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Trend Analysis of River Gomti Using Mann Kendall Test and Sen's Slope Estimates

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Abstract

This study is focused on emerging trend of water quality parameters of Gomti River. Study utilized 6 water quality parameter (pH, BOD, nitrate, electrical conductivity, DO and total coliform) data of a long period from 2008 to 2016 obtained from 2 monitoring station at Lucknow. Monotonous increase or decrease in trend of water quality parameter has been determined by Mann Kendall non parametric test and Sen's slope estimator. This method requires very few or no assumption regarding data distribution and it also reduces the effect of outliers and heterogeneity of variance. Skewness and kurtosis were also determined, values of these statistics came under the range of +2 to -2, which indicates that data lies under normal distribution population. Result showed increasing trend in the level of pH, BOD, nitrate, EC and total coliform while decreasing trend in the level of DO. Persistent increase in BOD and alongside decrease in DO is a matter of concern. It was observed that second monitoring station which is at Lucknow downstream is much more polluted than upstream station which may be due to discharge of untreated sewage directly.

KEY WORDS: *Mann Kendall test, Sen's slope estimator, Trend analysis, Gomti River*

1. INTRODUCTION

Gomti River originates from Fulhaar Jheel in Pilibhit district (U.P.) and meets River Ganga in Varanasi. It extends to 940 km and its catchment area is about 22735 square km. Stream gathers enormous amount of domestic and industrial pollutants as it courses through most popular cities (Lucknow, Sitapur, Varanasi, Lakhimpur, Jaunpur, Sultanpur etc.) of Uttar Pradesh (Parveen, 2016). River receive untreated raw municipal waste, domestic sewage and industrial effluents through its 5 major tributaries and more than 40 drains (UPPCB, 2013). The imprudent disposal of waste effluent may pollute water as a translocation of toxic elements and may pose adverse effects on the ecosystem of Gomti River.

The objective of this paper is to identify and detect the water quality trend of Gomti River at Lucknow over a period of long time from 2008 to 2016 using Mann Kendall test and Sen's slope estimator.

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Trend detection are very important to identify temporal and spatial changes in long term water quality data. The existence of trend in water quality time series data can be detected with the help of statistics. There are two statistical methods for analysing time series data, distinguished by whether or not they make assumptions regarding data distribution. Parametric methods assume that data belongs to normal distribution population and also variance is uniform either between groups or across the range. While non-parametric methods are suitable for non-normal continuous data. Besides that it can be used for data that has outliers or that has been measured imprecisely. Among all the non-parametric test Mann Kendall (MK) test is popularly used because of its simplicity and minimal data assumption of the test (Mustapha, 2013). This method is based on rank of observation instead of their measured values so that it is less sensitive to outliers (Carlos, 2016).

2. METHOD AND MATERIALS

Dataset of water quality parameter from 2008 to 2016 were acquired from Central Pollution Control Board (CPCB, ENVIS). Total of 6 water quality parameter were used for analysis: pH, biochemical oxygen demand (BOD), dissolved oxygen (DO), electrical conductivity (EC), nitrate, total coliform. The water quality data gathered in two collecting station along Gomti River. First station (S-1) is near water intake at Lucknow upstream, and the second one (S-2) is at Lucknow downstream.

Non parametric statistical analysis were done to detect positive or negative trend in water quality time series dataset. Non parametric test reduce the effect of outliers and heterogeneity of variance because it is directly depends on sign differences. This method requires very few or no assumption regarding data distribution. So that it can be used for dataset referring to irregular sampling interval and missing data (Mustapha, 2013).

Among all non-parametric statistical analyses Mann Kendall test is popularly used for detecting monotonous increase or decrease in trend. This test does not necessitate that the data be typically linear or normally distributed but there should not be any autocorrelation. Null hypothesis satisfies for this test in no trend condition and alternate hypothesis satisfies if there is an upward or downward trend (Onoz, 2002).

For time series data in the form of $x_1, x_2, x_3 \ldots, x_n$

$$\text{MK statistic } (S) = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sign}(x_j - x_i)$$

Where S is the MK test value, x_i and x_j are the sequential data values and x, j and n are the length of data.

Variance of S is calculated by

$$\text{Variance} = \frac{1}{18}\left[n(n-1)(2n-5) - \sum_{t} f_t (f_t-1)(2f_t+5)\right]$$

Where t differs over the arrangement of tied ranks and f_t is the frequency that the rank t appears. MK test uses the z-statistics. Z-statistics is the normalized test statistics and Se is the square root of variance.

- If S>0 then time series observations will be greater than that appears prior in the time series. This shows an increasing trend in the time series data. In this condition, $z = \frac{(S-1)}{S_e}$
- If S<0 then time series observations will be smaller than that appears prior in the time series. A very low value indicates decreasing trend. In this condition, $z = \frac{(S+1)}{S_e}$
- If S=0 then z=0, this is no trend condition.

For linear trend analysis, regression method is applied by using least square. But this method is only used when there are no significant correlation and the method is very sensitive to outliers. Solution of this come up with non-parametric analysis, where a skewed and heteroskedastic data can be analysed robustly by Sen's slope estimator. The method is very effective and insensitive to outliers or unit error in data. Sen's slope estimator is the median of N values of Q non parametric estimates (Sen, 1968).

$$Q = \text{median}\left[\frac{x_j - x_i}{j - i};\quad i < j\right]$$

At 1-α significance level upper limit (β_U) and lower limit (β_L) are determined. Where N is the no. of pair of time series data (x_i, x_j).

$\beta_L = x_{(N-k)/2}$

$\beta_U = x_{(N+k)/2+1}$

3. RESULT AND DISCUSSION

In non-parametric analysis outliers can widely affect the trend of variables. So that quality control should be done before analysing raw dataset. Table 1 represents descriptive statistical values of variable i.e. range of data, standard deviation, variance, Skewness and kurtosis of Lucknow upstream (S-1) and table 2 presents the same for Lucknow downstream (S-2). Table 3 and table 4 shows result of the Mann Kendall test and Sen's slope estimator. If statistical values of variable lies outside the range of -2 to +2 then it represents significant deviation of data from normal distribution population. Skewness and kurtosis of variables under study are ranging from 0.24 to -1.47 for S-1 and from 1.86 to -1.5 for S-2 which indicates that data came from normal distribution. Mann Kendall statistics (S and Z) were worked out on the basis of yearly data from 2008 to 2016. Mann Kendall test were applied with 90% confidence level ($p<0.1$), p values are the least level of significance at which null hypothesis would be rejected and alternate hypothesis will be accepted. Null hypothesis stands for no trend condition.

Trend analysis of pH of station S-1 indicates monotonous increasing trend (Z=1.89, Q=0.03). Significant trend (Fig 1) is noticeable, increase in magnitude of pH over this period is 1.89. Trend analysis of DO also shows monotonous trend (Z=1.58, Q=0.10) (Fig 2). DO is a very important parameter of water quality. It affects physical, chemical and biological activities of water. The increase in magnitude of dissolved oxygen content is 1.58 mg/l over the time period.

Table 1

Discriptive statistics of the variable (S-1)

PARAMETER	UNIT	MIN	MAX	MEAN	SD	VARIANCE	SKEWNESS	KURTOSIS
pH		7.80	8.10	7.95	0.10	0.01	0.50	-0.01
BOD	(mg/l)	2.90	3.60	3.25	0.26	0.07	-0.25	-1.47
DO	(mg/l)	6.80	8.00	7.40	0.44	0.19	-0.41	-1.15
Total Coliform	(MPN/100ml)	2900.00	4442.00	3671.00	495.00	245024.75	-0.06	-0.30
Nitrate	(mg/l)	0.73	3.60	2.17	0.97	0.93	0.51	-0.64
EC	(µmhos/cm)	307.20	475.00	391.10	52.56	2762.34	-0.72	0.24

Table 2

Discriptive statistics of variable (S-2)

PARAMETER	UNIT	MIN	MAX	MEAN	SD	VARIANCE	SKEWNESS	KURTOSIS
pH		7.4	7.70	7.55	0.11	0.01	0.55	-0.55
BOD	(mg/l)	7.5	11.50	9.50	1.12	1.27	-0.16	1.04
DO	(mg/l)	2.2	3.60	2.90	0.47	0.22	1.16	0.40
Total Coliform	(MPN/100ml)	103367	170000.00	136683.50	20893.33	436531090.00	1.31	1.86
Nitrate	(mg/l)	1.16	5.00	3.08	1.48	2.18	-0.69	-1.50
EC	(µmhos/cm)	427	828.50	627.75	135.28	18300.61	1.30	0.82

Table 3

LUCKNOW U/S (S-1)

PARAMETER	UNIT	S	Z	Q	p value	Cv	Trend ≥90% confidence level
pH		18	1.89	0.03	0.06	0.10	INCRESING
BOD	(mg/l)	18	1.79	0.07	0.07	0.08	INCRESING
DO	(mg/l)	16	1.58	0.10	0.11	0.06	INCRESING
Total Coliform	(MPN/100ml)	16	1.56	90.63	0.12	0.14	INCRESING
Nitrate	(mg/l)	22	2.19	0.30	0.03	0.50	INCRESING
EC	(µmhos/cm)	-8	-0.73	-8.24	0.47	0.13	NO TREND

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Table 4							
LUCKNOW D/S (S-2)							
PARAMETER	**UNIT**	**S**	**Z**	**Q**	**p value**	**Cv**	**Trend ≥90% confidence level**
pH		27	2.84	0.03	0.00	0.01	INCRESING
BOD	(mg/l)	19	1.89	0.35	0.06	0.13	INCRESING
DO	(mg/l)	-16	-1.58	-0.10	0.11	0.19	DECRESING
Total Coliform	(MPN/100ml)	14	1.36	4888.83	0.18	0.17	INCRESING
Nitrate	(mg/l)	20	1.98	0.44	0.05	0.44	INCRESING
EC	(µmhos/cm)	20	1.98	41.56	0.05	0.24	INCRESING

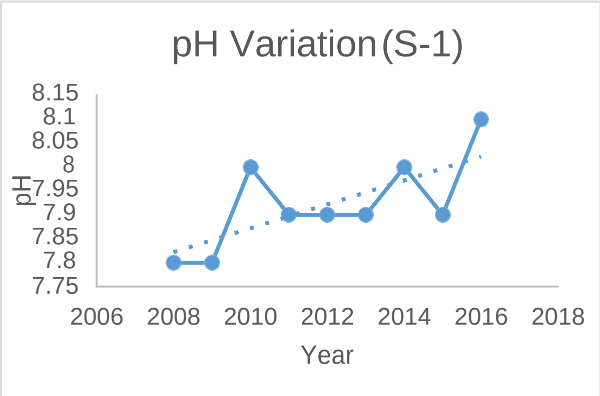

Fig 1. pH trend analysis

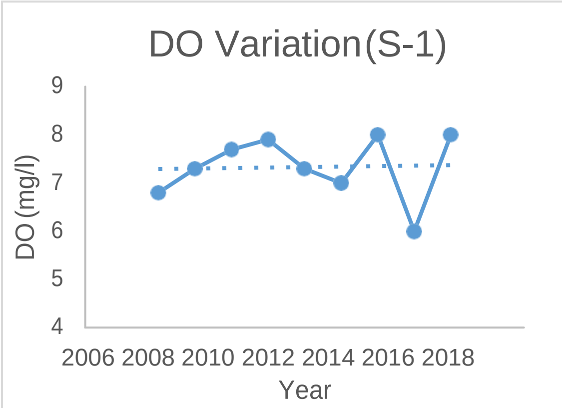

Fig 2. DO trend analysis

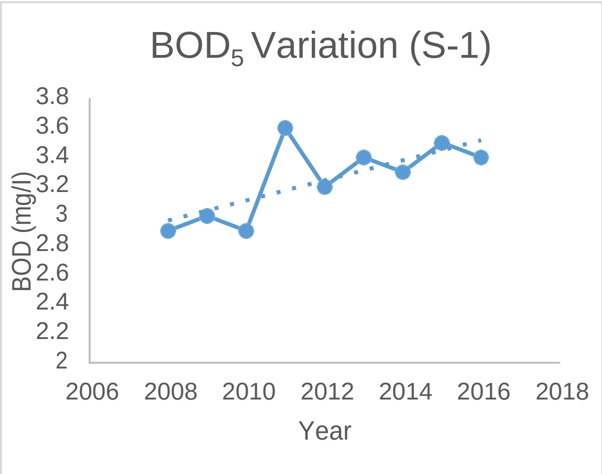

Fig 3. BOD_5 trend analysis

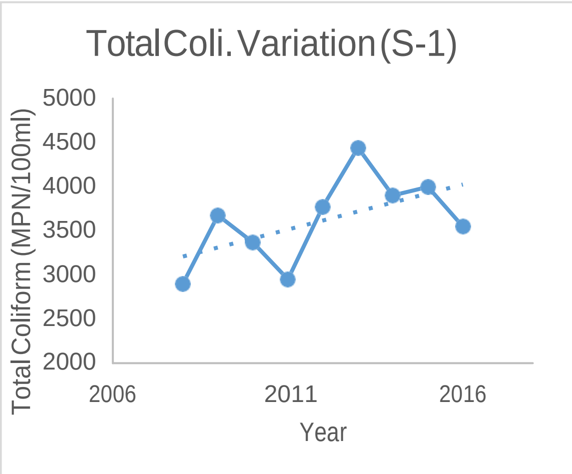

Fig 4. Total coliform trend analysis

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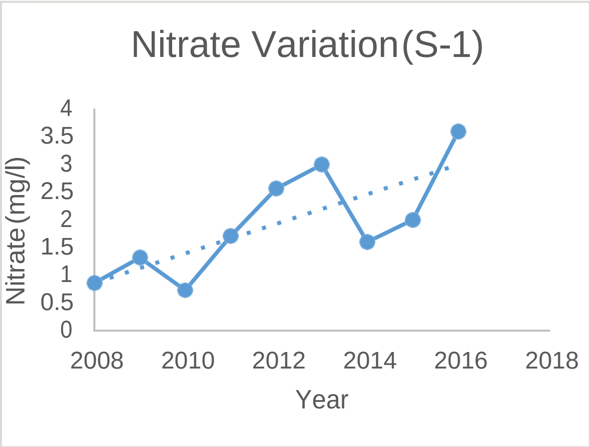


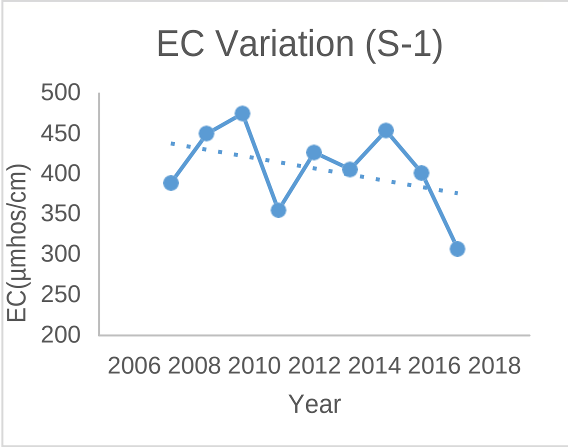
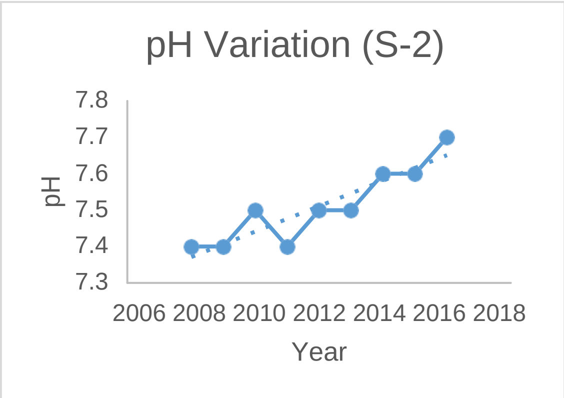


Fig 5. Nitrate trend analysis

Fig 6. EC trend analysis

The Mann Kendall test and Sen's slope method demonstrated a positive trend in yearly value of BOD_5 (Z=1.79, Q=0.07), Total coliform (Z=1.56, Q=90.63) and nitrate (Z=2.19, Q=0.3). (Fig.3, 4, and 5) while there were no significant trend found in EC (Z = -0.73, Q = -0.8) (Fig6). Mann Kendall test and Sen's slope estimator indicates a steep slope in the magnitude of these variables with 90% significance level. As table 3 revealed that there is annual increase of 1.79mg/l, 1.56mg/l and 2.19 mg/l of BOD_5, Total coliform and nitrate respectively.



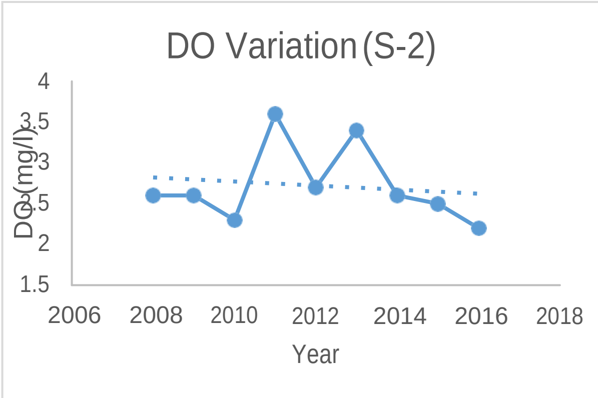
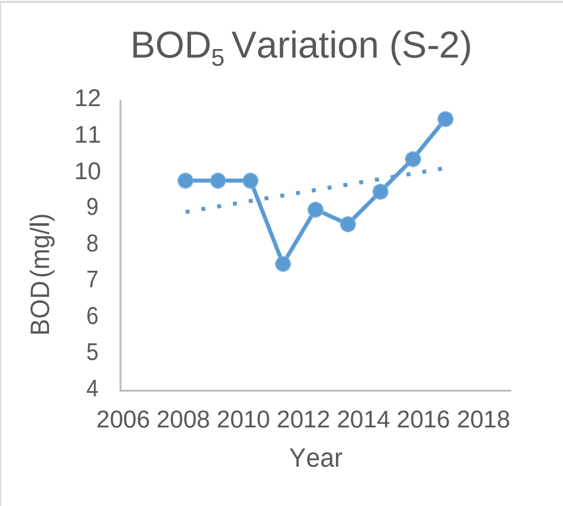


Fig 7.pH trend analysis

Fig 8. DO trend analysis



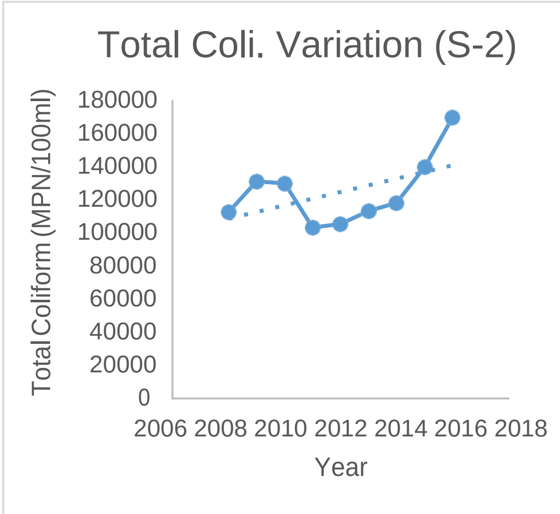
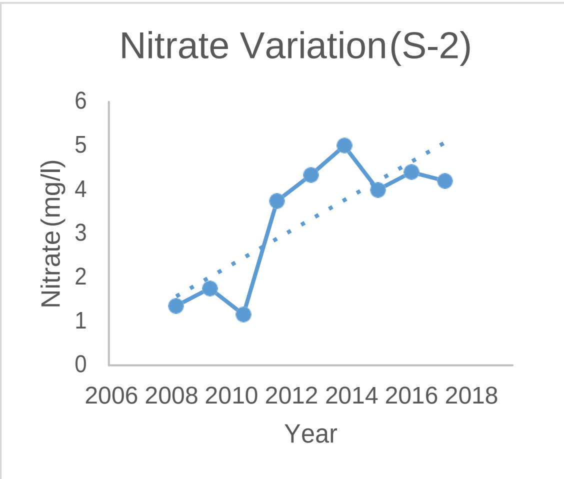
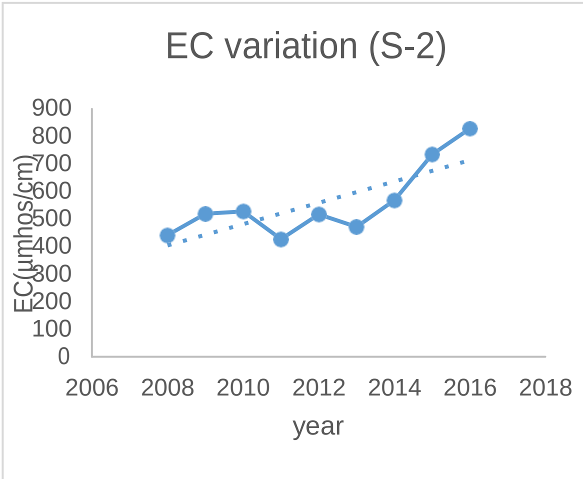


Fig 9. BOD_5 trend analysis

Fig 10. Total coliform trend analysis





. Fig 11. Nitrate trend analysis

Fig 12. EC trend analysis

Mann Kendall test has revealed a positive warning trend for pH (Z=2.84, Q=0.03), BOD_5 (Z=1.89, Q=0.35), Total coliform (Z=1.36, Q= 4888.83), nitrate (Z=1.98, Q=0.44) and EC (Z=a.98, Q=41.56) for Lucknow downstream (S-2).

Trend analysis of DO of Lucknow downstream (S-2) over 2008 to 2016 indicates a monotonous decreasing trend (Z= -1.58, Q= =0.10). Decrease in magnitude of DO over this period is 1.58 mg/l. While comprising water quality data of two station (S-1 and S-2), it is found that dissolved oxygen is much more depleted in S-2 (negative trend). This is because of enormous discharge of raw and untreated sewage which dumped directly into Gomti River. The quantity of domestic sewage and industrial waste produced in Lucknow is about 325 million litres per day (MLD) according UPPCB, 2013. At present there is only one treatment plant located at Gaughat having capacity of 42 MLD, rest of the sewage directly discharged into Gomti River.

4. CONCLUSION

Study determined monotonous increase or decrease in trend of water quality data over a period of 2008- 2016. Mann Kendall test and Sen's slope estimator were used for analysing water quality dataset and trend depiction. Result revealed in this paper indicates positive trend in pH, BOD_5, EC, nitrate and total coliform while negative trend in DO content. Depletion trend of oxygen is a matter of concern for Lucknow downstream area. DO level in S-2 ranges from 3.4 to 2.2 which is very low for the survival of water bodies also. If this monotonous decrease in DO sustained, then it will increase the amount of anthropogenic activities on water bodies. Gomti River were highly polluted in downstream of Lucknow having stagnated pollutant which results highly turbid and pungent water.

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