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Research Article

SPATIAL AND TEMPORAL ANALYSIS OF RAINFALL TREND FOR 30 DISTRICTS OF A COASTAL STATE (ODISHA) OF INDIA

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ABSTRACT

In the recent years the important scientific challenge faced by researchers worldwide is to have a better understanding about climate change at a regional scale. However, for all the regions the changes are unequal and have localized intensity. Therefore it should be quantified at a local scale. Precipitation is one of the important climatic variables responsible for climate change and required to be studied thoroughly. Odisha state is situated in east coast of India and agriculture plays a vital role in the state's economy which is greatly dependent on rainfall. Any change in rainfall pattern due to climate change can adversely affect the agricultural production. Therefore in the current study, an attempt has been made to observe the spatial and temporal rainfall variability and trend over a period of 110 years (1901-2010) at regional scale for the state of Odisha. For examining the monotonic trend direction and magnitude of change over time, the statistical trend analysis techniques namely Mann-Kendall test and Sen's slope estimator test were used. To determine the possible change points in the rainfall time series, Standard Normal Homogeneity test (SNHT) and Mann-Whitney-Pettitt (MWP) test were conducted. Inverse Distance Weighted (IDW) interpolation technique was applied in ArcGIS background for detection of spatial variation of rainfall on annual and seasonal basis in different districts of the state. The results of the analysis indicate that the annual rainfall was decreasing in northern region and extreme west region of Odisha with a maximum decrease (-1.425 mm/year) at Nuapada district, while highest decrease in monsoon rainfall (-1.25 mm/year) was found at district Sundargarh. In district Jagatsinghpur highest increase in rainfall was noticed in annual and monsoon season with maximum values 2.205 mm/year and 1.327 mm/year respectively, where significant change in annual rainfall was observed in the year 1961. Variation in rainfall was observed at different spatial scales of districts. This study gives district wise information on rainfall trend on long term basis and the impact of climate change in different parts of Odisha which will be helpful for a water resources manager in the planning and management of water resources for sustainable development.

Keywords: *Rainfall, Trend Analysis, Mann-Kendall (MK) Test and Sen's Estimator*

INTRODUCTION

Rainfall variation will be one of the important factors for determination of overall impacts of climate change. Systematic and Instant attention should be given towards the variation of rainfall since it affects the food production and availability of fresh water (Dore, 2005). Cruz *et al.*, (2007) reported that change in the rainfall pattern has considerable impact on water and agriculture sector of Asia Pacific region. The extreme events like floods, draughts are frequently occurring as a result of growth in population, increased urbanization and increased intensity of rainfall. Therefore worldwide several studies have been conducted regarding the analysis of spatial and temporal variations in rainfall to observe the effect of climate change. According to the report of Intergovernmental Panel on Climate change (IPCC, 2007) the seasonal, annual and spatial variation in precipitation trends were observed during past decades in all over Asia. It has been observed that precipitation has increased with in 10˚N to 30˚N for few decades from the year 1900 onwards and a decrease has noticed after 1970. A decreasing rainfall trend was noticed in the tropical areas from 10˚N to 10˚S. whereas the tropical and sub-tropical regions were facing increased draughts due to decrease in precipitation since 1970. Increasing summer rainfall was found in eastern Australia during 1950s and the trends were consistent for few decades after initial observation (Nicholls and Lavery, 1992). Savelieva *et al.*, (2000) and Peterson *et al.*, (2002) reported that the annual mean precipitation was decreasing in Russia. Seasonal and spatial differences in rainfall trend were observed on Canadian Prairies (Akinremi *et al.,* 2001). The variation in rainfall was studied for southern Spain by using 500 year time series data and a significant variation in rainfall on decadal to centennial time scales was noticed (Rodrigo *et al.,* 2000). Shi *et al.*, (2002) examined and found an increasing trend in annual mean precipitation in western China. Whereas a decreasing trend in rainfall was observed in north-east and north China (Hu *et al.*, 2003; Zhai and Pan, 2003). A rise in precipitation was found in North-east part of Brazil (Silva, 2004). Bruns *et al.,* (2007) detected raising rainfall trend in New York of USA. No significant trend in precipitation time series was noticed over Nepal (Ichiyanagi *et al.,* 2007). The long-term rainfall trend analysis on seasonal scale over a period (1920-2004) was done for Maxico and a rise in rainfall was noticed (Gonzalez *et al.,* 2008).

For assessing the spatial and temporal variation of rainfall in India, several studies were conducted. Parthasarathy and Dhar (1975) reported that the rainfall over India from 1931 to 1960 was increased. Whereas a decreasing trend was noticed from second half of 1960s (Kothyari and Singh, 1996). Lal (2001) observed the random fluctuation in precipitation in India over the century with no systematic change on annual and seasonal scale. The variability of rainfall was observed in India both on spatial and temporal scales (Sahai *et al.*, 2003; Pattanaik, 2005). A significant rising trend of extreme rain events in India was noticed during monsoon period from 1951 to 2000 (Goswami *et al.*, 2006). Basistha *et al.,* (2009) conducted a study on rainfall variability for Himalayan region of India and indicated that 1964 was the most probable year of change point in annual and monsoon rainfall. In India during (1871-2005) annual and monsoon rainfall were decreased, whereas increase was noticed in pre-monsoon, post-monsoon and winter seasons (Kumar *et al.*, 2009). Joshi and Pandey (2011) conducted the trend and spectral analysis of rainfall over India for a longer period (1901-2000) and reported that no significant trend was discernable during the last 10 decades. The analysis of rainfall variability was also carried out for different sub-divisions of India. Guhathakurta and Rajeevan (2008) applied linear trend analysis for observing the long-term rainfall trend in different sub-divisions of India. The statistical rainfall trend analysis on spatial and temporal scales for 45 districts of Madhya Pradesh, India was conducted and 1978 was found as most probable year of change in annual precipitation (Duhan and Pandey, 2013). Pingale *et al.,* (2014) studied the spatial and temporal variation of extreme rainfall and temperature for arid and semi arid state of Rajasthan, India in 33 urban centres by using the non-parametric test called Mann-Kendall test. Khare *et al.,* (2014) analysed the temporal trend of climatic parameters in Barinallah catchment over Himalayan region of India and concluded that positive insignificant rainfall trend was observed on monthly basis except October and December months. Spatio-temporal rainfall analysis over a maritime state Kerala, India was conducted for a better understanding of the rainfall variability in the state (Nair *et al.,* 2014). The daily monsoon rainfall in state of Odisha was varying spatially during 1980-1999 dividing it into five homogeneous regions (Mahapatra *et al.*, 2003). The summer monsoon rainfall over Odisha was studied and found that in most parts of the state the variation of seasonal rainfall was more during 1980-1999 than that of during 1901-1990 (Mahapatra and Mohanty, 2006). Patra *et al.*, (2012) studied the temporal variation of monthly, seasonal, annual rainfall over Odisha in twentieth century for a longer period (1871-2006) by using both parametric and non-parametric tests and concluded that annual and monsoon rainfall was decreasing insignificantly, where as post monsoon rainfall trend was rising over the state. All the above studies show the rainfall trend analysis in different parts of the world, in India and in various parts of India as well as in Odisha. However the information and analysis of rainfall trend both in temporal and spatial scales on monthly, seasonal and annual basis for every districts of Odisha state is limited. Agriculture being the main livelihood of the people of Odisha and is primarily dependent on rainfall, requires the detail information about the rainfall variation at district level. Therefore in this study an attempt has been made to find the long-term variability of rainfall both temporally and spatially over 30 districts of state Odisha for having a better understanding of climate change, rainfall variation, water resources management, disaster preparedness and flood control measures. The popular statistical technique Mann-Kendall test, Sen's slope estimation test and IDW interpolation technique were used for this study.

Study Area

The study area selected here is state Odisha which is situated along the east coast of India and has a coverage of 1,55,842 Sq.Km. with 480 Km. long coastline. The areal extension of this state is from 17˚ 48’ to 22˚34’ North latitude and 81˚24’ to 87˚29’ East longitude. The area covered by it is about 5.4% of the total geographical area of India. This state is administratively divided into 30 districts and surrounded by many states namely Jharkhand to the north, Andhra Pradesh to the south, Chhattisgarh to west, west Bengal to northeast and Bay of Bengal to the east side as shown in Figure 1. The study area is benefitted by a number of major and minor river systems such as Mahanadi, Brahmani, Baitarani, Indravati etc. as the major ones. Odisha is primarily an agriculture based state. Agriculture is the lifeline of the state’s economy and 2/3rd of the population of it is dependent on agriculture. Agriculture contributes about 15% of Gross State Domestic Product. Therefore for socio-economic development of the state, growth in agriculture sector is imperative. The major crops produced in Odisha are rice, pulses, oil seeds, jute, sugarcane, coconut etc. Climatically, the region is tropical in nature and is characterized by high temperature, medium to high rainfall, high humidity and short and mild winters. The average annual rainfall occurring here is 1452 mm distributed over 69 rainy days. South-west monsoon contributes a major part of about 81.2% of annual rainfall in 53-57 days during June-September and is varying spatially from about 1200 mm. in south coastal plain to about 1700 mm. in northern plateau. The mean annual temperature of the state is 26.89˚C with average annual maximum and minimum of 32.56˚C and 21.30˚C respectively. The temperature in Odisha rises to very high in the months April and May . Warm is occurring throughout the year in the western districts with maximum temperature lies between 40-46˚C. Whereas the climate in the coastal districts are highly humid and sticky. Due to tropical monsoon hydrology and change in climatic variables, the state is facing floods, draughts and cyclones in almost every year with different intensity which is adversely affecting the agricultural production.

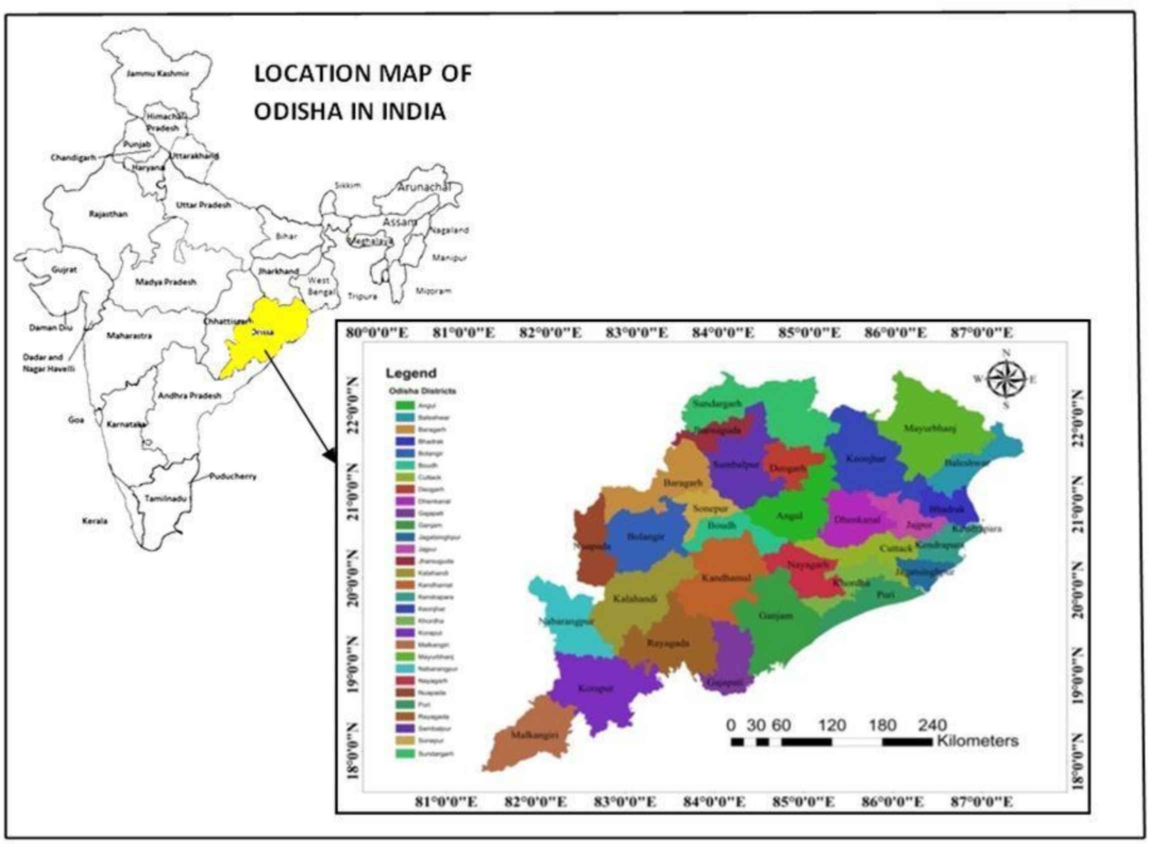

Figure 1: Location map of districts of Odisha

MATERIALS AND METHODS

Data and Methodology

The long term monthly rainfall data over a period of 110 years (1901-2010) of 30 stations were obtained from India Meteorological Department (IMD) website (http://www.indiawaterportal.org/metdata). The location map of Odisha with its districts is shown in Figure 1. The rainfall trend analysis was conducted for all the districts of Odisha on monthly, seasonal (pre-monsoon from March to May, monsoon from June to September, post-monsoon from October to November and winter from December to February) and annual basis. Pre-whitening method was used for eliminating the influence of serial correlation on Mann-Kendall test in trend detection studies of hydrological time series (Von and Navarra, 1995; Yue *et al.*, 2002). Pre-whitening method was adopted by Zhang *et al.*, (2000) and Hamilton *et al.*, (2001) in the trend analysis of Canadian temperature and rainfall data to eliminate the serial correlation effect on MK test. Mondal *et al.*, (2014) pre-whitened the rainfall and temperature data series of entire India for removing the impact of correlation on the result of MK test.

Many parametric and non-parametric methods can be applied for long-term rainfall trend analysis. In case of a parametric test the data should be followed to a particular distribution. While in a non-parametric trend analysis, the time series data used should be independent and allows the outliers present in the data (Lanzante, 1996).

The MK test can handle influence of extremes and missing values (Mishra *et al.*, 2009; Deni *et al.*, 2010). In the present study one of the most popular non-parametric tests called Mann-Kendall test (Mann, 1945; Kendall, 1975) was adopted for monotonic trend detection in rainfall time series. Xu *et al.*, (2003) stated that MK test is better than parametric test for monotonic trend analysis. Then Sen's slope estimator test was used for determining the magnitude of the trend (Sen 1968). Tabari *et al.*, (2011) indicated that MK test and Sen's slope estimator test are the most suitable methods for hydrological and meteorological trend detection.

Homogeneity test was applied to the rainfall data series at 5% level of significance by Standard Normal Homogeneity Test (SNHT) (Alexandersson, 1986; Alexandersson and Moberg, 1997) and Mann-Whitney-Pettitt (MWP) test (Pettitt, 1979) for knowing the homogeneity of the series and finding the break point in rainfall data series. The series was found as homogeneous according to SNHT test, as the critical value T_0 for 110 samples at 95% confidence level was 9.255 (Khaliq and Ouarda, 2007).

In Table 1 Ho and Ha stand for homogeneous and heterogeneous series. Change percentage was computed for 110 years of rainfall (Yue and Hashino, 2003). The spatial distribution of rainfall was analysed using the Inverse Distance Weighted (IDW) interpolation method. Pingale *et al.*, (2014) mentioned that IDW interpolation technique is an effective method and having the assumption that the variables at a point to be predicted are similar to the values in the nearby observation stations.

RESULTS AND DISCUSSION

The detailed trend analysis of rainfall during the period 1901-2010 on monthly, seasonal and annual basis was carried out in the current study by using the Mann-Kendall test and Sen's slope estimator for 30 districts of Odisha state. Percentage change in annual and seasonal rainfall was also determined to show the change in trend.

Inverse Distance Weighted (IDW) interpolation technique has been used for detecting the spatial distribution of rainfall over Odisha. The increasing, decreasing trend with the significance level and no trend for rainfall are represented in figures with different symbols.

Change Point Detection and Serial Correlation

Table 1 below shows break point in rainfall trend during 1901-2010 (110 years) over each districts of Odisha. The change points obtained for rainfall are quite variable but the most probable break point found was year 1961 as observed in four districts. For reducing the influence of serial correlation in the rainfall data series on MK test, pre-whitening test was applied before conducting the MK test.

Table 1: Results of Mann-Whitney-Pettitt (MWP) test and Standard Normal Homogeneity (SNHT) test for rainfall during 1901-2010

Station	Pettitt's test				SNHT test			
	k	t	Probability	Trend	T_0	t	Probability	Trend
Angul	322	1914	0.937	H_o	2.283	2009	0.87	H_o
Baleswar	848	1983	0.051	H_o	10.9	1985	0.023	H_a
Bargarh	868	1947	0.046	H_a	7.06	1947	0.149	H_o
Baudh	408	1948	0.634	H_o	2.157	1978	0.886	H_o
Bhadrak	552	1983	0.276	H_o	5.561	1985	0.307	H_o
Bolangir	872	1961	0.046	H_a	5.689	2005	0.292	H_o
Cuttack	836	1988	0.061	H_0	32.431	2004	<0.0001	H_a
Debagarh	864	1948	0.05	H_o	8.944	1994	0.08	H_o
Dhenkanala	370	1914	0.851	H_o	3.032	2004	0.726	H_o
Gajapati	690	1974	0.174	H_o	14.341	2003	0.005	H_a
Ganjam	530	1924	0.462	H_o	9.789	2004	0.062	H_o
Jagatsinghpur	1068	1983	0.006	H_a	22.221	2004	0.000	H_a
Jajapur	634	1985	0.251	H_o	5.891	2004	0.251	H_o
Jharsuguda	940	1949	0.023	H_a	8.259	1991	0.095	H_o
Kalahandi	498	1961	0.531	H_o	12.178	2005	0.013	H_a
Khandamala	706	2002	0.156	H_o	39.958	2004	<0.0001	H_a
Kendrapara	586	1983	0.340	H_o	4.297	1985	0.494	H_o
Kendujhar	350	1989	0.892	H_o	12.884	2004	0.031	H_a
Khurda	628	1984	0.271	H_o	10.017	2005	0.053	H_o
Koraput	628	2002	0.270	H_o	35.385	2003	0.020	H_a
Malkanagiri	842	1924	0.058	H_o	26.338	2003	0.001	H_a
Mayurbhanja	566	1989	0.379	H_o	10.343	2004	0.036	H_a
Nawarangapur	746	1961	0.059	H_o	5.508	1961	0.281	H_o
Nayagarh	820	1988	0.068	H_o	25.186	2004	<0.0001	H_a
Nuapada	1110	1961	0.003	H_a	10.791	1961	0.026	H_a
Puri	884	1985	0.039	H_a	26.755	2004	0.000	H_a
Rayagada	458	1924	0.632	H_o	3.400	2005	0.649	H_o
Sambalpur	716	1949	0.147	H_o	4.962	2009	0.400	H_o
Sonapur	628	1948	0.265	H_o	10.773	2005	0.071	H_o
Sundargarh	1006	1949	0.014	H_a	9.467	1991	0.065	H_o

Rainfall Trend Analysis (Monthly, Annual and Seasonal)

The spatial distribution of rainfall trend on seasonal (pre-monsoon, monsoon, post-monsoon & winter) and annual basis with symbolic representation of positive significant, positive non-significant, negative significant, negative non-significant and no trend over 30 districts of Odisha are shown in Figure-2 (a-e). Table 2 (Appendix-2) shows the value of Mann-Kendall test statistic (Z), Magnitude of Sen's slope (β) and percentage change of rainfall at seasonal and annual temporal scales for all the districts of Odisha. Further the trend of annual and seasonal rainfall (1901-2010) in entire Odisha by linear regression method is given in Figure 3. On temporal scale insignificant decline trend in annual and monsoon rainfall was observed. The pre-monsoon and post-monsoon rainfall was also showing decreasing trend. While the winter rainfall trend was increasing over the period 1901-2010 over Odisha. Many significant variations in rainfall trend were observed in the study area. A wide variation of change rate was also found at different places.

Significant decrease in rainfall was observed in the month February in most of the districts. The decrease in rainfall and change percentage at 5% level of significance in month February are: Angul (-0.124 mm/year and -51.69%), Bolangir (-2.37 mm/year and -47.93%), Dhenkanal (-0.105 mm/year and -

41.25%), Kalahandi (-0.049 mm/year and 49%), Kandhamal (-0.072 mm/year and -46.59%), Keonjhar (-0.183 mm/year and -57.51%), Malkangiri (-0.011 mm/year and -15.12%), Mayurbhanj (-0.187 mm/year and -58.77%) and Sambalpur (-0.118 mm/year and -59%).

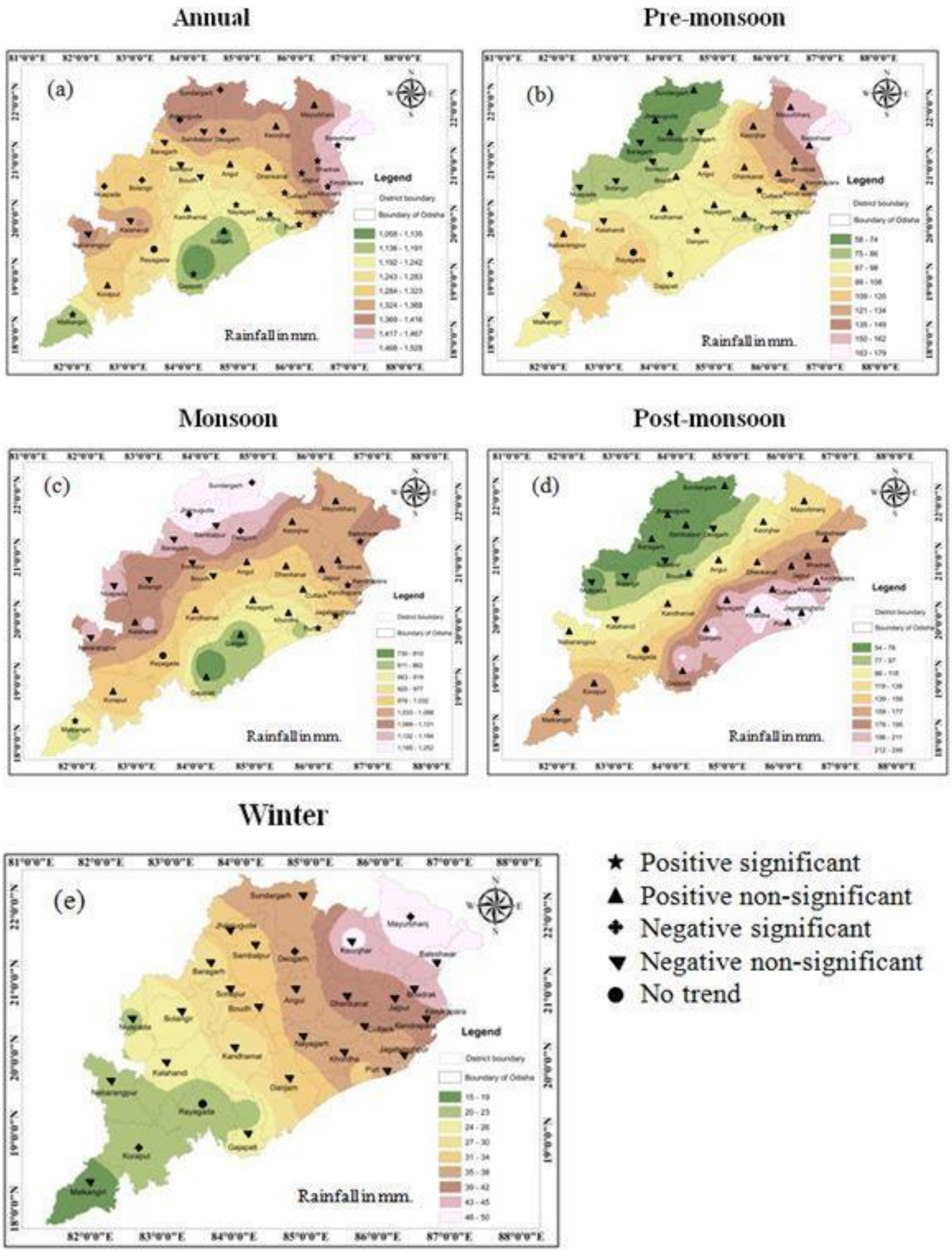

Figure 2(a-e): Spatial distribution of annual and seasonal rainfall with significance level over 110 years (1901-2010)

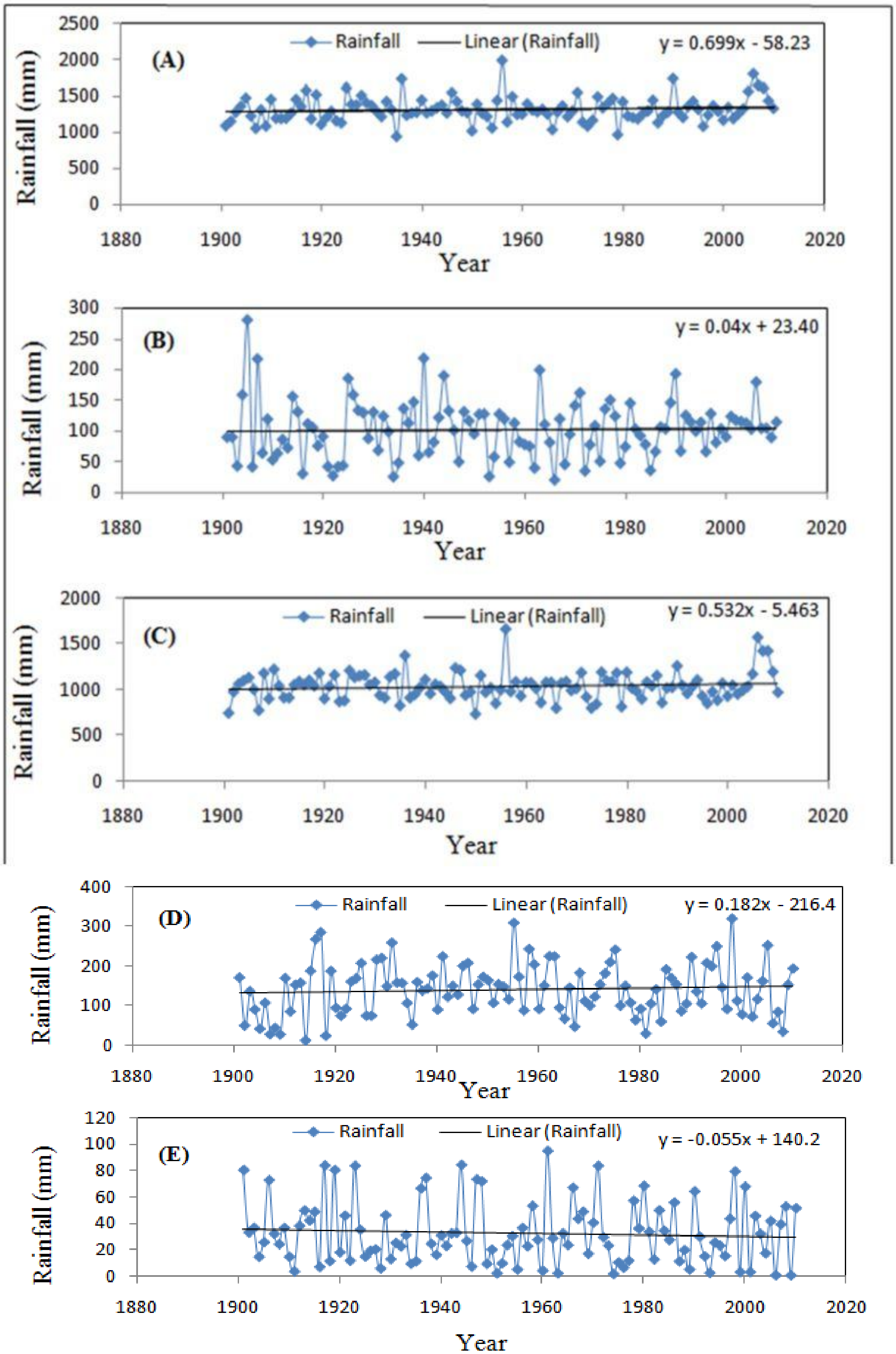

Figure 3: Trend of rainfall in entire Odisha (1901-2010) by linear regression method (A)- Annual, (B)- Pre-monsoon, (C)- Monsoon, (D)- Post-monsoon and (E)- Winter

The distribution of average monsoon rainfall for 110 years with respect to the average annual rainfall in percentage is graphically represented in Fig. 4 for 30 stations. This distribution indicates that the around 80% of annual rainfall is contributed from monsoon rainfall in Odisha. Therefore while determining the rainfall trend or quantifying the impacts of climate changes the contribution in other seasons are insignificantly considered. The monsoon rainfall variation and annual variation of rainfall mostly coincides with each other (Figure 2). The annual average rainfall in Odisha from 1901 to 2010 is 1308 mm. and monsoon average is 1033 mm. In the northern, western and north-western districts like Deogarh, Jharsuguda, sambalpur, Sonapur, Sundargarh, Nabarangpur, Nuapada, Kalahandi, Baudh, Bolangir and Bargarh the monsoon rainfall exhibits more than 80% of annual rainfall. Therefore in these areas the any variation in monsoon rainfall will affect the agriculture production.

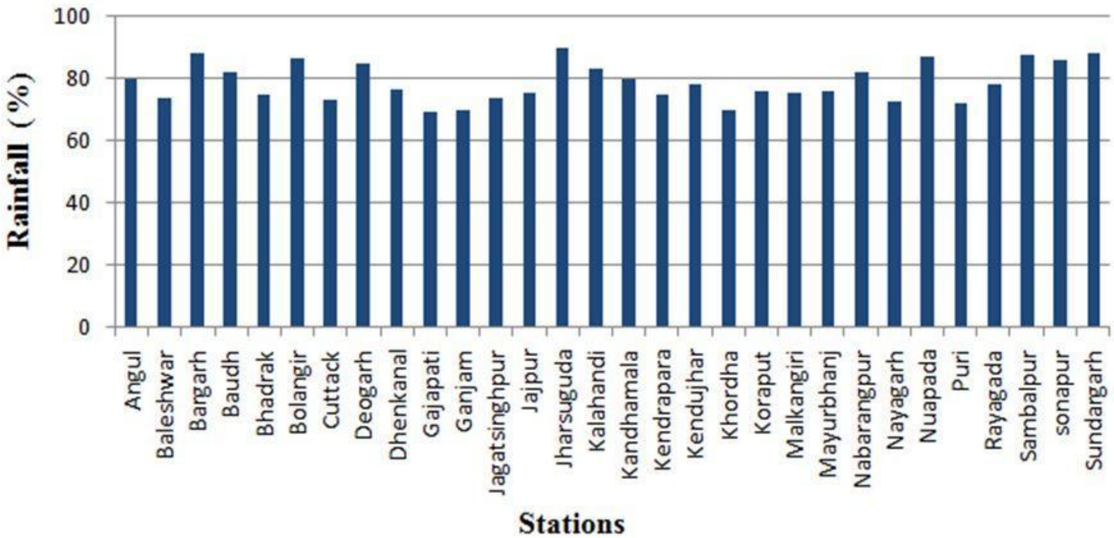

Figure 4: Average monsoon rainfall distribution (%) with respect to average annual rainfall (1901-2010) at various stations

Conclusion

In the present study, the variability of rainfall (1901-2010) on monthly, seasonal and annual basis were analysed for 30 districts of Odisha State. For the analysis part, the Mann-Kendall test and Sen's slope estimation test were applied for trend detection, Mann-Whitney-Pettitt test was used for identification of possible break points in rainfall (110 years) and change in percentage was calculated in terms of percentage change over mean value. Linear regression method was applied for detecting the rainfall and temperature trend of entire Odisha. Further the spatial variation of rainfall on annual and seasonal scales was determined by the Inverse-Distance-Weighted (IDW) technique using ArcGIS 10.2.2. Both increasing and decreasing trends in annual rainfall were observed in the districts of Odisha State. The annual rainfall trend varies from 2.205 mm/year in Jagatsinghpur to -1.425 mm/year in Nuapara. Significant decrease in annual rainfall was noticed in Balangir, Jharsuguda, Deogarh, Nuapada and Sundargarh with a maximum value of decreasing slope and change percentage (-1.425 mm/year and -11.95%) in Nuapara, while in monsoon rainfall, a significant decrease was observed in Deogarh, Jharsuguda and Sundargarh with highest values (-1.25 mm/year and -11.09%) in Sundargarh. Significant positive trend was mainly observed in the eastern districts (Jagatsinghpur being the highest with 2.205 mm/year and 18.1%) and non-significant mostly in north and west (Sundargarh, Jharsuguda, Mayurbhanj, Nabarangpur, Nuapara etc.) in annual rainfall. A similar result was found in case of monsoon rainfall where increasing rainfall was found in eastern districts and in the extreme south district (Baleswar, Cuttack, Jagatsinghpur, Kendrapara, Puri and Malkangiri) with a highest (1.327 mm/year and 14.79%) at Jagatsinghpur. In the case of pre-monsoon rainfall significant increase was noticed in the east side only and non-significant increasing and decreasing trend were found in the remaining districts. Significant positive post-monsoon rainfall was observed in the extreme south district Malkangiri only, while non-significant trends were noticed in winter rainfall over entire Odisha except Rayagada.

The trends and variability of rainfall clearly indicating the climate impact, which can have adverse impact on economic development of the state. To minimize the climatic impacts, proper adoption and mitigation measures are required to be taken, but we cannot have control on natural factors casing climate change, while the anthropogenic activities can be controlled. Therefore the assessment of rainfall trend in temporal and spatial scales are necessary for Odisha state to have a detailed information at district level for better understanding and control over disasters and management of water resources. The results from the study should be useful for proper management of water resources, agricultural development and economic development of the State.

ACKNOWLEDGMENT
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Appendix 1

Method

Pre-whitening for Elimination of Serial Correlation

Hamed and Rao (1998) and Yue *et al.*, (2002) said that trend detection in a data series is generally affected by positive and negative autocorrelation. Douglas *et al.*, (2000) tried to use the pre-whitening for reducing the influence of serial correlation on MK test for the trend detection study of low flows in United States. Therefore all rainfall and temperature time series are first tested for serial correlation. For a discrete time series for lag-k, the autocorrelation coefficient ρ_k is given by the following relation.

$$\rho_k = \frac{\sum_{k=1}^{n-k}(x_t-\overline{x_t})(x_{t+K}-\overline{x}_{t+k})}{\left[\sum_{k=1}^{n-k}(x_t-\overline{x_t})^2(x_{t+K}-\overline{x}_{t+k})^2\right]^{0.5}} \tag{1}$$

Where, $\overline{x}_t$ is the sample mean of first (n-k) terms, Var (x_t) is the sample variance of first (n-k) terms. Similarly $\overline{x}_{t+k}$ and Var (t+k) are the mean and variance of last (n-k) terms of the sample respectively.

Then the serial independence hypothesis was tested by the lag-1autocorrelation coefficient as H_0: $\rho_1 = 0$ against alternate hypothesis H_1: $|\rho_1| \geq 0$ by using the significance test of serial correlation indicated by Rai et al. (2010) as:

$$(\rho_k)t_g = \frac{-1 \pm t_g(n-k)^{0.5}}{n-k} \tag{2}$$

Where (ρ_k) t_g and t_g are the normally distributed value of ρ_k and normally distributed statistics at 'g' level of significance. At 10%, 5% and 1% level of significance the values of t_g are 1.645, 1.96 and 2.575 respectively. If $|\rho_k| \geq (\rho_k)$ t_g , the null hypothesis of serial independence was rejected at α level of significance (*here* α = 5% i.e 0.05). The MK test was applied in the current study, where at 5% level of significance, the autocorrelation was found to be non-significant.

Mann-Kendall (MK) Test

The Mann-Kendall test is used to test the null hypothesis H_0 of no trend in a data series, against the alternate hypothesis H_1 of monotonic increasing or decreasing trend. In this test the data values are evaluated as an ordered time series. The application of MK test can be done to a time series x_i which is ranked from i = 1, 2, 3,.........n-1 and x_j is ranked from j=i+1, 2, ...n in the following way such as,

$$\text{sgn}\ (x_j - x_i) = \begin{cases} +1 & \text{if } (x_j - x_i) > 0 \\ 0 & \text{if } (x_j - x_i) = 0 \\ -1 & \text{if } (x_j - x_i) < 0 \end{cases} \tag{3}$$

The test statistic of MK test can be computed as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(\chi_j - \chi_i) \quad (4)$$

Where sgn ($x_j - x_i$) is the signum function. For the sample size $n \geq 8$, the test statistic S is assumed to be approximately normally distributed with the mean. E(S) = 0 and the variance of statistic S is computed as follows:

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

Here t_p is the no. of data values in the pth group and q is the no. of tied groups.
The standardized test statistic (Z) of MK test can be computed by using equation (6) (Douglas *et al.*, 2000).

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & \text{if} \quad S > 0 \\ 0 & \text{if} \quad S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & \text{if} \quad S < 0 \end{cases} \quad (6)$$

The above Z follows the standard normal distribution. An upward (downward) trend can be signified by the positive (negative) value of standardized test statistic Z. The upward (downward) monotonic trend (a two tailed test) can also be tested by utilizing the significance level (α). If the value of Z appears to be greater than $Z_{\alpha/2}$, a significant trend can be considered.

Sen's Slope Estimator Test

The Sen's slope estimator test is used for estimation of the trend magnitude. If linear trend is present in a time series, the true slope is computed by this method (Sen, 1968) and given as :

$$T_i = \frac{x_j - x_k}{j-k} \qquad \text{for } i = 1,2,\ldots\ldots,N \quad (7)$$

Where x_j and x_k are the data values at time j and k (j>k) respectively. The Sen's estimator of slope represents the median of these N values of T_i which is given as:

$$Qi = \begin{cases} T_{\frac{N+1}{2}} & N \text{ is odd} \\ \dfrac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & N \text{ is even} \end{cases} \quad (8)$$

If N is Odd, the Sen's estimator is computed as $Q_i = T_{(N+1)/2}$ but in case of N is even, $Q_i = [\,T_{N/2} + T_{(N+2)/2}]/2$. Finally Q_i is computed by two sided test at 100 (1-α) % confidence interval and then true slope can be computed by using the non-parametric test. In a time series an upward or increasing trend is indicated by a positive value of Q_i and a negative value of Q_i gives a downward or decreasing trend.

Mann-Whitney-Pittitt (MWP) Method

If a time series { $x_1, x_2, \ldots x_n$} is considered with length n and t be the time of most expected point of change, then two samples { $x_1, x_2, \ldots x_t$} and { $x_{t+1}, x_{t+2}, \ldots x_n$} can be obtained by dividing the time series at time t. An index U_t is derived by the following relation as:

$$U_t = \sum_{i=1}^{t} \sum_{j=t+1}^{n} \text{sgn}(\chi_i - \chi_j) \quad (9)$$

Where

$$\text{sgn}\,(x_j - x_i) = \begin{Bmatrix} +1 & \text{if } (x_j - x_i) > 0 \\ 0 & \text{if } (x_j - x_i) = 0 \\ -1 & \text{if } (x_j - x_i) < 0 \end{Bmatrix} \quad (10)$$

By plotting the U_t value against time t in a time series with no change point will result the continuous increase in $|U_t|$ value. But when there is a change point, then $|U_t|$ will increase up to the change point and then it will start to decrease. The most probable change point is that where $|U_t|$ attains the maximum value:

$$K_t = \max_{1 \leq t \leq T} |U_T| \quad (11)$$

The approximated significant probability p(t) for a change point (Pettitt,1979) is given as:

$$p = 1 - exp\left[\frac{-6K_T{}^2}{n^3 + n^2}\right] \quad (12)$$

The change point will become statistically significant at time t with α level of significance, When probability p(t) exceeds (1-α).

Percentage Change of mean Over a Period

The percentage change of mean over a period of time can be estimated by assuming a linear trend (Yue and Hashino, 2003; Basistha *et al.*, 2009). Hence change percentage is calculated by multiplying the Theil and Sen's median slope with length of period and then divided by the mean value. It is expressed as percentage.

$$\text{Percentage change (\%) over a period} = \frac{\text{Median slope X Length of period}}{\text{Mean}} \text{X } 100 \quad (13)$$

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Appendix 2
See Table 2

Table 2: Results of Mann-Kendall test statistic (Z), Sen's slope estimator (β) and percentsge change for annual and seasonal rainfall during 1901-2010

Station	Annual				Pre-monsoon				Monsoon				Post-monsoon				Winter			
Districts	Z		β	% Change	Z		β	% Change	Z		β	% Change	Z		β	% Change	Z		β	% Change
Angul	0.66		0.346	2.97	0.62		0.102	10.58	0.39		0.175	1.88	0.10		0.026	2.58	-1.17		-0.090	-26.05
Baleshwar	2.38	*	1.682	12.11	0.39		0.100	6.14	1.89	+	1.098	10.70	1.52		0.433	27.53	-0.84		-0.070	-16.38
Bargarh	-1.20		-0.646	-5.45	-0.05		-0.004	-0.65	-0.76		-0.443	-4.22	0.25		0.026	5.02	-1.55		-0.083	-35.11
Boudh	-0.99		-0.640	-5.35	0.50		0.089	10.20	-1.34		-0.686	-6.96	0.58		0.106	11.38	-1.01		-0.079	-25.18
Bhadrak	1.68		1.185	8.30	0.48		0.117	8.23	1.16		0.663	6.23	1.53		0.446	25.27	-0.34		-0.036	-8.16
Bolangir	-1.65		-0.866	-7.36	-0.28		-0.032	-4.63	-1.10		-0.662	-6.49	-0.03		-0.006	-0.92	-0.53		-0.035	-14.28
Cuttack	2.16	*	1.426	12.00	1.74		0.273	30.03	1.73	+	0.998	11.45	0.66		0.230	12.06	-0.36		-0.025	-7.23
Debagarh	-2.24	*	-1.275	-10.47	-0.04		-0.003	-0.38	-2.09	*	-1.078	-10.43	-0.22		-0.029	-4.04	-1.65	+	-0.116	-34.49
Dhenkanal	1.12		0.689	5.80	0.45		0.082	7.77	0.85		0.450	4.96	0.23		0.069	4.90	-0.97		-0.074	-20.87
Gajapati	1.87		1.062	11.04	1.91		0.296	35.01	1.30		0.605	9.11	0.40		0.153	7.90	-1.05		-0.042	-22.00
Ganjam	1.55		0.834	8.19	1.80		0.258	31.89	0.94		0.383	5.37	0.43		0.153	7.86	-0.79		-0.060	-21.29
Jagatsinghpur	2.89	**	2.205	18.10	2.35	*	0.326	41.21	2.30	*	1.327	14.79	0.70		0.237	11.38	-0.58		-0.046	-13.67
Jajpur	1.97	*	1.259	9.80	1.29		0.242	20.32	1.24		0.702	7.24	0.85		0.218	13.62	-0.53		-0.046	-12.34
Jharsuguda	-1.98	*	-1.230	-9.68	0.22		0.030	5.69	-2.21	*	-1.228	-10.77	1.49		0.134	27.30	-0.56		-0.034	-12.06
Kalahandi	-0.22		-0.163	-1.30	-0.68		-0.113	-11.73	0.06		0.031	0.29	-0.12		-0.020	-2.20	-1.29		-0.058	-27.74
Khandamala	1.62		1.051	9.37	1.15		0.209	23.95	1.12		0.594	6.62	0.60		0.133	11.70	-0.74		-0.047	-19.15
Kendrapara	2.24	*	1.422	10.67	1.25		0.221	19.76	2.17	*	1.182	11.87	0.88		0.279	14.82	-1.21		-0.097	-27.36
Kendujhar	0.80		0.434	3.53	0.91		0.175	14.47	0.44		0.242	2.51	0.98		0.172	16.74	-1.34		-0.125	-29.25
Khordha	1.84		1.105	9.84	1.59		0.252	31.50	1.38		0.691	8.82	0.07		0.029	1.29	-0.64		-0.053	-15.34
Koraput	0.98		0.672	5.68	0.38		0.069	6.27	0.72		0.489	5.43	1.03		0.249	16.11	-2.25	*	-0.100	-55.00
Malkangiri	2.10	*	1.364	13.16	-0.76		-0.092	-10.88	1.83		0.924	11.86	1.85		0.510	32.24	-1.47		-0.050	-36.67
Mayurbhanj	1.39		0.865	6.81	0.43		0.091	6.26	0.97		0.553	5.74	1.35		0.260	22.70	-1.69		-0.171	-37.62
Nabarangpur	-1.32		-1.127	-8.23	0.57		0.104	9.14	-0.85		-0.612	-5.46	0.53		0.137	12.15	-1.19		-0.057	-26.43
Nayagarh	2.25	*	1.443	13.04	1.49		0.243	27.84	1.62		0.808	10.04	0.35		0.115	6.29	-0.23		-0.013	-3.97
Nuapada	-2.25	*	-1.425	-11.95	-0.61		-0.071	-10.27	-1.57		-0.960	-9.22	-0.18		-0.025	-3.98	0.76		-0.031	-15.50
Puri	2.51	*	1.304	12.31	1.90		0.250	32.74	1.98	*	0.924	12.08	0.68		0.223	11.79	-0.49		-0.037	-12.33
Rayagada	0.00		0.000	0.00	0.00		0.000	0.00	0.00		0.000	0.00	0.00		0.000	0.00	0.00		0.000	0.00
Sambalpur	-1.25		-0.679	-5.53	0.11		0.011	1.70	-1.05		-0.622	-5.79	0.46		0.044	7.56	-0.92		-0.063	-21.00
Sonapur	-1.11		-0.646	-5.67	-0.59		-0.085	-12.63	-1.07		-0.580	-5.90	-0.35		-0.048	-7.44	-1.17		-0.072	-26.40
Sundargarh	-2.13	*	-1.375	-10.74	0.43		0.050	8.09	-2.00	*	-1.250	-11.09	0.95		0.111	19.38	-1.36		-0.095	-28.24

*Where +, *, ** and indicate significant increase or decrease at 10%, 5% and 1% level of significance*