whereas, linear regression shows positive trend in presence of outliers but in absence of outlier it shows drastic change with negative trend. This occurs because linear regression is a mean based method and get affected by a single outlier whereas Sen Estimator is a median based method and does not get affected even in presence of outliers. From this we conclude that Sen Estimator method is a better method for those time series data that contains outliers in their data.

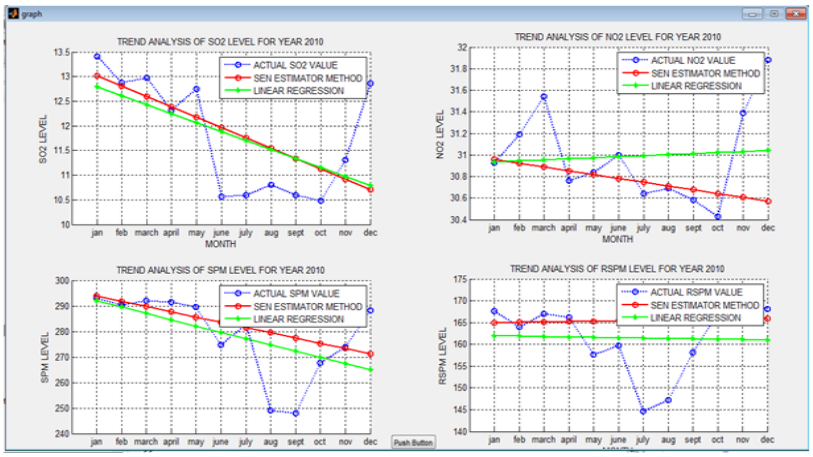

Fig 2 :GUI Showing Trend Analysis of Pollutant For Year 2010

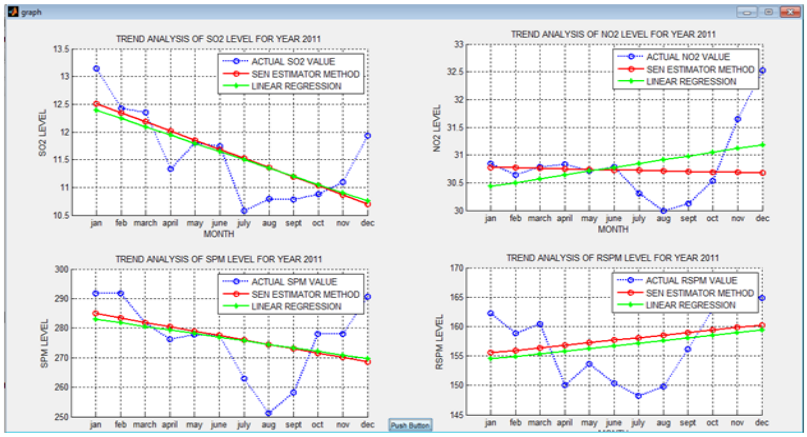

Fig 3 :GUI Showing Trend analysis of Pollutant For Year 2011

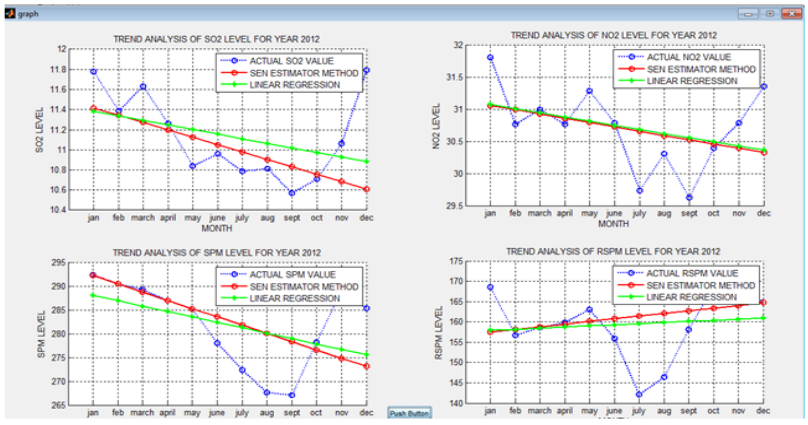

Fig 4 Showing trend analysis for year 2012

V. ERROR AND ACCURACY CHECK

Error calculation is one of the ways to evaluate the performance of an estimator.

Error is difference between actual and estimated value. It is calculated using formula:

$$e_i = (y_i - \bar{y}) \qquad (8)$$

Where, y_i is actual value and

$\overline{y_i}$ is estimated value

In this paper Mean Absolute Percentage Error (MAPE) is used for error detection and accuracy measure.

$$MAPE = \frac{1}{N}\left(\sum_{i=1}^{N}\frac{|e_i|}{|y_i|}\right).100\% \qquad (9)$$

Here, N= Total no. of data pairs

$|e_i|$ gives only magnitude of error without considering sign of error value.

Mean Absolute Percentage Error gives result in percentage form. Accuracy is also calculated based on MAPE value. Accuracy is calculated as:

$$Accuracy = (100 - MAPE)\% \qquad (10)$$

From table 5 error and accuracy check method it s concluded that Sen estimator method with Mann-Kendall method can be preferable for linear trend detection than Linear Regression.

Table 5 Showing Error and Accuracy Percentage For Both Methods

YEAR	POLLUTANT	SEN ESTIMATOR		LINEAR REGRESSION	
		MAPE (%)	ACCURACY (%)	MAPE (%)	ACCURACY (%)
2010	SO_2	6.34327	93.6567	6.56803	93.432
2010	NO_2	1.0105	98.9895	1.09326	98.9067
2010	SPM	3.40882	96.5912	3.54677	96.4532
2010	RSPM	4.06438	95.9356	4.21569	95.7843
2011	SO_2	3.80761	96.1924	3.88157	96.1184
2011	NO_2	1.34738	98.6526	1.52594	98.4741
2011	SPM	3.33162	96.6684	3.35839	96.6416
2011	RSPM	3.60422	96.3958	3.58294	96.4171
2012	SO_2	2.45598	97.54	2.74087	97.2591
2012	NO_2	1.43686	98.5631	1.43921	98.5608
2012	SPM	2.02155	97.9785	2.24441	97.7556
2012	RSPM	3.90984	96.0902	4.03674	95.9633

VI. CONCLUSION

On basis of result and analysis we can conclude that though Sen estimator and linear regression both gives almost same accuracy but sen estimator method performs better even in presence of outliers . Therefore Sen estimator method can be used as an alternative to linear regression. From result it is concluded that for year 2010, 2011 and 2012 there is decrease in trend of pollutant SO_2, NO_2, and SPM. From this study it is also determined that for year 2010, 2011 and 2012 the pollutant RSPM shows an increasing trend. Therefore, corrective measures should be taken to decrease the adverse effect of these pollutants.

VII. FURTHER WORK

Sen estimator method is used for trend estimation of air pollution data and already tested on hydrological time series data. Therefore, this statistical based method may be used for detecting trends of environmental time series data and is open for research. In proposed model air pollutants level are correlated with respect to time by taking year (month wise) as a period. But in future other variables may be taken into account like traffic flow or traffic volume. In future comparison of proposed model with linear regression may be done by taking skewness as a factor.

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