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Tropical Cyclone Damages in Sri Lanka

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1. INTRODUCTION TO TROPICAL CYCLONES

A tropical cyclone is a region of violently circulating air about a central core of low atmospheric pressure relative to its surrounding. These devastating atmospheric phenomena are capable of surface winds with sustained maximum speeds in excess of 62 km/hr, torrential rains along and between its spiral bands, huge swells and strong currents upto great depths when over the ocean and powerful storm surges while making landfall.

Tropical cyclones generally form between the 5°-25° North and South latitudes and are relatively rare events. Strong trends are immediately recognized over oceanic basins such as the North Atlantic or Northeast Pacific, Indian or Southwest Pacific and the Northwest Pacific, where they are also referred to as hurricanes, cyclones or typhoons. Variability in the quality and quantity of data as well as regional practices of climatology have led to several tropical cyclone classification systems from the more commonly known Saffir-Simpson Hurricane Wind Scale (SSHWS) to the Classification of Cyclonic Disturbances in the North Indian Ocean by the India Meteorological Department (IMD), and to the Japan Meteorological Agency's Tropical Cyclone Intensity Scale^[1]. Table 1 depicts many different tropical cyclone classification systems adopted^[1].

Historic records show that the Northwest Pacific basin generates the most number of tropical cyclones (approximately 25-26 per annum on average) and that the North Indian basin generates the least (approximately 5-6 per annum on average)^[1]. The North Atlantic cyclone basin yielded the costliest tropical cyclone, when hurricane Katrina caused property damage estimated to be

in excess of 100 billion US dollars in eastern North America^[2]. The North Indian cyclone basin has dealt the deadliest one where the Bhola cyclone of 1970 killed more than 300,000 people in Bangladesh^[3]. Furthermore, IMD's Regional Specialized Meteorological Centre (RSMC) states that among all recorded cases of tropical cyclones around the world which caused great loss to human life, 9 out of the leading 10 had their origins in the North Indian cyclone basin^[4]. This indicates the serious lack of regional preparedness, disaster warning, proper implementation of standardized operational procedures and resilient infrastructure. Sri Lanka, being situated within the 5°-10° northern latitudes and the 79°-82° eastern longitudes, is prone to face destructive weather conditions during the North Indian cyclone season.

2. FREQUENCY AND SEASONALITY OF TROPICAL CYCLONES

Thambyahpillay (1959) conducted a comprehensive study on tropical cyclones which impacted Sri Lanka during the period 1845-1958 and found that 71 (approximately 72%) of the total of 99 cyclones and depressions had occurred between October and December^[5]. A similarity emerges when compared with the data jointly compiled by the Disaster Management Centre (DMC) of Sri Lanka and UNDP, where among the 22 cyclones, that had crossed or been in the vicinity of the coasts of Sri Lanka over the period 1881-2001, 16 (approximately 73%) of these had occurred during the months of November and December^[6]. When considering the direction of approach and/or coastal impact, 17 among those 22 cyclones have affected the East coast of Sri Lanka, three affected the West Coast and

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one each had affected the North and South Coasts of the country^[6]. Also 13 among the said 22 were classified as Cyclonic Storms (CS) and the rest as Severe Cyclonic Storms (SCS)^[6]. Furthermore, 11 among the 13 CSs (17/12/1912 & 5/5/1930 were in the vicinity) and 8 among the 9 SCSs (29/11/1955 was in the vicinity) have crossed Sri Lanka in the last century^[6]. In a detailed study carried out by Perera (2004) on the origins, track and rainfall distribution resulting from cyclones over Sri Lanka, it was identified that 10 CSs and 7 SCSs have crossed within the last century^[7]. Though records show that SCSs which crossed the country have been the most destructive, a few of those that were in the vicinity have had devastating impacts as well. Table 2 compiles CS as well as SCS of the past century, emphasizing similar findings among other valuable research carried out by Zubair (2003)^[8] and Wijetunge (2013)^[9]. Figures 1a & 1b show CS and/or SCS trajectories over Sri Lanka^{[5][6]}.

3. SEVERE CYCLONIC STORMS OF THE PAST CENTURY

Among the tabulated SCSs in Table 2, the Dec 1964 Trinco-Mannar cyclone was the worst in terms of loss of lives. The death toll was estimated to be well over a 1,000 with unofficial estimates placing it at over 2,000^[10]. The government, at that time, regarded this as "the greatest tragedy to ever hit Ceylon". Known also as the 1964 Rameswaram or Dhanushkodi Cyclone, it resulted in the Dhanushkodi train disaster, due to the storm surge which was estimated at 7m^[11]. Maximum sustained wind speeds reached 161 km/hr in Trincomalee, 158 km/hr in Mannar and approximately 240 km/hr near Pamban Island (India) with wind gusts peaking as high as 280 km/hr (in modern times this system would be classified as a Super Cyclonic Storm)^{[11][12]}. The lowest pressure was observed at Mannar, registering a value of 978 mbars^[11]. The twenty-four hour daily rainfalls were over 127 mm and the highest was 245.9mm at Vavuniya^[12]. Figure 2a & 2b respectively show the wind speed and pressure measurements for Trincomalee^[13]. Figures 3a & 3b highlight the extent of damage.

The Batticaloa cyclone of Nov 1978 was amongst the most destructive endured by Sri Lanka, and claimed more than 915 lives, injured more than 4,500 and severely damaged well over 100,000 buildings^{[12][14]}. Much damage was caused to crops (cocunut 90%, perennial crops 70% and paddy 60%) and it was estimated that only 2% of the total buildings of the affected area had not suffered damage, where the total damage estimated was about 50 million US dollars^[14]. It also blew away the roofs of 50% of all buildings in its path^{[12][15]}. Suppiah (1982), states that this was one of the major catastrophic events in the country's history within the last 136 years and that an area approximately 11,000 sqkm comprising of Batticaloa,

Polonnaruwa, Amparai and Trincomalee Districts suffered its passage. Damaged regions due to the passage of the cyclone are shown in Figure 4^[14]. Maximum wind speeds of 145 km/hr were reported at Batticaloa with satellite estimates as high as 222 km/hr (Super Cyclonic Storm Category) and the storm surge height recorded at Batticaloa was 2m where it was reported that the sea had come inland upto 1.5 km at Kalkuda^[12]. Figures 5a, 5b & 5c highlight the extent of damage^[14].

The SCS that struck Batticaloa in March 1907 resulted in 64 lives being lost and about 1,842 buildings being destroyed^[16]. According to the Ceylon Sessional Paper in 1907 - XLI, the coconut industry of that region was devastated with 371,053 trees blown down, indicating the possible prevalence of very severe winds at that time^[16]. Figures 6a & 6b highlight the extent of damage.

The November 1992 SCS had recorded wind speeds of upto 88 km/hr and pressure of 998.2 mbar at Colombo^[12]. Though heavy rains and strong winds were experienced which led to 30,277 families being affected and 29,116 houses being severely damaged, the number of deaths was four^[12]. A similar pattern was observed for the SCS of December 2000 which resulted in eight deaths and a significant amount of property damage, having recorded maximum sustained wind speeds of 165 km/hr and a lowest recorded pressure of 970 mbar^[17].

Though the SCS of May 2003 did not cross the island and had its nearest approach approximately 700 km away from the East coast (DMC, UNDP report, 2009), it resulted in torrential downpours and landslides which caused severe damage to infrastructure and killed 250-300 people after it had stalled in the central regions of the Bay of Bengal^{[6][9][18][19]}. As per the Department of Meteorology 9,136 houses were destroyed and 30,385 were partially damaged due to this storm^[6]. Maximum wind speeds reached 140 km/hr for the storm and the District of Ratnapura had recorded nearly 360 mm of rainfall in 18 hrs on 17th of May, 2003^{[19][20]}. Similarities could be drawn to the record rainfalls of December 1957 within the North Central Province, which seriously damaged 35 major irrigation systems and 1300 village tanks^[21]. Though the devastation caused by the Dec 1957 floods is not generally attributed to a cyclone, Thambyahpillay (1959) states that it was a SCS from the Bay of Bengal that reached the eastern coast of the Island^[5]. Archival data available at the IBTrACS browser hosted by UNC Asheville reveals that it was a CS^[20]. In the context of dam safety, Fernando and Wickramasuriya (2011) have clearly demonstrated the importance of wind maximization when estimating probable maximum precipitation (PMP) in countries such as Sri Lanka^{[22][23]}. Figures 7a & 7b show the extent of damage due to the Dec 1957 floods.

When comparing the November 1992 cyclone which made landfall, and the December 2000 cyclone which crossed, to that of the May 2003 cyclone which did not cross but resulted in a significantly large death toll, Wijeytunga (2013) states how the casualty figures are due to the combined influence of one or more cyclone related effects being storm surges, high winds and/or heavy rainfall^[9]. More interestingly on a larger scale, Wickramasuriya (1990) postulated on whether the collapse of an ancient civilization could be directly attributed to the combined influence of such destructive cyclonic storms and devastating floods^[24]. Table 3 summarizes some of the more important characteristics of the SCSs that crossed or were in the vicinity of Sri Lanka or had caused a significant impact to Sri Lanka in the past century, inclusive of some highlighted earlier. Table 4 summarizes the devastation caused by the SCSs listed in Table 3.

4. ACTION PLANS, REGULATIONS AND GUIDELINES

Prior to the November 1978 Batticaloa Cyclone, neither design guidelines nor codes of practice were used to engineer buildings for resistance against strong winds due to cyclones in Sri Lanka^{[15][25]}. A team of technical experts sent by the Australian Government jointly worked with a team of consultants from the UNDP as well as members of the Department of Buildings in Sri Lanka to propose cyclone prone zones, design wind velocities and construction techniques for cyclone resistant construction^{[15][26]}. The collaboration introduced new concepts into strengthening techniques developed by Australian designers and engineers which lead to the creation of a three volume report titled “Technical Assistance to Sri Lanka on Cyclone Resistant Construction” in 1980, wherein the third volume comprised the design manual, “Design of Buildings for High Winds in Sri Lanka”^[26]. The purpose of the manual was to provide a sound basis for economic design of structures to resist high winds and cyclones as well as provide reference material for educational purposes^[26]. It is also considered to be the first step in leading Sri Lanka to develop its own unique solutions towards high wind resistant design of buildings^[26].

Wijeratne and Jayasinghe (1998), state that three basic wind speeds were established dividing Sri Lanka into three different wind zones considering the phenomenon whereby when a cyclone makes landfall, wind speeds are maintained for the first 50 km inland from the coast, rapidly decreasing to 80% by 70 km and reaching 50% by 100 km inland^[25]. Furthermore, these wind speeds were recommended to be 3 second gust speeds and were not proposed based on statistical predictions but on three past major cyclones that impacted the country, resulting in

zone 1 (comprising the eastern coast) being assigned the greatest value of 47 m/s and Zone 3 (comprising the western coast) being assigned the least value of 33 m/s^{[25][26]}.

In a publication released in 1980 by the Sri Lanka Foundation Institute, titled “Construction and Preparedness in Cyclone Prone Areas”, valuable research work has been compiled. The publication covers topics such as cyclonic characteristics, cyclone prone areas and degrees of risk, cyclone forecasting systems, cyclone warning system establishment, cyclonic impacts on the coasts, guideline for settlement planning in cyclone prone areas, inspection criteria for damaged buildings and reconstruction of damaged buildings^[27].

In more recent times, the DMC-UNDP report on tropical cyclones (2009) highlights details on the issuing of alert bulletins by the Department of Meteorology of Sri Lanka based on how far the storm centre is to the coast of concern^[6]. Action plans have also been described for each alert status being Information (likely formation), Alert (formed and approaching), Warning (making landfall) and Threat Over (storm has died down)^[6]. Wind hazard maps have also been developed considering average winds during the period of 1958-2009 as well as for maximum sustained wind speeds experienced when tropical cyclones cross or were in the vicinity^[6]. The Ministry of Disaster Management has published the “Sri Lanka Comprehensive Disaster Management Programme 2014-2018” (March, 2014) highlighting key disasters, losses incurred, guidelines and proposed management programmes. The World Meteorological Organization (WMO) on its “Tropical cyclone operational plan for the Bay of Bengal and the Arabian Sea” (2014 Edition), comprehensively describes regional and country wise terminology used, classification systems followed, tropical cyclone characteristics, warning systems, tropical cyclone observation systems, tropical cyclone forecasting and practices for the archival of data^[28].

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Table 1: Tropical Cyclone Classifications (WMO, 1986) ^[1]

	SOUTHWEST INDIAN OCEAN	NORTH INDIAN OCEAN	WESTERN NORTH PACIFIC	S. PACIFIC/S.E. INDIAN OCEAN	JTWC AREAS OF RESPONSIBILITY	NORTH ATLANTIC/E. NORTH PACIFIC	
10	Tropical Depression	Low	Tropical Depression	Tropical Depression	Tropical Depression	Tropical Depression	20
20		Depression					40
30		Deep Depression					60
40	Moderate Tropical Depression/Storm	Cyclonic Storm	Tropical Storm	Tropical Cyclone with Gale Force Winds	Tropical Storm	Tropical Storm	80
50	Severe Tropical Depression/Storm	Severe Cyclonic Storm	Severe Tropical Storm	Tropical Cyclone with Storm Force Winds			100
60							120
70	Tropical Cyclone	Severe Cyclonic Storm with a Core of Hurricane Winds	T y p h o o n	T y p h o o n	H u r r i c a n e	H u r r i c a n e	140
80							160
90	Intense Tropical Cyclone						180
100							200
110							220
120	Very Intense Tropical Cyclone						240
130							260
140							
	RA I	PANEL COUNTRIES	TYPHOON COMMITTEE	RA V	JTWC	RA IV	

Table 2: Cyclonic Storms (CS) and Severe Cyclonic Storms (SCS) of the Past Century ^[23]

SOURCE	CS	SCS	OCCURRENCES OF SCSs
DMC (2009) ^[6]	13	9	'07, '12, '22, '31, '55, '64, '78, '92 & 2000
Perera (2004) ^[7]	10	7	'07, '22, '31, '64, '78, '92 & 2000
Zubair ^[8]	10	3	'07, '64, '78 & (1884)
Wijetunga (2013) ^[9]	11	5	'07, '22, '31, '64 & '78

Figure 1a: Cyclonic Trajectories & Ceylon's Climate, 1845-1958 ^[5]

Figure 1b: Tropical Cyclone Tracks of Sri Lanka during 1881-2001^[6]

Figure 2a: Dec 1964, wind speed measurements for Trincomalee^[13]

Figure 2b: Dec 1964, pressure measurements for Trincomalee^[13]

Figure 3a: A philatelic item indicating the extent of damage at Trincomalee, Dec 1964^[31]

Figure 3b: Ceylon Daily News headline highlighting the death toll, Dec 1964^[32]

Fig. 1. Damages due to the cyclone and the track over Sri Lanka.
1. Extreme damages due to strong winds, tidal waves and heavy rainfall.
2. Heavy damages due to strong winds, heavy rainfall and floods.
3. Damages due to strong winds and rainfall.
4. Damages due to rainfall and landslides.

Figure 4: Nov 1978 cyclone track and regional damage extent^[14]

Plate.1. Railway station after the cyclone (November 24, 1978 by Rajah Studio, Batticaloa).

Plate.2. Cyclone damage on coconut plantations and houses (November 24, 1978 by Rajah Studio, Batticaloa)

Plate.3. Fallen coconut trees and disrupted communications (November 24, 1978 by Rajah Studio, Batticaloa)

Figures 5a, 5b & 5c: Indicated as plate 1, 2 & 3 respectively show the extent of damage after the Nov 1978 cyclone^[14]

Figure 6a: Mar 1907, cyclone damage to the coconut industry^[16]

Figure 6b: Mar 1907, a ship washed ashore^[16]

Figure 7a: Dec 1957, Huruluwewa bund breach^[33]

Figure 7b: Dec 1957, Nachchaduwa breach around the sluice^[33]

Table 3: Some features of the SCSs that crossed or were in the vicinity of Sri Lanka^{[12][19][20][23][30]}

CYCLONE	ORIGIN		MOVEMENT		CROSSED	COAST	MAXIMUM WIND SPEED [km/hr]	PRESSURE [mb]	3-DAY HIGHEST RAINFALL [mm]
	° N	° E	From	To					
Dec 1964	4.9	93.0	E	W/WNW/NW	C	EC	161	<970	200-250
Nov 1978	6.5	92.5	E	NW/WNW/NW	C	EC	>145	953	400-500
Nov 1992	7.5	87.2	E	W/WNW/NW	C	EC	>120	998.2	125-150
Dec 2000	7.5	90.0	E	W/WSW/WNW	C	EC	~165	970	300-350
May 2003	6.0	90.5	E	NW/Northerly	DNC	-	~140	980	*360
May 2010	9.8	90.4	E	NW/Northerly	DNC	-	~120	972	?
Dec 2011	9.2	88.3	E	N/W/NW	DNC	-	>140	969	?

* 18 hour rainfall on May 17th 2003 at Ratnapura

Table 4: Devastation caused by the SCSs listed in Table 3

CYCLONE	PEOPLE		BUILDINGS		REFERENCES
	DEATHS	AFFECTED	COMPLETELY DESTROYED/ SEVERELY DAMAGED	SERIOUSLY/P ARTIALLY DAMAGED	
Mar 1907	64	?	1,842	?	[16]
Dec 1964	>1,000	?	~5800 (Trincomalee)	>20,500 (Trincomalee)	[10], Figure 3a & 3b
Nov 1978	~915	>1,000,000	>100,000	85,000	[12],[14],
Nov 1992	4	30,277 families	1,600	15,463	[12],[15]
Dec 2000	8	>900,000	9,820	71,851	[12],[15]
May 2003	>250	>800,000	24,750	30,385	[6],[9],[18],[19]
May 2010	20	>500,000	?	?	[29]