(v) Student’s $t$-test shows that increasing and decreasing trends noticed during various sub periods are not significant. However, the increasing trend observed during the period 1926 to 1950 was very close to become significant.

(vi) Only one significant cycle of 2.14 yr i.e., Quasi Biennial Oscillation is observed in 100-year period but is not consistently observed throughout the data record.

References


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IDENTIFICATION OF COASTS VULNERABLE FOR SEVERE TROPICAL CYCLONES – STATISTICAL ELUCIDATION

1. Severe Tropical Cyclone (STC) is among the most destructive natural hazards, initiating catastrophic ravages to life, property and environment.

An accurate prediction of occurrence of STC with adequate lead time or forecasting a definite trend of occurrence of these cyclonic storms over different coasts is essential for mitigating the squandering due to such casualty.

The purpose of the present study is, thus, to identify those coasts over Bay of Bengal, which are vulnerable for the occurrence of STC by using method of statistical techniques.

2. It would suffice to acquire the intent of the study if the following could be ordained;

(i) Occurrence of STC is random over the concerned coasts.

(ii) Degree of uncertainty in forecasting the occurrence of STC is high over such coasts.

(iii) Veering of TC to STC represents a linear regression relationship over the coasts.

2.1. Fitting of Poisson distribution - Severe Tropical Cyclones being discrete events, a Poisson distribution is tried to fit to the data under consideration. The probability distribution function (pdf) for Poisson distribution is ;

$$ P(X = x) = \frac{e^{-\lambda} \lambda^x}{x!} $$ (1)

Where,

$x$ varies from 0 to $\infty$

and, $\lambda$ implies the average occurrence rate.

The recurrence relation is;

$$ P(X = x + 1) = \frac{\lambda}{x + 1} P(X = x) $$ (2)

Different probability levels are computed for each of the coasts under consideration by using expression (1)
and (2). Expected decadal frequency distributions have also been computed for each coast by multiplying these probability levels with total frequency of STC over the coasts.

To observe whether Poisson distribution fits well with the decadal frequency distribution of STC, a null hypothesis, \( H_0 \) is defined;

\[ H_0 : \text{Poisson distribution is a good fit.} \]

This proposition is tested against an alternative hypothesis, \( H_1 \);

\[ H_1 : \text{Poisson distribution is not a good fit.} \]

Under the null hypothesis, a Chi-square (\( \chi^2 \)) statistic is computed;

\[ \chi^2 = \sum_i \frac{(O_i - E_i)^2}{E_i} \quad (3) \]

Where,

\( O_i \) = Observed frequency of the \( i^{th} \) class.

\( E_i \) = Expected frequency of the \( i^{th} \) class.

Computed values of Chi-square are compared with the standard tabular (Wilks, 1995) values with appropriate degree of freedom. The null hypothesis is accepted if the tabular value exceeds the computed value otherwise, rejected. Tests have been carried out at 5% level of significance. A false acceptance of null hypothesis generates type - II error. In any situation, if the null hypothesis is accepted but either skewness or kurtosis is observed to be negative, type - II error appears. To reach an error free conclusion, results with type - II error are to be identified.

2.2. Measure of uncertainty - Shannon (1948) introduced the concept of entropy that measures the degree of uncertainty. Shannon entropy is defined as;

\[ H[\{p(x)/x \in X\}] = -\sum_{x \in X} p(x) \log_2 p(x) \quad (4) \]

where,

\[ \{p(x)/x \in X\} \Rightarrow \text{Probability distribution on a finite set } X. \]

In the present study different probability levels are used to observe the uncertainty associated with the occurrence of STC or the anticipation of development of TC to STC using equation (4).

2.3. Analysis of variance - A linear regression equation of the form;

\[ \hat{y} = a + bx \quad (5) \]

is tried to fit to the data set of decadal frequency of TC and STC over the coasts.

Frequency of TC is considered to be the predictor (x) and frequency of STC as predictand (y). \( \hat{y} \) represents the predicted value of \( y \).

In expression (5),

\[ b = \frac{n \sum_{i=1}^{n} x_i y_i - \left( \sum_{i=1}^{n} x_i \right) \left( \sum_{i=1}^{n} y_i \right)}{n \left( \sum_{i=1}^{n} (x_i)^2 \right) - \left( \sum_{i=1}^{n} x_i \right)^2} \quad (6) \]

and

\[ a = \bar{y} - b \bar{x} \quad (7) \]

where \( n \rightarrow \text{number of observations.} \)

Analysis of variance (ANOVA) is executed to test the goodness of fit of the regression to the observed data. Total sum of squares (SST), regression sum of squares (SSR), sum of squared error (SSE), mean squared regression (MSR), mean squared errors (MSE) are computed for this purpose;

\[ \text{SST} = \sum_{i=1}^{n} y_i^2 - n\bar{y}^2 \quad (8a) \]

\[ \text{SSR} = b^2 \left[ \sum_{i=1}^{n} x_i^2 - n\bar{x}^2 \right] \quad (8b) \]

\[ \text{SSE} = \sum_{i=1}^{n} (y_i - \hat{y}(x_i))^2 \quad (8c) \]

\[ \text{MSE} = \frac{1}{n-2} (\text{SST} - \text{SSR}) \quad (8d) \]

**Fig. 1.** The Bay of Bengal and Arabian Sea. The segments of the Bay coast are marked in the figure by numbers 1 to 6. Segments of west coast of India are marked by the letters A, B, C, D. The cities marked are: AKB, Akyab, BMB, Mumbai (Bombay); CAL, Calcutta (Kolkata); CHT, Chittagong; CLB, Colombo; GPL, Gopalpur; MDS, Madras (Chennai); VSK, Visakhapatnam

**TABLE 1**

<table>
<thead>
<tr>
<th>Coasts</th>
<th>Skewness</th>
<th>Kurtosis</th>
<th>Observed Chi-square</th>
<th>Degree of freedom</th>
<th>Tabular Chi-square</th>
<th>Decision regarding null hypothesis</th>
<th>Type of error</th>
<th>Amount of uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>TN</td>
<td>0.96</td>
<td>1.23</td>
<td>0.001</td>
<td>3</td>
<td>7.815</td>
<td>accepted</td>
<td>No error</td>
<td>2.713</td>
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<tr>
<td>AP</td>
<td>0.46</td>
<td>-1.32</td>
<td>0.090</td>
<td>5</td>
<td>11.070</td>
<td>accepted</td>
<td>Type II</td>
<td>2.646</td>
</tr>
<tr>
<td>O/WB</td>
<td>-0.33</td>
<td>-1.07</td>
<td>1.020</td>
<td>4</td>
<td>9.488</td>
<td>accepted</td>
<td>Type II</td>
<td>2.550</td>
</tr>
<tr>
<td>BD</td>
<td>1.73</td>
<td>2.30</td>
<td>2.040</td>
<td>2</td>
<td>5.991</td>
<td>accepted</td>
<td>No error</td>
<td>2.766</td>
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<tr>
<td>AR</td>
<td>-0.54</td>
<td>-1.13</td>
<td>2.057</td>
<td>1</td>
<td>3.841</td>
<td>accepted</td>
<td>Type II</td>
<td>1.881</td>
</tr>
<tr>
<td>ESL</td>
<td>0.86</td>
<td>-2.51</td>
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<td>1</td>
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<td>Type II</td>
<td>0.897</td>
</tr>
</tbody>
</table>

TN - Tamilnadu coast, AP – Andhra Pradesh coast, O/WB - Orissa & West Bengal coast, BD - Bangladesh coast, AR - Arakan coast, ESL - East Sri Lanka coast
Fig. 2. Randomness of occurrence of severe tropical cyclones over different coasts

\[ MSR = \frac{SSR}{1} = SSR \]  \hspace{1cm} (8e)

\[ F = \frac{MSR}{MSE} \]  \hspace{1cm} (9)

The present study is executed with 110 years data available in Report No. TCP-28, TD-No. 430, WMO, Geneva (Mondal, 1991).

The coasts considered for this study are the segments of Bay coasts comprising Tamilnadu (TN), Andhra Pradesh (AP), Odisha/West Bengal (OWB), Bangladesh (BD), Arakan (AR) and East Sri Lanka (ESL).

<p>| TABLE 2 |
|----------------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Source</th>
<th>Degree of freedom</th>
<th>Sum of squares</th>
<th>Mean of squares</th>
<th>F- Statistic</th>
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<tr>
<td><strong>East Sri Lanka</strong></td>
<td></td>
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<tr>
<td>Total</td>
<td>10</td>
<td>2.574</td>
<td></td>
<td></td>
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<tr>
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<td>1.058</td>
<td>1.058</td>
<td>6.30</td>
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<tr>
<td>Residual</td>
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<td>1.516</td>
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<td>0.168</td>
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<tr>
<td><strong>Tamil Nadu</strong></td>
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<td>Total</td>
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<tr>
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<td>0.768</td>
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<td>Total</td>
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<td>41.272</td>
<td></td>
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</tr>
<tr>
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<td>14.104</td>
<td>61.13</td>
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<td>Residual</td>
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<td>3.110</td>
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<tr>
<td><strong>Orissa / West Bengal</strong></td>
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<td></td>
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</tr>
<tr>
<td>Total</td>
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<tr>
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<td>2.626</td>
<td>2.626</td>
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<td>Residual</td>
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<td>4.294</td>
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<td><strong>Bangladesh</strong></td>
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<tr>
<td>Total</td>
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<td>86.570</td>
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<td><strong>Arakan</strong></td>
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<td>Total</td>
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<td></td>
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<tr>
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<td>3.024</td>
<td>3.87</td>
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<tr>
<td>Residual</td>
<td>9</td>
<td>8.620</td>
<td></td>
<td>0.780</td>
</tr>
</tbody>
</table>
Fig. 3. Uncertainty of occurrence of severe tropical cyclones (STC) over different coasts

Figs. 4(a-f). Actual (—) and predicted (---) decadal frequencies of STC over different segments of Bay coast. (a) Tamilnadu coast (1881-1989), (b) Bangladesh coast (1881-1989), (c) Andhra Pradesh coast (1881-1989), (d) Orissa/West Bengal coast (1881-1989), (e) Arakan coast (1881-1989) and (f) East-Sri Lanka coast (1881-1989)
Values of Chi-square are computed and compared with the standard table for all these coasts at 5% level of significance with suitable degree of freedom (Table 1). The computed values of Chi-square are found to be less than the tabular values. Tamilnadu and Bangladesh coasts are observed to own both skewness and kurtosis to be positive (Table 1). It is, thus, perceived that the acceptance of null hypothesis for all the coasts under consideration except the coasts of TN and BD involve type-II error. It can, therefore, be affirmed that decadal frequency distribution of STC over the coasts of TN and BD imitate Poisson distribution. This indicates that the occurrence of STC over these two coasts has high degree of randomness. This is made schematically apparent in Fig. 2. Fig. 3 exhibits that the measure of uncertainty in the occurrence of STC is also high over the coasts of Tamilnadu and Bangladesh.

Table 2 displays that the computed values of ‘F’ exceeds the standard tabular values at 1% level of significance, only for the coasts of TN and BD. For the coast of ESL, on the other hand, the null hypothesis is rejected at 5% level of significance. It is mentioned here that the tabular values of $F_{0.05;1,9}$ and $F_{0.01;1,9}$ are 5.12 and 10.56 respectively. It is also indicative from the table that the coasts of TN and BD hold high coefficient of determination. Coefficient of determination is neither high nor low over the coast of East Sri Lanka (ESL). No specific decision is, thus, possible for the randomness of veering of TC’s to STC’s over the coast of ESL, whereas, over the coasts of TN and BD frequency of the occurrence of STC is related linearly to the frequency of occurrence of TC.

4. Among the different segments of Bay coast under consideration, the coasts of Tamilnadu and Bangladesh are most vulnerable for Severe Tropical Cyclones as the anticipation of occurrence of such weather calamities are difficult over these two coasts.

References


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