RAINFALL CHANGES AND POSSIBLE LINKAGES WITH THE LARGE-SCALE CIRCULATION IN THE EASTERN INDIA (THEME: CLIMATE CHANGE)

D. K. Panda & A. Kumar
Directorate of Water Management (ICAR), Bhubaneswar

ABSTRACT

In this study, the rainfall of Orissa, a tropical region in eastern India, and the cyclonic disturbances over the Bay of Bengal were analyzed to assess the trends and variations using the parametric statistical procedures. This study revealed noticeable changes in the last century (1901-2000) rainfall of Orissa and in the cyclonic disturbances over the Bay of Bengal. Test of structural changes and the locally weighted regression technique (LOWESS) indicated that the spatially averaged annual rainfall of Orissa experienced three significant regime shifts: 1487 mm with standard deviation 167 mm during 1901-1940, 1412 mm with standard deviation 184 mm during 1940-1969, and 1354 mm with standard deviation 241 mm during 1970-2000 respectively. Study of structural breaks in rainfall during the period 1901-1940 and 1941-1969 indicated a significant change in both slope as well as the intercepts. However, structural breaks analysis during the period 1941-1969 and 1970-2000 indicated a non-significant change. The annual depression in the Bay of Bengal also exhibited a structural change with occurrence of an average of 10.7 depressions during 1901-1948 in comparison to 9.6 during 1949-2000.

1. INTRODUCTION

The Orissa state of India is the most climate change-affected region due to frequent occurrence of hydrologic extremes in the recent past (Swiss Re, 2002; Mirza, 2003). The Center of Environmental Studies (CES, 2007) reported that the erratic behavior of climate of Orissa is primarily due to the combination of anthropogenic factors such as deforestation, extensive construction activities, uncontrolled mining, elimination of water bodies and extensive carbon consumption over a period of time. Further, a minor change in the pressure anomaly of the Bay of Bengal can have profound hydrological impact on the land mass of Orissa due to its geographical location at the head of the Bay where the weather forms (CES, 2007). Therefore, it is imperative to explore the long-term changes in rainfall of the study area and also changes in the synoptic disturbances.

2. METHODOLOGY

Test of structural changes

Test of structural change is a general form of the Chow test, commonly used in forecasting (Johnston and Dinardo, 1997). If the parameters of interest in a model differ from one subset of data to another, then structural breaks or change occurs in that time series. The parametric linear regression of response variable i.e. rainfall with time (year) can be defined as

$$y = \alpha + \beta X + u$$

where, y is represents the dependent variable, α is the intercept, β is the slope, X is the independent variable year, and u is the random error. This model can be defined in the matrix form as

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{u}$$

y is a vector of n observation representing the dependent variable, **X** is a matrix of independent variable, $\boldsymbol{\beta}$ is a column vector of parameters i.e. α and β , and **u** is the column vector of errors which is normally distributed with mean 0 and constant variance $\boldsymbol{\sigma^2}$.

In this study, for simplification of the procedure, we investigate the structural change in two subsets of data that form the complete time series, although there is possibility of several subsets with structural breaks. Let the total time series of n observation be divided into two subsets of samples with n_1 and n_2 observation i.e. $n= n_1+n_2$.The structural change may occur between the subset of time series due to the change in intercept or change in slope or combination of both the parameters.

The models representing the subsets of time series can be defined as

$$y_1 = X_1\beta_1 + u_1$$
$$y_2 = X_2\beta_2 + u_2$$

i.e.

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} X_1 & 0 \\ 0 & X_2 \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \end{bmatrix} + \mathbf{u}$$

Here, $X_1= [\ i_1 \ \ X_1^*]$ and $X_2=[\ i_2 \ \ X_2^*]$, where, i_1 and i_2 are n_1 and n_2 vectors of ones, and X_1^* and X_2^* are subset vectors of years. Further, the β vectors can be partitioned to a conformable form as

$$\beta`_1=[\ \alpha_1 \ \ \boldsymbol{\beta}_1{*`}] \ \ \beta`_2=[\alpha_2 \ \ \boldsymbol{\beta}_2{*`}]$$

Null hypothesis of no structural breaks is H_0: $\boldsymbol{\beta}_1 = \boldsymbol{\beta}_2$

Under null hypothesis of common parameters

I. $$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} i_1 & X_1^* \\ i_2 & X_2^* \end{bmatrix} \begin{bmatrix} \alpha \\ \beta^* \end{bmatrix} + \mathbf{u}$$ (common parameters: RSS1)

II. $$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} i_1 & 0 & X_1^* \\ 0 & i_2 & X_2^* \end{bmatrix} \begin{bmatrix} \alpha 1 \\ \alpha 2 \\ \beta^* \end{bmatrix} + \mathbf{u}$$ (different intercept, common slope: RSS2)

III. $$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} i_1 & 0 & X_1^* & 0 \\ 0 & i_2 & 0 & X_2^* \end{bmatrix} \begin{bmatrix} \alpha 1 \\ \alpha 2 \\ \beta_1^* \\ \beta_2^* \end{bmatrix} + \mathbf{u}$$ (different intercept, common slope: RSS3)

The following hypotheses are evaluated for the structural change test.

H_0: $\boldsymbol{\alpha}_1 = \boldsymbol{\alpha}_2$ $$F = \frac{RSS_1 - RSS_2}{RSS_2/(n-k-1)}$$

H_0: $\boldsymbol{\beta}_1^* = \boldsymbol{\beta}_2^*$ $$F = \frac{(RSS_2 - RSS_3)/(k-1)}{RSS_3/(n-2k)}$$

H_0: $\boldsymbol{\beta}_1 = \boldsymbol{\beta}_2$ $$F = \frac{(RSS_1 - RSS_3)/k}{RSS_3/(n-2k)}$$

3. Results and Discussion

3.1 Rainfall distribution during 1901-2000 in Orissa

In last century during 1901-2000, the state Orissa has experienced 99 extreme events that include 49 floods, 30 droughts, 10 cyclones, and 1 super cyclone. The locally weighted regression technique (LOWESS) indicated that the spatially averaged annual rainfall of Orissa experienced three significant regime shifts (Fig. 1). Hence, the climatology is experiencing a erratic distribution in recent years. The detail descriptive statistics of annual rainfall in different regimes of last century are presented in Table 1.

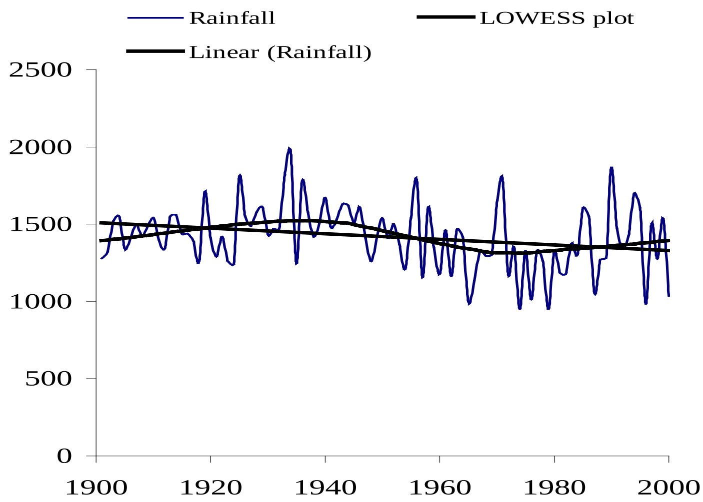

Figure 1. Structural breaks of annual rainfall distribution during 1901-2000

The decadal maximum, minimum and average rainfall of Orissa in last century indicated a decreasing trend as illustrated in Fig. 2. Table 2 shows the decadewise maximum, minimum and average rainfall amount follow decreasing trend and standard deviations of rainfall follow increasing trend.

Table 1. Descriptive statistics of annual rainfall (mm) in different periods of last century

Period	1901-1940	1941-1969	1970-2000	1901-2000
Observations	40	29	31	100
Mean	1487.25	1403.33	1344.51	1418.67
Standard deviation (SD)	167.59	180.67	244.48	205.18
Skewness	0.84	-0.20	0.22	-0.01
Kurtosis	0.79	-0.20	-0.50	0.17
Minimum	1240	997	950.7	950.7
P10	1270	1160	1012.9	1169.9
Q1	1395	1296	1179.9	1286.6
Median	1470	1417.9	1325.6	1420
Q3	1555	1530	1535.9	1545
P90	1745	1620	1654	1662
Maximum	1970	1790	1865.8	1970
sapiro-wilk	0.942	0.984	0.970	0.989
p<w	0.042	0.922	0.521	0.581

Table 2. Descriptive statistics of decadal annual rainfall (mm) in last century

Decade	Minimum rainfall	Maximum rainfall	Average rainfall	S.D.

1910	1280	1550	1437	97.64
1920	1260	1710	1450	127.28
1930	1240	1810	1468	178.75
1940	1250	1970	1594	215.88
1950	1260	1630	1501	114.74
1960	1160	1790	1412	202.75
1970	997	1654	1322.07	190.37
1980	951	1791	1246.81	249.54
1990	1052	1866	1367.09	242.08
2000	985	1700	1388.69	233.19

3.2 **Study of structural breaks in different regimes during 1901-2000 in Orissa**

The parametric method of structural breaks was studied using the theory presented in theory section. In last century, the annual rainfall of Orissa experienced three significant breaks. The avarage of annual rainfall during these three regimes were: 1487 mm with standard deviation 167 mm during 1901-1940, 1412 mm with standard deviation 184 mm during 1940-1969, and 1354 mm with standard deviation 241 mm during 1970-2000 respectively. This indicates that the average rainfall is decreasing, but the standard deviation is increasing over rainfall regimes.

Table 3 Test of structural breaks during 1901-1940 and 1941-1969

Id	Parameters	SE	t-cal	P value	F-cal	P
α_1	-8725.99	4128.30	-2.11	0.04	22.05	0.003
α_2	23435.41	6809.50	3.44	0.00		
β_1	5.32	2.15	2.47	0.02		
β_2	-11.27	3.48	-3.24	0.00		

Study of structural breaks/ regime shifts during the period 1901-1940 and 1941-1969 indicated a significant test of structural breaks both in slope as well as the intercepts (Table 3). During the period 1901-1940, the annual rainfall exhibited a significant increasing trend having positive slope (β_1=5.32), where as during 1941-1969 it experienced a significant decreasing trend with a negative slope (β_2=-11.27). Further, the intercepts are significant in both the regimes of the study period.

Results of structural breaks analysis during the period 1941-1969 and 1970-2000 indicated a non-significant test of structural breaks (Table 4). During the period 1941-1969, the annual rainfall exhibited a significant decreasing trend having slope (β_1=-11), where as during 1941-1969 it experienced a non-significant increasing trend with a slope (β_2= 2.88). Further, the intercepts are significant in both the regimes of the study period.

Table 4 Test of structural breaks during 1941-1969 and 1970-2000

Id	Parameters	SE	t-cal	P value	F-cal	P
α_1	23435	9036	2.59	0.01	7.89	0.103
α_2	-4381	8300	-0.53	0.60		
β_1	-11	4.62	-2.44	0.02		
β_2	2.88	4.18	0.69	0.49		

3.3 **Study of structural breaks in annual cyclonic disturbances (depression) over during 1901-2000 in Orissa**

The annual cyclonic disturbances (depression) over the Bay of Bengal during 1901-2000 indicated a structural change in 1948 (Fig. 3).

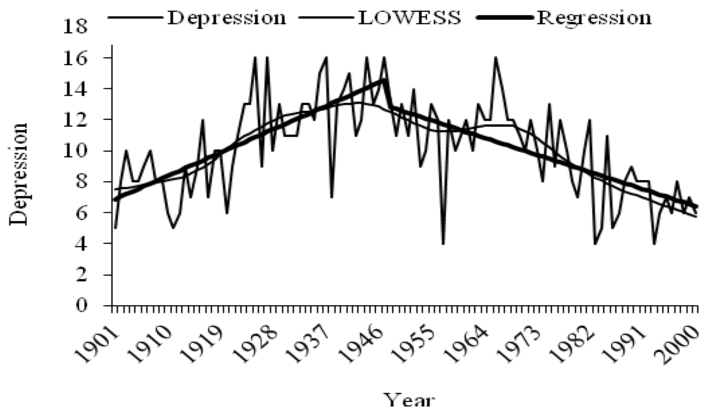

Figure 3. Structural breaks of annual depression over the Bay of Bengal during 1901-2000.

Descriptive statistics indicated that an average of 10.7 depressions occurred during 1901-1948 in comparison to 9.6 during 1949-2000. It is evident that the depression frequency increased significantly during 1901-1948. In contrast, a marked decrease took place from 1949 onwards. This may have decreased the rainfall in recent decades in Orissa and adjacent regions. Since structural change provide enough evidence of climate change, more research need to be carried out to know the reason of these structural breaks in climatic variables.

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