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## CYCLONE PRONE AREAS IN THE EAST COAST OF INDIA

1. The Bay of Bengal, part of Indian Ocean, is one of the six regions of the world where the tropical cyclones originate. To the Bay of Bengal, the coastline of the Tamilnadu, A.P, Orissa is the western boundary and West Bengal (India) and Bangladesh, the northern boundary. The cyclonic storms usually affect the East Coast of India (ECI) every year mostly during monsoon seasons.

The ECI, between latitudes 10° N and 16° N is nearly parallel to Longitude 80° E, between Latitudes 16° N and 21° 30' N it runs NE-SW direction and then runs nearly parallel to Latitude 21° 30' N up to Cox's Bazar (Bangladesh). The inter-relationship between the topography of the coast and hinterland and cyclones is presented in this paper.

2. The Andhra coast was battered by high-energy storms on 25<sup>th</sup> November 1922, 18<sup>th</sup> November 1933, 18<sup>th</sup> November 1938 and 6<sup>th</sup>, 7<sup>th</sup> and 21<sup>st</sup> November 1969 and 6<sup>th</sup> November 1996 in the last century.

The 19<sup>th</sup> November 1977 cyclone, a 100year super cyclone, devastated Divi taluk in Krishna district killing thousands of people and livestock. It is known that storm surge tidal waves battered the same coastal strip, the Krishna delta in 1699, 1777 and 1864.

Desai and Waikar (1997) have studied translation speed and place of recurvature of cyclonic storms between 1970 and 1994. Rao *et al.*, (1997) have studied the storm surge prediction and frequency analysis for Andhra coast of India. Krishna Rao (1997) has studied the synoptic methods of forecasting tropical cyclones and Dube *et al.* (1997), storm surge in the Bay of Bengal and Arabian Sea. The tropical cyclones / hurricanes / typhoons “develop over the oceans in Latitudes 8° to 15° N and S, but not close to the equator, where the Coriolis force is extremely weak” (Strahler, 1969). These in the western North Pacific, Bay of Bengal and Arabian Sea develop through out the year but the frequency is more from May through November (Strahler, 1969). This is obvious from the analysis presented in this paper.

Bay storms, which are in northern Latitude moves northwest and later, recurve towards the northeast (IMD, 1979; IMD, 1996; NATMO, 1981). In the Bay of Bengal, the cyclones season is from June to November, where as in the Celebes Sea and the south China sea (Pacific ocean), the typhoon season is July to October (Macmillan School Atlas, 2001). The forces and fluxes of the Pacific

Ocean that cross the Gulf of Thailand, Malay Peninsula, Andaman Sea and Andaman & Nicobar Islands also contribute to the disturbances (depressions, cyclones, storms) in the Bay of Bengal.

The May and November disturbances are just before northern summer solstice (June 21) and northern winter solstice (December 22) respectively. Some of the cyclones may coincide with El Nino and La Nina phenomena.

3. The total number of cyclonic disturbances originated from Bay of Bengal between 1891 and 1997, were 1256 in which 457 intensified into storms (IMD, 1979, 1996). The month-wise frequency data is presented in Table 1.

3.1. In May, the total number of cyclonic disturbances originated from Bay of Bengal was 88 (Table 1). Most of them originate between Latitudes 10° N and 15° N, and Longitudes 85° E and 95° E. They move initially in a northwesterly or northerly direction and then recurve towards the northeast.

In the month of May, the total number of disturbances (depressions, cyclones and storms) that crossed the ECI was 52, out of which 45 intensified into cyclones and crossed and damaged the coastal area. In these cyclones 9 crossed the A.P. coast. Most of the above cyclones crossed the coasts of Nellore (Pennar delta), Prakasam, Guntur and Krishna (Krishna delta), west and east Godavari (Godavari delta) districts in Andhra Pradesh. In the remaining 36 cyclones, the area wise frequency is Nagapattinam to Nellore (Cauvery delta), 10; Gopalpur to Calcutta (Mahanadi delta), 6; Calcutta to Akyab (Ganges and Brahmaputra delta), 20. The six cyclonic storms that devastated Andhra coastal districts in May are listed below:

26 <sup>th</sup> May 1904	- West Godavari district
15 <sup>th</sup> May 1914	- Srikakulam district
16 <sup>th</sup> May 1925	- Krishna district
19 <sup>th</sup> / 20 <sup>th</sup> May 1940	- Nellore district
7 <sup>th</sup> May 1979	- Guntur district
6 <sup>th</sup> May 1990	- Krishna district

3.2. The source region of the majority of the storms during November is between Latitudes 8° N and 15° N and Longitudes, 85° E and 95° E. These move in west-northwesterly direction, strike the north Tamil Nadu and adjoining south Andhra coast (Nellore district). Some

TABLE 1

Annual variation of frequency of cyclonic disturbances originating over Bay of Bengal during the period 1891-1997

S. No.		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1.	Total No. of disturbances	19	4	6	30	88	127	162	196	194	189	160	81	1256
2.	Percentage distribution	1.5	0.3	0.5	2.4	7.1	10	12.9	15.6	15.4	15	12.2	6.4	100
3.	Total number which intensified into storms	6	1	4	22	52	38	41	30	39	79	101	44	457
4.	Percentage distribution	1.3	0.2	0.9	4.8	11	8.3	9	6.6	8.5	17.3	22.1	9.6	100
5.	Percentage of cyclonic disturbances intensifying into storms	32	25	67	73	59	30	2.3	15.3	20.1	41.8	63.1	54.3	36.4

TABLE 2

Cyclones crossed in coastal districts of Andhra Pradesh, Orissa, West Bengal and Bangladesh during months of May and November from the year 1891-1997

Name of the district/area	Major Rivers	1		2		3	4
		a	b	a	b		
Srikakulam	Vamsadhara	0	0	1	1	0	1.63
Vizianagaram	Nagavali	0	0	0	0	0	0
Visakhapatnam	Sarada	0	0	1	1	0	1.63
East Godavari	Godavari	1		0		2.23	0
West Godavari				3		2	
Krishna	Krishana	2		7		4.45	11.47
Guntur				3		8	
Prakasam		1		1		2.23	1.63
Nellore	Pennar	1	1	6	6	2.23	9.83
Nellore-Nagapatnam	Cauvery	2	2	6	6	4.45	9.83
Gopalpur-Calcutta	Mahanadi	10	10	23	23	44.45	38
Calcutta-Akyab	Ganges- Brahmaputra	6	6	4	4	13.34	6.55
Total			20	20	10	10	44.45
		45		61			

1. No. of cyclones crossed in the month of May
2. No. of cyclones crossed in the month of November
3. % of cyclones crossed in the month of May
4. % of cyclones crossed in the month of November

- a : Through the district  
b : Through the river basin

cross the land and emerge into the Arabian Sea. In November, out of the total 160 numbers of cyclonic disturbances that originated from Bay of Bengal (Table 1), 61 crossed the ECI. Of these, the cyclones that crossed the A.P. coast were 24, Nagapattinam to Nellore, 23; Gopalpur to Calcutta, 4; Calcutta to Akyab, 10 (Table 2).

In Tamil Nadu, most of the cyclones cross the coastline between Nagapattinam and Pondicherry (Cauvery delta) and also because of Sri Lanka.

In Andhra Pradesh, most of the cyclone crossing points is in the Godavari, Krishna and Pennar delta areas. In Orissa, the Mahanadi delta area suffers from cyclones. Most of the delta areas of Krishna, Godavari and Mahanadi rivers are below 10 m contour level. The reported storm tidal height in the recent cyclones is upto 10 m, and hence, these coastal plains are subjected to inundation.

High tide coupled with cyclonic storm surge impedes the discharge of river flood flows into sea, which results in

TABLE 3

Width of coastal plain upto +50 m and continental shelf up to -100 m along the latitudes in the east coast of India

S. No.	Latitude in degrees (North)	1	2
1	10° (Devakottai)	43	32/141
2	10° 15'	24	20/105
3	10° 30' (Thanjavur)	83	6/39
4	10° 45' (Nagapattinam)	76	4/36
5	11° (Karikal)	77	3/36
6	11° 15' (Mannargudi)	50	1/24
7	11° 30' (Vridhachalam)	61	4/20
8	11° 45'	50	5/19
9	12° (Madras coast)	42	2/24
10	12° 15' (Olakkur)	38	3/29
11	12° 30' (Madurantakam)	45	4/38
12	12° 45' (Chingleput)	38	3/67
13	13° (St. Thomas Mount)	34	3/26
14	13° 15' (Arani)	40	5/22
15	13° 30' (Nagari hills)	46	3/19
16	13° 45' (Kalahasti)	53	6.5/19
17	14° (Venkatagiri)	60	2/21
18	14° 15'	54	5/18
19	14° 30' (Buchireddipalem)	55	4/20
20	14° 45' (Bitragunta)	35	4/20
21	15°	47	2/25
22	15° 15'	38	5/32
23	15° 30' (Nishankonda)	50	7/46
24	15° 45'	53	4/27
25	16° (Chilakalurupeta)	113	14/34
26	16° 15' (Guntur)	180	12/86
27	16° 30' (Amaravathi)	220	13/20
28	16° 45' (Tammileru)	142	2/17
29	17° (Chintalapudi)	135	5/50
30	17° 15' (Eleswaram)	46	5/80
31	17° 30' (Sanjibkonda)	40	3/65
32	17° 45' (Chodavaram)	50	3/59
33	18° (Jami)	33	4/68
34	18° 15' (Ponduru)	34	7/45
35	18° 30' (Rajam)	55	4/47
36	18° 45' (Nuvalrevu)	4	5/45
37	19° (Mahendragiri)	29	2/40
38	19° 15' (Regara)	20	4/42
39	19° 30' (Taptani Ghat)	67	4/55
40	19° 45' (Sumondolo)	69	7/66
41	19° 45' (Sumondolo)	112	2/50
42	20° (Calcutta coast)	135	3/75
43	20° 15' (Mahanadi)	130	8/119
44	20° 30' (Mahavinayaka)	94	14/131
45	21° (Bhadrak plain)	86	10/230
46	21° 15' (Bola)	56	21/249

1. Coastal plain upto +50m contour (kilometers)

2. Continental shelf width upto -10m depth / -100 m depth (kilometers)

inundation of the coastal areas. Hence, it is noted that the areas between Kakinada and Nagapattinam in the south and between Gopalpur (Orissa) and Bangladesh coast in the north are 'High' cyclone damage prone. The remaining areas such as the Vamsadhara and Nagavali basins suffer from heavy rains with wind and high river floods.

4. The continental shelf (-10 & -100 m bathy contours) widths, measured along the Latitudes vary between 19 km and 270 km (Table 3). However, most of the widths are between 20 km and 70 km. The east coast continental shelf of India has greater width - off Ganga-Brahmaputra, Mahanadi, Godavari-Krishna and Cauvery deltas. The highest widths are in the north of the Mahanadi delta (Lat. 20° 30' N and 21° 30' N).

The continental shelf off Ganga-Brahmaputra deltas at the northern part of the Bay of Bengal is wide. In this region, the tide height at Haldia, Diamond Harbour (Calcutta) is about 6 m and at Akyab (Myanmar), about 2.5 m. Similarly, storm waters also pile up in this region. As the Ganga-Brahmaputra delta in West Bengal and Bangladesh is pretty wide with number of distributaries and tidal creeks as well as good population density, the damage due to cyclones will be severe. It is noted that continental shelf widths between coastline and -10 m bathy contour and between -10 m & -50 m bathy contours are more at the Mahanadi, Krishna and Cauvery deltas (Table 3). The tide heights in this region-Tuticorn to Visakhapatnam to Paradip vary between 1 m and 2.5 m. During cyclonic disturbances, the waves that approach the coast with wide continental shelf will have large wave heights, which prevent river flood, flow resulting in the coastal floods.

5. The width of the east coastal plain (upto +50m above msl) varies from 4 km to 220 km (Table 3). However, most of the widths are between 30 km and 70 km. It is noted that the coastal plain having greater widths coincide with the Cauvery, Pennar, Krishna-Godavari, Mahanadi and Ganga-Brahmaputra river delta areas (Table 3). As a result, more number of cyclones crosses the land at these areas. The cyclones are not crossing the ECI in the narrow coastal plain between the Godavari and Mahanadi because of the eastern Ghats which run into the Bay of Bengal. Some of the cyclones crossing the ECI, turn northeastwards parallel to the trend (NE-SW) of eastern Ghats. This results in heavy rainfall in the upper reaches of the ephemeral rivers (e.g., Vamsadhara, Nagavalli, Sarada, Tandava, Tammileru) which cause in flooding of the plains. As the density of population in the coastal region is high, the damage is directly proportional.

6. The eastern Ghats acts as barriers, to the storm tracks. The eastern Ghats starts from Vaigai valley in the south and runs nearly parallel to the east coast upto Mahanadi valley in the north. The maximum elevation in different parts of the eastern Ghats in A.P. are at - Mallama Konda, 893 m (Pennar); Papikonda, 679 m (Godavari); Cherukonda, 1441 m; Arma Konda, 1680 m; Nimgiri, 1515 m; Singarazu Parbat, 1516 m; Mahendra Giri (near Mandasa, Srikakulam district) 1510 m. In the Krishna delta, the eastern Ghats are far from the coastline and have altitudes less than 550 m. Therefore, the cyclones that cross the Krishna delta region travel westward into Telangana Plateau.

The cyclonic storms cross the ECI at the delta region of the Brahmaputra-Ganges, the Mahanadi, the Godavari, the Krishna, the Pennar and the Cauvery and pass further inland through the respective river valley. The cyclonic disturbances are less between Pentakota (east Godavari district) and Baruva (Srikakulam district) because the eastern Ghats run near and into the Bay of Bengal and their high altitudes.

7. The following broad conclusions can be drawn from the above analysis

(i) Most of the cyclones are originating between the Latitudes  $8^{\circ}$  N and  $15^{\circ}$  N and Longitudes between  $85^{\circ}$  E and  $95^{\circ}$  E.

(ii) Most of the cyclone tracks cross the coast at the mouths of the rivers with wide continental shelf and coastal plain. The deltas of the – Cauvery, Pennar, Krishna, Godavari, Mahanadi, Ganga and Brahmaputra – are high cyclone prone areas.

(iii) The area between Pentakota (east Godavari district) and Baruva (Srikakulam district) are less prone to cyclones because the eastern Ghats is on the coast.

(iv) The high storm surge associated with high tide will impede the river flood flow, which results in inundation of the coastal areas below +10 m contour.

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P. MALLESWARARAO  
B. S. JASMIN

*Department of Civil Engineering, Andhra University,  
Visakhapatnam, India  
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