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# Cyclonic storms of the Arabian Sea, 1877-1980

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**सार** — 1877 से 1980 की अवधि में अरबसागर में आए और तटीय क्षेत्रों तक पहुंचने वाले अनेक चक्रवाती तूफानों/भीषण चक्रवती तूफानों का अध्ययन किया गया है। यद्यपि अरबसागर के तटीय क्षेत्रों तक पहुंचने वाले तूफानों की वार्षिक श्रृंखला एक जैसी है, तथापि अरबसागर में बनने वाले तूफानों में 1965–80 की अवधि में विशेष बढ़ोतरी लक्षित होती है। 1965–80 के दौरान तूफानों में वृद्धि, तूफानों की जानकारी देने वाली अच्छी तकनीकों या तूफान बनने के लिए अनुकूल परिस्थितियों के कारणवश हो सकती है। भारत के पश्चिमी तट पर पहुंचने वाले तूफानों के कुछ जलवायुविक अभिलक्षणों को भी शोधपत्र में प्रस्तुत किया गया है। समुद्र में बनने वाले तूफानों की संख्या और अरबसागरीय तटीय क्षेत्रों तक पहुंचने वाले तूफानों की संख्या के लिए प्वासों प्रायिकता निदर्श काफी उपयुक्त है। इस निदर्श का उपयोग आगामी 50 वर्षों की अवधि में तटों पर पहुंचने वाले तूफानों की बारंबारता के आकलन के लिए किया गया है।

ABSTRACT. The series of cyclonic storms/severe cyclonic storms forming over the Arabian Sea and reaching the sections of the coast around it during the period 1877 - 1980 are studied. Although the annual series of storms reaching the coast around the Arabian Sea is homogeneous that of the storms forming over the Arabian Sea shows significant increase during the period 1965 - 80. Increase in the number of storms during 1965 - 80 may be due to better aids for detection of storms or due to more favourable conditions for formation of storms. Some climatological features about the storms reaching the west coast of India are also presented. Poisson probability model is a good fit to the number of storms forming over the sea and to the number of storms reaching the coast around the Arabian Sea during the year and this model has been used to estimate the frequencies of storms reaching the coast during the next 50-year period.

## 1. Introduction

Tropical cyclones are synoptic systems disastrous to human life, cattle and property due to strong winds, high tides and heavy rains they bring with them. Tropical cyclones have long-term impact on the economy of the countries struck by them. A large amount of money has to be diverted for providing shelter and other facilities to the people affected by cyclones. A number of studies have been made on the tropical cyclones of the Arabian Sea. Jayaraman (1964) examined the combined series of storms and depressions for the period 1901 to 1955 for trend and suitability of Poisson distribution. Thiruvengadathan (1975) studied the storms and depressions during the period 1961-74 to assess the genuineness of certain peculiar features shown by storms and depressions of earlier years. There have also been some case studies by Desai (1967), Gupta *et al.* (1977), Mukherjee and Padmanabham (1980) etc. It is proposed to examine the series of cyclonic storms/severe cyclonic storms (*i*) forming over the Arabian Sea, and (*ii*) reaching the coast around the Arabian Sea, for trend, changes in the mean annual frequency during different periods and to present climatological features of these systems. An attempt is made to examine the suitability of a statistical model for storms forming over the sea and for those reaching the coast. Storms affecting the west coast of India are studied in detail.

## 2. Data

The period considered in this study is 1877 - 1980. The data for the period 1877 - 1970 has been obtained from the India Meteorological Department publication (1979), *"Tracks of storms and depressions over the Bay of Bengal and the Arabian Sea,* 1877 - 1970" and that for the period 1971 - 80 from the storm accounts by Das *et al.* (1972, 1973), Alexander *et al.* (1974, 1976, 1977), Pant *et al.* (1978, 1980), Mukherjee *et al.* (1981, 1982). Fig. 1 shows the map of the Arabian Sea and the coast (with its subsections) around it.

## 3. Frequency of formation of storms

The storms with their origin over the Bay of Bengal (either as depressions or storms), travelling over land as depressions and again regenerating over the Arabian Sea are also considered as storms forming over the Arabian Sea. These are treated as storms having origin in Bay. If a storm has originated over the Bay and has come to the Arabian Sea without weakening into depression over land, but has intensified into a severe

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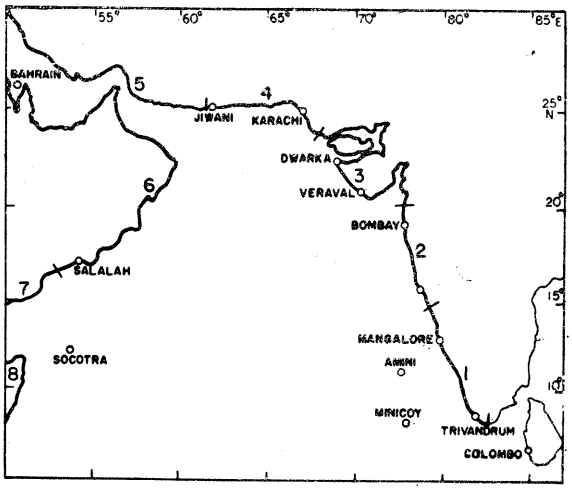


Fig. 1. Map showing the coast around the Arabian Sea and its sections (1) Kerala-Karnataka, (2) Maharashtra, (3) Gujarat-Saurashtra, (4) Pakistan, (5) Iran, (6) Oman, (7) Yemen, (8) Somalia

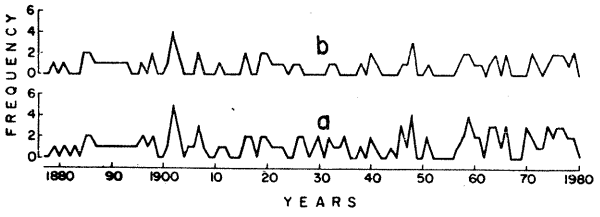


Fig. 2. Annual frequency of (a) cyclonic storms, (b) severe cyclonic storms forming over the Arabian Sea

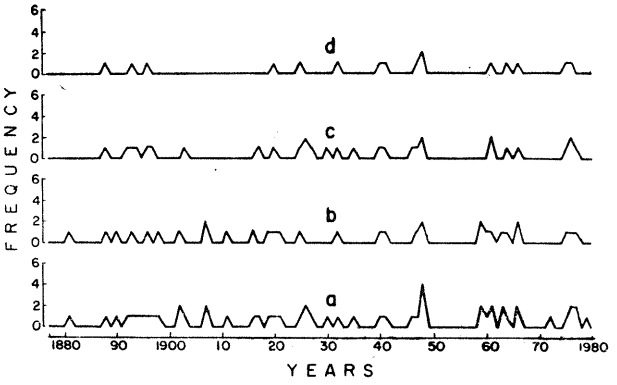


Fig. 3. Annual frequency of (a) cyclonic storms, (b) severe cyclonic storms reaching the coast around the Arabian Sea and annual frequency of (c) cyclonic storms, (d) severe cyclonic storms reaching the west coast of India

**TABLE 1**

**Number of cyclonic storms (severe cyclonic storms) which formed over the Indian seas (1877-1980)**

| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Apr-Jun | Oct-Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **(a) Arabian Sea** | | | | | | | | |
| 1 | 0 | 0 | 6 | 23 | 22 | 3 | 2 | 8 | 22 | 28 | 5 | 51 | 55 | 120 |
| (0) | (0) | (0) | (4) | (19) | (14) | (0) | (0) | (3) | (11) | (21) | (2) | (37) | (34) | (74) |
| 0 | 0 | 0 | 66.7 | 82.6 | 63.6 | 0 | 0 | 37.5 | 50.0 | 75.0 | 40.0 | 72.5 | 61.8 | 60.8 |
| | | | | | | **(b) Bay of Bengal** | | | | | | | | |
| 6 | 0 | 6 | 20 | 48 | 42 | 47 | 30 | 41 | 82 | 93 | 48 | 110 | 223 | 463 |
| (1) | (0) | (3) | (10) | (32) | (5) | (7) | (4) | (13) | (32) | (46) | (19) | 47 | 97 | 172 |
| 16.7 | 0 | 50.0 | 50.0 | 66.7 | 11.9 | 14.9 | 13.3 | 31.7 | 39.0 | 49.5 | 39.6 | 42.7 | 43.5 | 37.1 |
| | | | | | | **(c) Number of cyclonic storms (severe cyclonic storms) over Arabian Sea with origin over the Bay of Bengal** | | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 3 | 13 | 1 | — | | 20 |
| (0) | (0) | (0) | (0) | (0) | (0) | (0) | (0) | (1) | (3) | (11) | (1) | — | — | (16) |

*Note* : Third line under (a) and (b) gives the percentage of severe storms

**TABLE 2**

**Incidence of cyclonic storms (severe cyclonic storms) on the different sections of coast around the Arabian Sea (1877-1980)**

| Coast | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Apr-Jun | Oct-Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kerala-Karnataka | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 2 (2) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 2 (1) | 0 (0) | 2 (2) | 2 (1) | 4 (3) |
| Maharashtra | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 1 (1) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 1 (1) | 4 (2) | 0 (0) | 1 (1) | 5 (3) | 6 (4) |
| Gujarat-Saurashtra | 1 (0) | 0 (0) | 0 (0) | 1 (1) | 1 (0) | 4 (3) | 2 (0) | 0 (0) | 4 (1) | 4 (1) | 3 (3) | 0 (0) | 6 (4) | 7 (4) | 20 (9) |
| Pakistan | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 1 (0) | 5 (3) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 6 (3) | 0 (0) | 6 (3) |
| Iran | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 1 (1) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 1 (1) | 0 (0) | 1 (1) |
| Oman | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 3 (3) | 6 (5) | 0 (0) | 0 (0) | 0 (0) | 3 (2) | 1 (1) | 1 (0) | 9 (8) | 5 (3) | 14 (11) |
| Yemen | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 2 (2) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 1 (0) | 0 (0) | 0 (0) | 2 (2) | 1 (0) | 3 (2) |
| West India | 1 (0) | 0 (0) | 0 (0) | 1 (1) | 4 (3) | 4 (3) | 2 (0) | 0 (0) | 4 (1) | 5 (2) | 9 (6) | 0 (0) | 9 (7) | 14 (8) | 30 (16) |
| Complete | 1 (0) | 0 (0) | 0 (0) | 1 (1) | 10 (8) | 15 (11) | 2 (0) | 0 (0) | 4 (1) | 9 (4) | 10 (7) | 1 (0) | 26 (20) | 20 (11) | 53 (32) |

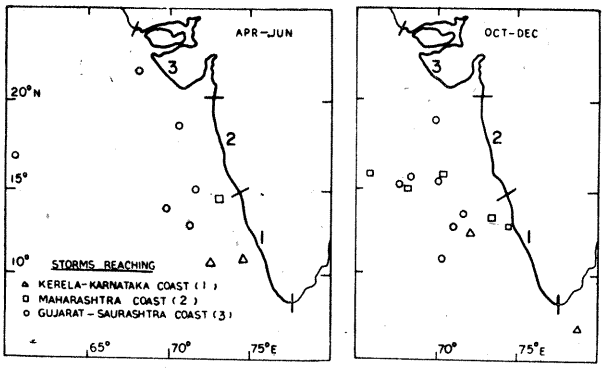


Fig. 4. Locations of formation of storms reaching the different sections of west coast of India

cyclonic storm over the Arabian Sea, it is considered that severe cyclonic storm formed over the Arabian Sea. The annual frequency of the cyclonic storms and the severe cyclonic storms forming over the Arabian Sea is shown in Fig. 2. Table 1 gives the number of cyclonic storms (severe cyclonic storms) which formed over the Indian seas in each month during the period 1877 - 1980. The table shows that majority of the storms over the Arabian Sea form in two different seasons, April - June and October - December. About 79% of cyclonic storms and 89% of severe cyclonic storms form in the four months, May, June and October, November. Pratically no storm forms in January to March, very few in April, July to September and December. Arabian Sea experiences, on an average, one storm every year compared to 4.5 storms experienced by the Bay of Bengal. The percentage of storms intensifying into severe storms, however, is much more over the Arabian Sea (61) than that over the Bay of Bengal (about 37). It is seen that although a good number of cyclones form over the Head Bay during the monsoon months of June to September, very few cyclones form over the Arabian Sea during this period (except in June), one of the reasons being lower water temperatures of the Arabian Sea. Saha (1974) has shown in detail how the surface temperatures of the Arabian Sea gradually falls from May to September. The normal monthly sea-surface temperature compiled by Shri P.V. Joseph on the basis of data for the period 1965 to 1973 also brings out this feature.

The number of storms (severe storms) with their origin over the Bay of Bengal for the period 1877 - 1980 for each month is given in Table 1(c). It is seen that during November a good number of cyclonic storms (about 40%) and severe cyclonic storms (about 52%) has origin in the Bay. This is easily explained by the fact that during this month most of the storms over Bay form south of 13.5 deg. N and travel westwards.

### 3.1. *Frequency of storms incident on the different sections of the coast around the Arabian Sea*

The different sections of the coast around the Arabian Sea are : Kerala, Karnataka, Goa, Maharashtra, Gujarat-Saurashtra, Pakistan, Iran, Oman, Yemen and Somalia. The coasts of Kerala, Karnataka, Goa, Maharashtra and Gujarat - Saurashtra together constitute the west coast of India. Karnataka coast being small in length is coupled with Kerala coast to constitute Kerala-Karnataka coast, and Goa coast, also being very small in length, is considered along with Maharashtra coast. Fig. 3 gives the annual frequency of storms/severe storms reaching the coast around the Arabian Sea and the west coast of India during the period 1877 - 1980. Table 2 gives the number of storms (severe storms)

reaching the different sections of the coast in each month during the period 1877 - 1980. It may be mentioned that a storm which crosses at the boundary of two sections of the coast has been considered for each of the two sections since it is equally dangerous to both the coasts. Table 2 shows that the coasts of Gujarat - Saurashtra and Oman are much more affected than any other sections. The coast of Iran was affected only once in May 1898 during the long period of 104 years. The remaining sections of the coast are rarely affected by storm. The complete coast, in general, is not affected by cyclones during December to March and July to September.

#### 4. Trend in the series of storms/severe storms

It will be shown in the later section that the number of storms (severe storms) forming over the Arabian Sea and reaching the coast around the Arabian Sea in a year is distributed according to the Poisson probability model. The test statistic for linear trend, as given by Cochran (1954), when the variate is distributed according to the Poisson probability law is :

$$\chi^2 = \frac{[\Sigma (y_i - \bar{y})(z_i - \bar{z})]^2}{\bar{y}\Sigma (z_i - \bar{z})^2} \quad \text{d.f. 1}$$

and is distributed as Chi-square with 1 d.f. Here $y_i$ is the number of storms/severe storms forming over the Arabian Sea or reaching the coast around it in a year and $z_i$ is the time variable. The results of the test for the different series are presented in Table 3. It is seen from this table that the series of storms forming over the Arabian Sea shows a trend significant at 5% level.

The annual series of tropical storms/hurricanes of southern north Atlantic was tested for trend by Thom (1960) by fitting linear regression equation to the year number as independent variable and transforming frequency as dependent variable and then applying the analysis of variance and the F-test. The same method has also been applied to the different series mentioned in Table 3 and it is found that the results given in Table 3 are generally confirmed.

**TABLE 3**

**Test for linear trend in the different series of cyclonic storms/severe cyclonic storms (1877-1980)**

| Series | Value of test-statistic, $\chi^2$ (d.f. 1) |
|---|---|
| Storms forming over the Arabian Sea | 4.238* |
| Severe storms forming over the Arabian Sea | 0.655 |
| Storms crossing the coast around the Arabian Sea | 1.410 |

*Significant of 5%.

**TABLE 4**

**Tests for significant change in the mean annual frequency for different series**

| Series | Period From | Period To | Test statistic $\chi^2$ (d.f. 1) |
|---|---|---|---|
| Storms forming over the Arabian Sea | $P_1$ | $P_2$ | 0.02 |
| | $P_2$ | $P_3$ | 0.08 |
| | $P_3$ | $P_4$ | 5.39* |
| | $P_5$ | $P_6$ | 1.63 |
| | $P_7$ | $P_8$ | 3.64+ |
| Severe storms forming over the Arabian Sea | $P_1$ | $P_2$ | 0.68 |
| | $P_2$ | $P_3$ | 0.57 |
| | $P_3$ | $P_4$ | 4.57* |
| | $P_5$ | $P_6$ | 0.00 |
| | $P_7$ | $P_8$ | 1.36 |
| Storms crossing the coast around the Arabian Sea | $P_1$ | $P_2$ | 0.04 |
| | $P_2$ | $P_3$ | 0.17 |
| | $P_3$ | $P_4$ | 1.28 |
| | $P_5$ | $P_6$ | 0.17 |
| | $P_7$ | $P_8$ | 0.10 |

Note : $P_1$=1877-1902 $P_2$=1903-1928 $P_3$=1929-1954
$P_4$=1955-1980 $P_5$=1877-1928 $P_6$=1929-1980
$P_7$=1877-1964 $P_8$=1965-1980
*Significant at 5%, +Significant at 10%

#### 5. Change in the mean annual frequency

Mooley (1981) has brought out a significant increase in the mean frequency of severe storms striking the Bay coast from the period 1877 - 1964 to the period 1965 - 1980. Mooley and Mohile (1983) have shown highly significant increase in the mean annual frequency of storms reaching Bangladesh coast during the period 1965 - 80. They have also pointed out the fact that there is highly significant increase in the mean annual frequency of severe storms reaching some sections of the coast around the Bay of Bengal in the post-monsoon season. The different series of storms/severe storms were examined to see whether there are any significant changes in the mean for the different periods. The period of 104 years (1877 - 1980) was divided in four equal parts $P_1$ (1877 - 1902), $P_2$ (1903 - 28), $P_3$ (1929 - 54), $P_4$ (1955 - 80), two equal parts $P_5$ (1877 - 1928) and $P_6$ (1929 - 80). Changes in the mean from $P_1$ to $P_2$ from $P_2$ to $P_3$ and from $P_3$ to $P_4$ as well as from $P_5$ to $P_6$ were examined by applying the method given by Cochran (1954). Changes in the mean over the two periods $P_7$ (1877 - 1964) and $P_8$ (1965 - 80) were also tested for significance. The test statistic (Cochran 1954) is given by :

$$\chi^2 = \frac{n_1 n_2}{(n_1 + n_2)} \quad \frac{(\bar{Y}_1 - \bar{Y}_2)^2}{\bar{Y}} \quad \text{d.f. 1}$$

where $\bar{Y}_1$ and $\bar{Y}_2$ are the means for the two component periods of $n_1$ and $n_2$ years respectively and $\bar{Y}$ is the mean for the whole period. The test statistic is referred to Chi-square distribution for 1 d.f. The results of the test are given in Table 4. The examination of the table shows that there is increase in the mean significant at 5% level for storms and severe storms forming over the Arabian Sea from the period $P_3$ to $P_4$. It is interesting to note that in respect of the storms forming over the area there is increase significant at 10% level from the period $P_7$ to $P_8$, *i.e.*, from the period 1877 - 1964

TABLE 5

**Ratio of severe cyclonic storms/cyclonic storms during different periods**

| Series | Period | No. of storms | Ratio of severe storms to storms |
|---|---|---|---|
| Storms forming over the Arabian Sea | 1877-1884 | 3 | 0.66 |
| | 1885-1900 | 18 | 0.77 |
| | 1901-1916 | 19 | 0.63 |
| | 1917-1932 | 18 | 0.55 |
| | 1933-1948 | 17 | 0.58 |
| | 1949-1964 | 19 | 0.58 |
| | 1965-1980 | 26 | 0.58 |
| | 1877-1980 | 120 | 0.62 |
| Storms crossing the complete coast | 1877-1884 | 1 | 1.00 |
| | 1885-1900 | 9 | 0.55 |
| | 1901-1916 | 7 | 0.71 |
| | 1917-1932 | 10 | 0.50 |
| | 1933-1948 | 9 | 0.55 |
| | 1949-1964 | 8 | 0.75 |
| | 1965-1980 | 9 | 0.55 |
| | 1877-1980 | 53 | 0.60 |

to 1965 - 80, but no such increase is observed in case of the severe storms. The series of storms/severe storms reaching the coast do not show any significant increase during any period.

Ratios of severe cyclonic storms/cyclonic storms for the 16-year period 1965 - 80 and also for 16-year periods like 1885 - 1900, 1901 - 1916 etc were computed and are presented in the Table 5. The ratios are normally steady, both in respect of storms forming and storms reaching the coast.

Two reasons may be assigned to the increased frequency of storms over the Arabian Sea; improved network of observations with modern aids like satellite and radar, and more favourable meteorological conditions for formation of storms over the sea. Holland (1981) has studied in details the quality of data base in the Australian region and shown that the observations regarding the detection of storms over sea were very poor compared to that over the coast lines of that area. Same arguments may hold good for the storms over the Arabian Sea although no such studies have been made for the Indian region. It may be noted that 94(59) storms (severe storms) formed over the Arabian Sea from 1877 to 1964 and 44(27) reached the coast. The figures for the period 1965 - 80 are 26(15) and 9(5) respectively, showing significant increase in the mean annual frequency of storms forming over the sea. The empirical relationship used for estimation of storm intensity from satellite and radar pictures is quite complex and may not hold good for Indian region since it is obtained by using the data of other regions. Arnold (1977) has pointed out the cases in which estimation of intensity was rather difficult for some cyclonic storms of West Pacific. A comparative study of the estimation of storm intensity over the north Indian seas based on satellite cloud photographs and conventional wind data was made by Sikka (1971). He studied the tropical storms during 1965 - 68 and found that the exact agreement between the two in respect of intensity of the systems was in 60% of the cases. In majority of the cases of difference in intensity, the intensity determined by satellite pictures was higher. As such only a fraction of the increase of storms forming over the Arabian Sea can be attributed to better detection of storms by satellite/radar pictures.

**6. Location of origin of storms reaching the west coast of India**

Fig. 4 gives the locations of formation of storms which reached the west coast of India. The figure has been prepared for two different seasons, *viz.*, April - June and October - December. The main features are as follows :

(a) *Gujarat - Saurashtra coast* — During April - June storms are mainly formed around 70 deg. E between 12.5 deg. N & 22.5 deg. N and during October - December storms are mostly formed within 2 deg. around 70 deg. E between 10 deg. N & 20 deg. N.

(b) *Maharashtra and Kerala - Karnataka coast* — For both the seasons the storms are mostly formed to the east of 70 deg. E between 10 deg. N & 15 deg. N.

Fig. 5 gives for two different seasons the climatological information in respect of storms forming over the different sectors of the Arabian Sea and the number of storms from these sectors reaching the four main sections of the coast. The sectors are 2.5 deg. Lat. × 2.5 deg. Long. The underlined figure at the top of each sector gives the number assigned to the sector. The number within the circle gives the total number of storms which formed within that sector. The numbers in the left portion indicate, from top to bottom, the numbers of storms reaching the Yemen-Oman coast and the Pakistan coast and those in the right portion from top to bottom indicate the numbers of storms reaching the Gujarat-Saurashtra coast and the Kerala-Karnataka-Maharashtra coast. The difference between the total number of storms which formed over the sector and the total number of storms which reached the different sections of the coast gives the number of storms which dissipated over the sea. Only those sectors over which at least two storms were formed are considered. It is seen from this figure that :

(a) During April - June, the storms forming to the west of 67.5 deg. E do not strike the west coast of India. The maximum number of storms which formed is 6 in the grid number 13; of these, 2 reached Gujarat-Saurashtra coast and the remaining 4 dissipated over the sea.

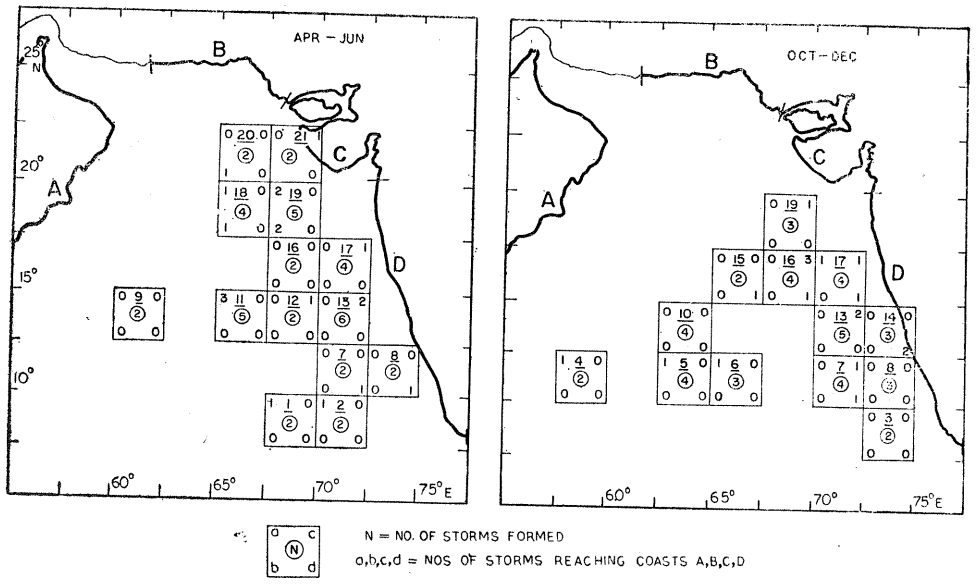


Fig. 5. Storms forming over different sectors (1 to 21) of the sea and reaching different sections (A to D) of the coast

**TABLE 6**

**Results of the variance test for applicability of the Poisson distribution to the different series**

| Series | Period | Value of test criterion | d.f. |
|---|---|---|---|
| Storms forming over the Arabian Sea | 1877-1964 | 96.98 | 87 |
| Do. | 1877-1980 | 112.27 | 103 |
| Severe storms forming over the Arabian Sea | 1877-1964 | 91.64 | 87 |
| Do. | 1877-1980 | 105.89 | 103 |
| Storms reaching the coast around the Arabian Sea | 1877-1964 | 92.00 | 87 |
| Do. | 1877-1980 | 109.87 | 103 |

**TABLE 7**

**Results of Chi-square test for fit of Poisson distribution to the different series**

| Series | Period | Value of test criterion | d.f. |
|---|---|---|---|
| Storms forming over the Arabian Sea | 1877-1964 | 0.30 | 2 |
| | 1877-1980 | 1.24 | 3 |
| Severe storms forming over the Arabian Sea | 1877-1964 | 0.29 | 1 |
| | 1877-1980 | 3.63 | 2 |
| Storms reaching the coast around the Arabian Sea | 1877-1964 | 0.18 | 1 |
| | 1877-1980 | 0.04 | 1 |

**TABLE 8**

**Observed and theoretical (on the basis of Poisson distribution) frequency distribution of storms forming over Arabian Sea/ crossing coast (Annual series)**

| Series | Period | No. of storms in a year | Observed frequency | Frequency on Poisson hypothesis |
|---|---|---|---|---|
| Storms forming over the Arabian Sea | 1877-1964 | 0 | 32 | 30.24 |
| | | 1 | 30 | 32.30 |
| | | 2 | 18 | 17.25 |
| | | 3 | 5 | 6.14 |
| | | ⩾4 | 3 | 2.06 |
| Severe storms forming over the Arabian Sea | 1877-1964 | 0 | 46 | 45.01 |
| | | 1 | 28 | 30.18 |
| | | 2 | 12 | 10.12 |
| | | ⩾3 | 2 | 2.70 |
| Storms crossing the coast around the Arabian Sea | 1877-1980 | 0 | 63 | 62.48 |
| | | 1 | 31 | 31.84 |
| | | 2 | 9 | 8.11 |
| | | ⩾3 | 1 | 1.57 |

(b) During October-December, majority of the storms are formed over the region between 62.5 deg. E and 75.0 deg. E and 10.0 deg. N to 17.5 deg. N. Maximum number (5) of storms formed in the same sector number 13 and of these, 2 reached Gujarat-Saurashtra coast and the remaining 3 dissipated over sea.

It can be concluded from Figs. 4 and 5 that the storms forming to the west of 67.5 deg. E normally do not pose any danger to the west coast of India.

**7. Probability model**

Mooley and Mohile (1983) have shown that Poisson probability model is a good fit to the number of storms (0, 1, 2, etc) reaching the different sections of the Bay coast in different seasons. It is expected that the same model may give a good fit to the number of storms/ severe storms forming over the Arabian Sea and reaching the coast around it. The test of variance for Poisson distribution as suggested by Cochran (1954) has been applied to the annual series of storms/severe storms forming over the sea for two different periods 1877-1964 and 1877-1980. The test has also been applied for the same periods to the series of storms reaching the coast around the Arabian Sea. Since the number of storms/severe storms in the two seasons April - June and October - December is small, only the annual series is considered. The results of the variance test are presented in Table 6. The test statistic for variance test is not significant at 5% level for any of the series for both the periods and thus supports the Poisson probability model. Chi-equare test has also been applied in these cases. The results are presented in Table 7. It is seen from the values of Chi-square ($\chi^2$) statistic that Poisson distribution is a good fit to the number of storms/severe storms forming in a year for the period 1877 - 1964. Due to significant increase in the mean annual frequency after 1964 in respect of storms forming over the Arabian Sea, the fit of the Poisson probability model is vitiated. However, for the number of storms reaching the coast around the Arabian Sea, the fit is very good for the period 1877-1964 as well as for the complete period 1877-1980. Table 8 gives the observed frequency distribution and the frequency distribution on the basis of the Poisson distribution.

**8. Climatological expection of storms reaching the coast for the next 50-year period**

It has been shown in the preceding section that the number of storms reaching the coast around the Arabian Sea is consistent with the Poisson probability model. The model can be used to obtain the frequencies of 0, 1, 2, 3 storms in a year and these can be used for planning funds for providing relief to the people affected by the cyclones. The mean-annual frequency of storms reaching these coasts during the period 1877-1980 is used to obtain the frequencies of 0, 1, 2, 3 storms reaching the coast in the next 50-year period (1981-2030 A.D.) on the basis of the Poisson model and these frequencies are 30, 15, 4, 1 respectively.

**9. Conclusions**

The following conclusions can be drawn :

(*i*) Increase in the mean annual frequency of cyclonic storms forming over the Arabian Sea during the period 1965 - 1980 is significant at 10% level. However, there is no significant increase in the number of storms reaching the coast around the Arabian Sea during 1965 - 80.

(*ii*) Poisson probability model is a good fit to the number of storms reaching the coast around the Arabian Sea during the year.

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