**Frequency, Intensity and Trend of Tropical Cyclone in Arabian Sea Basin**

***Abstract***

The world’s 40 percent population is living 100 km along the cost and the tropical cyclone is one of the serious threats to coastal population. Its vulnerability increasing as population increases along the coastal area because of economic activities. Hazard of abrupt sea water level rise due to meteo-tsunami caused by tropical cyclone may also give severe impact on coastal population which are underrated. In this study data of 130 years of tropical cyclone frequency over the Arabian Sea Basin from 1891 to 2020 were considered. Regression analysis, extrapolation of data, seasonality and anomaly were computed. The result indicates that the frequency of Cyclonic Depression (CD) during the months of October, November and December is higher than months of April, May and June, whereas the frequency of Cyclonic-Storm (CS) and Severe-Cyclonic-Storm (SCS) is reverse. The statistics indicate an overall increasing trend conclusively while in future more frequent tropical cyclone with greater intensity will be formed in the Arabian Sea. All stake holders need to focus on capacity building to minimize its devastations.

**Keywords: Tropical Cyclone, Regression analysis, North Indian Ocean, Arabian Sea, Risk of Tropical Cyclone, Disaster Management**

1. **Introduction**

Tropical Cyclones are among the most destructive natural disasters of the world. The Arabian Sea basin accounts for 7% of global tropical cyclones (Gray, Technical Document, 1985). More cyclones form in the Bay of Bengal than the Arabian Sea; the ratio of their respective frequencies is about 4:1 (Dube, Rao, Sinha, Murty, & Bahulayan, 1997). There are two cyclone seasons in the north Indian Ocean, pre-monsoon April, May and June (AMJ) and post monsoon October, November and December (OND). A few cyclones form in monsoon months July, August and September (JAS) due to position of (Intertropical Convergence Zone) ITCZ over land and establishment of Somali Jet stream which prevent formation of cyclone over Arabian Sea. Cyclone rarely form during winter months January, February and March (JFM) due to lower sea surface temperature however few cyclone form in late March and early January. On an average about 1–3 tropical cyclones (maximum sustained wind of 34 knots or more) form in Arabian Sea every year, among them 1-2 reach Severe stage (maximum sustained wind of 48 knots or more). The total number of tropical cyclones and frequency in Arabian Sea Basin during 1891-2020 is given in Table 1.

Table 1. Tropical cyclones in Arabian Sea during the period 1891 - 2020

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Cyclones in Arabian Sea Basin** | | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Sep** | **Oct** | **Nov** | **Dec** |
| Cyclonic Disturbance (CD) | Total | 1 | 0 | 1 | 8 | 36 | 55 | 9 | 2 | 14 | 52 | 42 |
| Freq | 0.008 | 0.000 | 0.008 | 0.062 | 0.277 | 0.423 | 0.069 | 0.015 | 0.108 | 0.400 | 0.323 |
| Cyclonic Storm  (CS) | Total | 1 | 0 | 0 | 6 | 29 | 26 | 2 | 1 | 9 | 32 | 21 |
| Freq | 0.008 | 0.000 | 0.000 | 0.046 | 0.223 | 0.200 | 0.015 | 0.008 | 0.069 | 0.246 | 0.162 |
| Severe Cyclonic Storm (SCS) | Total | 0 | 0 | 0 | 4 | 20 | 17 | 0 | 0 | 5 | 15 | 16 |
| Freq | 0.000 | 0.000 | 0.000 | 0.031 | 0.154 | 0.131 | 0.000 | 0.000 | 0.038 | 0.115 | 0.123 |

The socio-economic impact of tropical cyclones is significant (Obasi, 1997). Major aviation and shipping routes of Arabian Sea adversely affect by tropical cyclone and induce hazards for trading ships and international flights. Tropical Cyclone of Arabian Sea land falls over India 26.7%, Oman 19.9%, Pakistan 4.2%, Somalia 3%, Yemen 3% whereas terminates at sea 43.2% (40.7% in Arabian Sea and 2.5% in Gulf of Aden) coasts of India receive more frequent Tropical Cyclones however rest countries surrounding Arabian Sea receive comparable less frequent TC whereas but they suffer an enormous loss of life and property(Suad Al-Manji and Gordon Mitchell and Amna Al Ruheili, 2021)(Fritz, Blount, Albusaidi, & Al-Harthy, 2010). The frequency of cyclone exhibits variation in different time scales. For instance, Cyclone activity may be affected by the changes in sea surface temperature (SST). Therefore, El-Nino/Southern Oscillation is known to influence cyclone frequency in different ocean basins (Shapiro, 1982).(Chan & Gray, 1985).

Some investigators have studied the changes in the tropical cyclone frequency in the north Indian Ocean (Ali, 1995)(Joseph, 1995), but they have not been able to bring out significant changes due to the smoothing of frequencies on the annual time scale. The main objective of this present study is to find out the trend and frequencies of cyclone of Arabian Sea during past centuries (1891-2020, 130 years data) and predict the future trend (30 years projected frequency 2021-2050. This study will help to assess the trend of tropical cyclonic hazards which is a serious threat to coastal populations and will cause socio-economic losses.

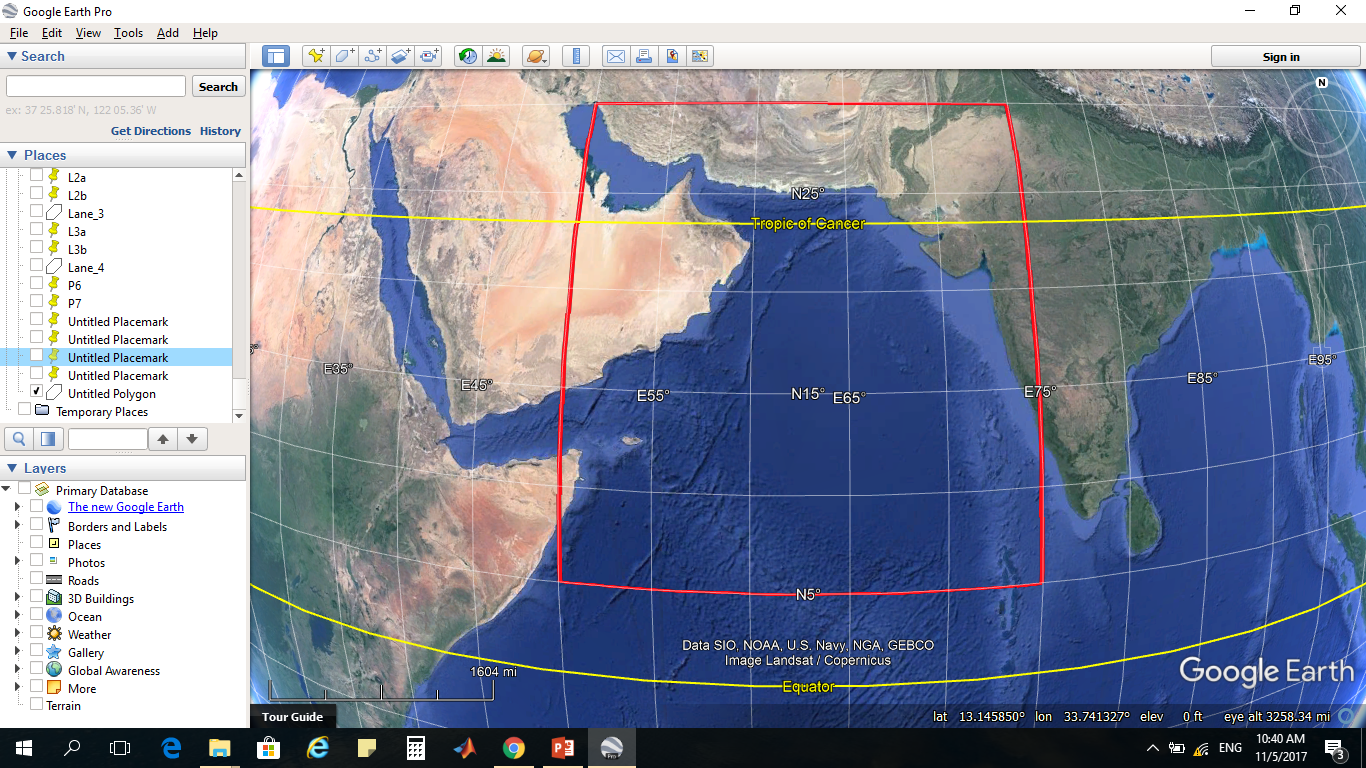


Figure 1 Study Area (Arabian Sea Basin) Courtesy Google Earth

*The regression analysis shows increasing trend of Cyclonic-Depression, Cyclonic-Storm and Severe-Cyclonic-Storm* ***0.0146****,* ***0.0037*** *and* ***0.004*** *respectively. The anomaly of cyclone formation (Cyclonic Depression, Cyclonic Storm and Severe Cyclonic Storm) frequency and percentage increase also computed using 100 years Normal (1891-1990) and 30 years average (1991-2020). The anomaly of frequency and [percentage increase in frequency] are, for Cyclonic-Depression* ***0.86 [65.3%]****, Cyclonic-Storm* ***0.57 [61.4%]*** *and Severe-Cyclonic-Storm* ***0.48 [52.0%]****.*

1. **Material and Methods**

The source of data of tropical cyclone frequency in the north Indian Ocean for the period 1891–2020 is an India Meteorological Department publication (IMD, 1979). The domain of investigation is 5°N–30°N and 50°E– 75°E and the same domain has been considered for the data for 1891–2020, which have been obtained from different volumes of the quarterly journal Mausam and official website of India Meteorological Department.

The criteria used in the classification of Cyclonic-Depression, Cyclonic-Storm and Severe-Cyclonic-Storm are as follow (Tang, Sui, Lavy, Pozdnyakov, Song, & Switzer, 2014)

|  |  |  |
| --- | --- | --- |
| **S.No** | **Classification of Cyclone** | **Maximum Sustained Wind** |
| 1 | Cyclonic Depression (CD) | 17 Knots or more |
| 2 | Cyclonic Storm (CS) | 34 Knots or more |
| 3 | Severe Cyclonic Storm (SCS) | 48 Knots or more |

Decadal moving average of frequencies for Cyclonic-Depression (CD), Cyclonic-Storm (CS) and Severe-Cyclonic-Storm (SCS) on annual basis have been calculated and the linear trends have been computed using the least-squares method (Legendre, 1805). The intensification rates of Cyclonic-Disturbances to Cyclonic-Storm and Severe-Cyclonic-Storm stages have been computed for each season and year to classify the cyclonic disturbance, CS and SCS its frequency and trend computed separately. Decadal smoothing ten years moving averages of these intensification rates along with the trends have also been computed. In order to assess whether the increasing or decreasing anomaly (changes) in frequencies trends of CD, CS and SCS over two time-scales (1891-1990 and 1991-2020) in the Arabian Sea. One time scale is used for 100 years climatic normal based on 1891 to 1990 events. Second-time scale used to compute 30 years average based on 1991 to 2020 data and anomaly were also computed through difference of these two datasets. Seasonal trend and annual trend of all three stages of cyclone from Cyclonic-Disturbance, Cyclonic-Storm and Severe-Cyclonic-Storm have also been computed for Arabian Sea separately. For next 30 years 2021-2050 projected trends were also computed.

1. **Results and Discussion**

Tropical cyclones generally form during AMJ and OND these are cyclonic season for Arabian Sea and pre-monsoon and post-monsoon respectively. Frequency of formation of cyclonic depression (CD) are higher during OND (I.e 109 events in last 130 years) than AMJ (99 events in last 130 years), whereas the frequency of Cyclonic-Storm (CS) and Severe-Cyclonic-Storm (SCS) is higher during AMJ (i.e 61 events and 41 events respectively) than OND (i.e 60 events and 35 events respectively) as shown in Figure 2.

Figure 2 Quarterly Frequency (along y-axis) of Cyclonic Depression, Cyclonic Storm and Severe Cyclonic Storm in Arabian Sea (1891-2020)

In the Arabian Sea during the months of January, February and March rarely tropical cyclone form as shown in figure 3. Two prominent cyclonic seasons can be seen i.e. pre-monsoon and post-monsoon period. Whereas during monsoon period specially July, August and September Somali jet stream formed over Arabian Sea which prevent the formation of a tropical cyclone in the Arabian Sea and ITCZ form over the land area north of Arabian Sea.(Lashkari, Mohammadi, & Keikhosravi, 2017) In figure 3 it can be observed that the highest frequency of formation of Cyclonic-Depression (CD) 55 events during the month of June (in last 130 years), Cyclonic-Storm (CS) 32 events during the month of October (in last 130 years) and Sever-Cyclonic-Storm (SCS) 20 events during the month of May (in last 130 years).

Figure 3 Seasonality of Tropical Cyclone in Arabian Sea

Trend of Frequency of Cyclonic-Depression, Cyclonic-Storm and Severe-Cyclonic-Storm is computed by linear regressions (Least square method). Results show the increasing trend of Cyclonic-Depression, Cyclonic-Storm and Severe-Cyclonic-Storm **0.0146**, **0.0037** and **0.004** with regression coefficient **R2 0.1273, 0.0164** and **0.0274** respectively. Trend line regression of Cyclonic-Depression has significant rising trend. Cyclonic-Storm and Severe-Cyclonic-Storms regressions indicating very small increasing-trend as mentioned in Figure 4.

Figure 4 : Trend and Frequency of Tropical Cyclone in Arabian Sea (1891-2020)

To minimize small variations in order to examine the trend in broader spectrum 10 years moving average plot has been generated as shown in Figure 5, which shows a decadal smoothing of Cyclonic-Disturbance, during winter season (1st quarter- January, February, and March) tropical cyclone very low rate of formation. The 2nd quarter (April, May, June) and 4th quarter (October, November, December) are almost pre-monsoon and post-monsoon periods, respectively. During 1900 to 1908, 1917 to 1940, 1949 to 1959 and 2005 to 2012 frequency of development of cyclonic disturbance is higher during pre-monsoon period than post-monsoon from 1908 till 1916 both frequency of cyclonic disturbance during pre and post-monsoon are same for rest of the period. The frequency of cyclonic disturbance is higher during post-monsoon period than pre-monsoon period, during 1960 to 1990 and 1999 till 2019 frequent cyclonic disturbance also developed during monsoon (July, August and September) period.

Figure 5 Seasonality trend of Cyclonic Disturbance with decadal smoothing

Figure 6 shows the decadal trend of cyclonic formation where it is evident that during winter season (1st quarter- January, February, March) tropical cyclone rarely form. However, during 1935 to 1944 development of cyclonic Storm can be seen. During 2nd quarter (April, May, June) and 4th quarter (October, November, December) during 1900 to 1908, 1915 to 1937, 1949 to 1965, 1960 to 1969, 1977 to 1987, 1991 to 1993 and 2006 to 2012 frequency of development of cyclonic Storm is higher, during pre-monsoon period than post-monsoon. However, during 1908 till 1912, 1937 till 1939, 1947 till 1949, 1955 till 1965, 1969, 1970, 1975, 1976, 1987, 1988, 1993, 1994, 2005 and 2006 frequency of cyclonic Storm during pre and post-monsoon are nearly same for rest of the period. The frequency of cyclonic Storm is higher during the post-monsoon period than pre-monsoon period. Occasionally tropical Cyclone form during monsoon period of the years 1990 and 1912, 1926 to 1939, 1963 to 1989 and 2000 till 2014.

Figure 6 Seasonality trend of Cyclonic Storm with decadal smoothing

Figure 7 shows a decadal trend of Severe Cyclonic Storm, where during winter season (1st quarter- January, February, March) Severe Cyclonic Storm did not observe. During 2nd quarter (April, May, June) and 4th quarter (October, November, December) during 1900 to 1939, 1947 to 1956, 1960 to 1970 and from 2000 to 2010 the frequency of development of Severe Cyclonic Storm is higher, during pre-monsoon period than post-monsoon and for rest of the period, the frequency of Severe Cyclonic Storm is higher during the post-monsoon period than pre-monsoon period.

Figure 7 Seasonality trend of Severe Cyclonic Storm with decadal smoothing

In order to compute the impact of climate change on the frequency of Tropical Cyclone anomaly has been calculated based on climatic normal of 100 years from 1891 till 1990 and average of 30 years from 1991 to 2020.

Figure 8 shows that during months of April, July and August anomaly is negative showing that the frequency of Cyclone Depression (30 year average) is decreased from climatic normal of 100 years. Whereas positive anomaly is observed for the months of May, June, September, October, November and December means an ~~i~~ncreased frequency of Cyclonic Depression. However, almost no change in anomalies for months of January and February.

Figure 8 Anomalies in Frequency of formation of Cyclonic Disturbance in Arabian Sea

During months of April, July and August anomaly is negative showing decreasing trend. Whereas positive anomaly observed for the month of May, June, September, October, November and December means increasing trend these months as shown in Figure 9. No change in the month of January, February and March.

Figure 9 Anomalies in Frequency of formation of Cyclonic-Storm in Arabian Sea

Figure 10 shows Climate Normal (100 years 1891 – 1990) in the blue line, Average 30 years (1991-2020) in the orange line, anomalies in gray colour (100 years climatic normal and 30 years average), during months of April anomaly is negative means frequency of Severe-Cyclone-Storm decreased. Whereas positive anomaly observed for the month of May, June, September to December means increased trend in these months. Whereas anomaly for the month of Jan, Feb, March, July and August is equal to zero indicating no change of frequency during these months.

Figure 10 Anomalies in Frequency of formation of Severe-Cyclonic-Storm in Arabian Sea

Figure 11 shows the comparison of Cyclonic-Depression, Cyclonic-Storm and Severe-Cyclonic-Storm and its anomaly, which indicate that overall increased anomaly of frequency of formation of Cyclonic-Depression, Cyclonic-Storm and Severe-Cyclonic-Storm is **0.86**, **0.57** and **0.48** respectively and percentage change **65.3%** for Cyclonic-Depression, **61.4%** for Cyclonic-Storm and **52.0%** for Severe-Cyclonic-Storm.

|  |  |  |  |
| --- | --- | --- | --- |
| **Frequency of formation of Cyclone in Arabian Sea** | **CD\_AS** | **CS\_AS** | **SCS\_AS** |
| 100 Years Normal 1891-1990 | 1.61 | 0.90 | 0.52 |
| 30 Years Average 1991-2020 | 2.47 | 1.47 | 1.00 |
| Anomaly | 0.86 | 0.57 | 0.48 |
| Percentage Increase | 65.3 | 61.4 | 52.0 |

Figure 11 Normal & Mean Annual Frequency of CD, CS & SCS in Arabian Sea

In order to forecast the future trend of formation of tropical cyclone, forecast generated for next 30 years (From 2021-2050) based on Linear Regression Model of Frequency Trend of Tropical Cyclone in the Arabian Sea which reveals that Frequency of Cyclonic-Depression (Shown in Blue) will be about 3.1 base line which was about 1 in 1891 whereas Cyclonic-Storm (Shown in brown) will be about 1.5 base line which was 0.9 in 1891 and for Severe-Cyclonic-Storm (Shown in Gray Colour) 1.0 base line which was 0.5 in 1891 as shown in Figure 12.

Figure 12 : Forecasting for 2050 based on Linear Regression Model of Frequency Trend of Tropical Cyclone in Arabian Sea (1891-2020)

1. **Conclusion and recommendation**

This paper endows with a basic knowledge about frequency, intensity and trend of tropical cyclone in the North Arabian Sea during 1891-2020 (130 years). The frequency of Cyclonic-Depression is higher during post-monsoon than pre-monsoon while the frequency of Cyclonic-Storm and Severe-Cyclonic-Storm is higher in pre-monsoon than post-monsoon period.

Anomalies of long term climate normal (100 years) and 30 years Average showing positive change which indicate that overall increased anomaly of frequency of formation of Cyclonic-Depression, Cyclonic-Storm and Severe-Cyclonic-Storm is **0.86**, **0.57** and **0.48** respectively and percentage change **65.3%** for Cyclonic-Depression, **61.4%** for Cyclonic-Storm and **52.0%** for Severe-Cyclonic-Storm.

Increasing trend of tropical cyclone in the Arabian Sea is a alarming situation (because of increasing trend of frequency and intensity) countries surrounding the Arabian Sea is more prone to cyclonic hazard. Due to this increasing trend, it is determined that there were several very severe storms since 1891 in the north Arabian Sea. It is need of to focus all the stake holders of the region should take indispensable measures to increase the awareness in common people, growth of mangrove forest along the coast, upgrading of warning systems of the weather broadcasting centre and the countermeasures taken by the respective administrative agencies. In another words all stake holders need to focus on capacity building in a synergic way to minimize devastations of Tropical Cyclone related disasters.

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