IDENTIFYING PATTERNS OF TROPICAL CYCLONES MAKING LANDFALL ON INDIAN COAST USING GIS

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Abstract: For assessment of vulnerability and policy formulation with regard to cyclonic hazard management, it is very important to characterize and identify patterns in the incidence of tropical cyclones (TC) along the coastline. In practice, characterization needs the allocation of particular events to individual districts or any such unit in the historical record. A publication of the India Meteorological Department, 'Tracks of Storms and Depressions in the Bay of Bengal and the Arabian Sea' is the reliable data source for cyclone incidences. These are basically cyclone tracks drawn on non scaled map of India. Moreover, these maps exhibited only the external physical boundary of the coastline and not the internal district or state boundaries. Therefore, it was difficult to ascertain with accuracy, the exact district in which the land crossing point of a particular cyclone lied. So, an attempt had been made with the help of Geographic Information System (GIS) and computational program to allocate cyclone to a particular coastal district.

Based on this allocation, we examine spatio-temporal patterns of cyclone incidences on the coastal India using available data on tracks of storms and depressions in the Bay of Bengal and the Arabian Sea. Trends in TC incidences over a particular state have been analyzed. Seasonality in TC events has been also examined. It is found that the brunt of TCs has been borne by the East coast of India. On the West Coast of India too, it is the state of Gujarat which has experienced a much higher proportion of TCs as compared to other states on this coast. Orissa experienced the maximum number of TC incidences over the data period. For the individual categories of TCs too, Orissa experienced maximum number of Depressions and Storms, whereas in severe storm category Andhra Pradesh tops the list. At the district level, North Twenty Four Paraganas has experienced the highest number of TC incidences. In terms of individual categories of TCs, the districts that experienced greatest number of depressions, storms and severe storms are Bhadrak, Puri and South Twenty Four Paraganas respectively.

For depression, West Bengal and Gujarat are showing significant increasing trends while Orissa is revealing significant decreasing trend. However, Andhra Pradesh and Tamil Nadu are depicting insignificant increasing trends in depression crossings. All five coastal states are showing decreasing trends in storm incidences while only Orissa is depicting significant. For severe storm, West Bengal and Andhra Pradesh are showing significant increasing trends while Orissa, Tamil Nadu and Gujarat are showing insignificant trends. Finally, in view of these patterns, implications in vulnerability assessment and policy formulations with regard to cyclonic hazard management are discussed.

INTRODUCTION

India possesses a long coastline of 7500 kms. long with 9 coastal states and 69 coastal districts (http://censusindia.net/). Also, 3 of the 4 major metropolitan cities are located near the coastal region. Natural disasters strike the Indian coastline which impacts the ecological as well as socio-economic systems in the coastal regions. The socio-economic and ecological impacts of tropical cyclones are enormous (Obasi, 1997). Cyclones are intense low-pressure areas-from the centre of which pressure increases outwards- the amount of the pressure drops in the centre and the rate at which it increases outwards gives the intensity of the cyclones and the strength of winds. A 'Cyclonic Storm' is an intense vortex or a whirl in the atmosphere with very strong winds circulating around it in anti-clockwise direction in the Northern Hemisphere and in clockwise direction in the Southern Hemisphere. The damages caused by the cyclones are due to strong winds, storm surges and heavy and prolonged rainfall.

North Indian Ocean has witnessed increase in frequency of intense cyclones over the recent past (Singh *et al*, 2001). Annual and seasonal frequencies of cyclonic disturbances that occurred over the North Indian Ocean region during the period 1891-2000 have been studied in the past and revealed that there is significant decline in the annual number as well as seasonal (monsoon) number of cyclonic disturbances (Patwardhan, 2001). None of the studies have looked into the characteristics and nature of cyclonic disturbances making landfall to Indian coastline. These TCs are of utmost importance pertaining to their consequences on socio-economic and ecological systems.

Therefore, in this study, we explore various tropical cyclone indices and their relative importance for vulnerability assessment and adaptation strategy of coastal India. It develops methodology to allocate cyclonic event to a specific district. Further, an attempt is made to develop various kind of normalized indices based on allocation of cyclonic event to a district which forms the basis for adaptation and vulnerability studies. The study explores the secular trend in TC incidences in various states. Limitations in the developed methodology are discussed in detail. Finally, in view of the above, implications in vulnerability assessment and policy formulations with regard to cyclonic hazard management are discussed.

The next section discusses the data and methodology. The subsequent section deals with the results and discussion. Finally we conclude with implications and the way forward for research in cyclonic incidences and hazard management.

DATA AND METHODOLOGY

The data source for cyclone incidences was the 'Tracks of Storms and Depressions in the Bay of Bengal and the Arabian Sea', a publication of the India Meteorological Department (IMD, 1996). These are basically cyclone tracks drawn on non scaled map of India. Moreover, these maps exhibited only the external physical boundary of the coastline and not the internal district or state boundaries. Tropical cyclones have been broadly classified into three categories based on wind speed and pressure-Depression (D), Storm (S) and Severe Storm (SS).

Cyclone Allocation to a District and Development of Hazard Index

The cyclone track maps in the atlas mentioned above were maps without a proper scale. Moreover these maps exhibited only the external physical boundary of the coastline and not the internal district or state boundaries. Therefore it was difficult to ascertain with accuracy, the exact district in which the land crossing point of a particular cyclone lay. So the following approach was adopted for allocating the landfall point of a particular cyclone to a particular district.

First of all, IMD cyclone track maps mentioned above were scanned. Then these maps were geo-registered in GRAM++ which is indigenous GIS (Geographical Information Systems) software of IIT Bombay. The land crossing point of each of the cyclones was digitized and the latitude and longitude for these crossing points were extracted using GRAM++. A digitized district map of India of 1991 was taken as the base map for allocating the cyclone land crossing points to the districts. But when the latitude and longitude of the crossing point was compared with the latitude and longitude of the base district map, it was found that these crossing points were lying off the coast and not on the coastline of the base map. To resolve this problem, a C language program was written to compute distance between a crossing point (which actually was lying off the coast when compared with the coastline latitude and longitude of the base district map) and all the points on the coastline that would form the coastline. From among these distances the program selected the minimum distance and gave the latitude and longitude of that point on the coastline which was minimally distant from the crossing point lying off the coast. The district to which the latitude and longitude of this minimally distant point on the coastline corresponded was the district in which the cyclone had the landfall.

Once all the cyclones land crossing point were allocated to districts in the manner described above, development of Hazard Index became feasible. After allocation of cyclonic event to a particular district, an attempt was made to develop various hazard indices and rank these districts. A number of such indices were developed namely, events per year, normalization of events by coastline area and coastal length, probability maps.

We compared our district allocation results using GIS with the Centre for Research on the Epidemiology of Disasters' (CRED) database for the cyclonic events those made landfall to the Indian coastline between 1971 to 1990. It was found that a total of 147 cyclonic events of different intensities (depression, storm and severe storm) occurred from 1971 to 1990. It was revealed that the allocation of 73 events to their respective districts did not match with our district allocation results using GIS and minimum distance technique. The CRED database is open source for the information on disasters globally, and is often used in research work pertaining to hazard management. The database draws information periodically from governmental and non-governmental organizations working in the field of disaster management.

Practical Issues in the Allocation

It was observed that there was no proper scale given to all these IMD maps. Hence the scales for these maps were calculated using a reference Survey of India (SOI) toposheet with known scale. The procedure for determining the scale of IMD map is as follows. Firstly, the distance between the two cities of these two maps was determined. Again it was difficult to exactly determine the distance between the two cities in IMD maps as the locations were large circles (*w.r.t.* scale it was large). For calculating the length the centre of these circles were assumed the centre points of these cities (In our case Mumbai and Delhi were the two cities considered as both were clearly observed in both the reference and IMD maps. This procedure was followed for three maps and an average of this was assumed as a correct scale. Also, it was assumed that all the maps from 1877-1990 were of the same size and scale. With these assumptions and inherent errors, the scale of IMD maps were determined (Scale 1: 144,00,000). Hence an error in measurement of 1 mm gives rise to ground distance error of 14.4 kms.

As time goes by paper also shrinks. It was assumed that there was no paper shrinkage for all maps. Further, personnel errors were inherent such as errors in measurement, errors in registration of tics, extraction of latitude and longitude of crossing cyclone points and digitization errors. Also, during scanning the maps were assumed to have no folds. Further, the coastline of IMD maps and coastline extractor's coastline (used in program) was assumed to not have changed over a period of time.

The major problem faced during development of indices was the coastline length of states/district (in kms.) was different for different scales of maps. It was found that as the resolution of map was increased the coastline length increased. There were a lot of absurd results obtained in this exercise.

RESULTS AND DISCUSSION

Characteristics of Various Cyclone Indices

On an average about 9 cyclonic events crossed the Indian coast during 1877 to 1990. The brunt was borne by the East coast of India with 899 cyclones out of 964 (93 %) which crossed the land. On the West Coast of India, it is the state of Gujarat which experienced a much higher proportion of cyclones (74%) as compared to other states on the west coast.

Orissa experienced the maximum number of cyclone incidences (422) over the period 1877 to 1990. For the individual categories of cyclones, Orissa tops the list as it experienced maximum number of Depressions (309) and Storms (87), whereas in severe storm category Andhra Pradesh tops the list with 40 severe cyclonic storm events. In case of the state of Tamil Nadu, the proportion of severe storms is much higher than the proportion of depressions and storms. In fact the absolute number of severe storms that crossed Tamil Nadu (38) is very near to the absolute number of severe storms that crossed Andhra Pradesh (40) which tops the list as far as severe storm incidences are concerned, and this number (38) is much larger than the number of severe storm incidences in other states like Orissa (26) and West Bengal (31).

The top 10 districts based on the frequency of cyclones with three categories (depression, storm and severe storm) are given in Table 1. On the individual category wise of cyclones, it was observed that the maximum number of depressions, storms and severe storms were in Bhadrak (66), Puri (27) and South Twenty Four Paraganas (14) respectively. A depiction of district wise depressions, storms, severe storms per year is presented in Figure 1.

Table 1: Top 10 districts based on the frequency of cyclones

Rank	Coastal district	Depression	Coastal district	Storm	Coastal district	Severe Storm
1	Bhadrak	66	Puri	27	South 24 Paraganas	14
2	Baleshwar	55	North 24 Paraganas	20	North 24 Paraganas	13
3	North 24 Paraganas	54	Kendrapara	17	Nellore	13
4	Puri	54	Baleshwar	15	Srikakulam	9
5	Kendrapara	52	Srikakulam	15	Nagapattinam	9
6	Srikakulam	46	South 24 Paraganas	11	Junagadh	8
7	Jagatsinghpur	42	Bhadrak	11	East Godavari	7
8	South 24 Paraganas	28	Nellore	10	Baleshwar	6
9	Vishakhapatnam	25	East Godavari	9	Kendrapara	6
10	Medinipur	24	Kancheepuram	9	Krishna	6

After normalizing depression, storm, severe storm and total cyclone crossing per district by corresponding districts' coastline length, area, total number of years (*i.e.* 114) and total number of cyclones crossing Indian coastline (*i.e.* 964), ranking of districts has been done. It has been found that by normalization with coastline length and area we get ranking of districts reshuffled. This implicates that there are differential vulnerability even if the frequency of the cyclones is the same and requires the adaptation strategy developed keeping in view of these heterogeneities.

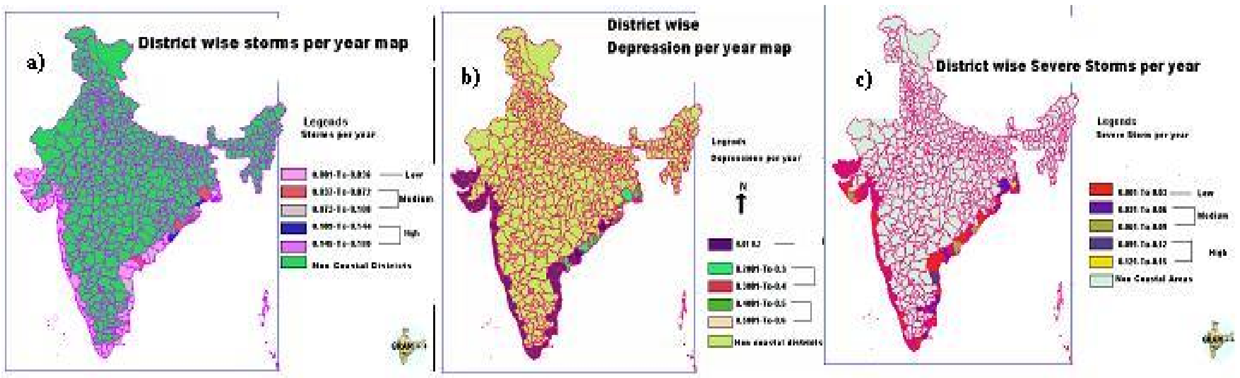

Figure 1: Tropical cyclones making landfall per year: a) Storms, b) Depression and c) Severe Storms

PATTERNS IN CYCLONE INDICES

During the period 1877 to 1990, 1474 cyclonic events (depressions, storms and severe storms) originated in the Bay of Bengal and Arabian Sea. Figure 2 depicts the variation in genesis of the different events by season. Here, we see that there are two peaks in storms and severe storms while there is one peak in depression.

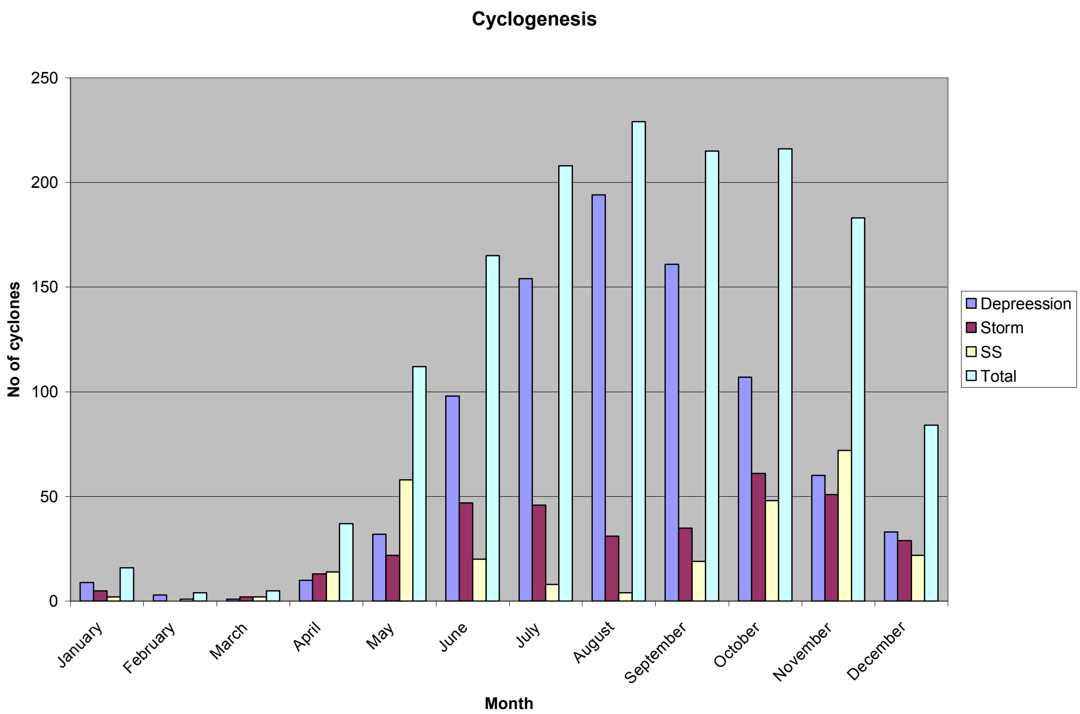

Figure 2: Seasonality in tropical cyclone category-wise

Out of the 1474 cyclones that originated in the Bay of Bengal and the Arabian Sea, the number of cyclones that crossed the Indian coastline was 964. The rest of them either didn't cross the land or crossed foreign coastlines such as Bangladesh, Myanmar and Pakistan. Also, among the once not included in our dataset (out of the 1474 that are shown in the 'Tracks of Storms and Depressions in the Bay of Bengal and the Arabian Sea') are those depressions which formed on land and dissipated on land.

It is observed that on an average per year 15 depressions, 1.93 storms and 1.35 severe storms crossed the Indian coastline. The state-wise trends in cyclone incidences have been computed (Table 2). For depression, West Bengal and Gujarat are showing significant increasing trend while Orissa is revealing significant decreasing trend. In case of storm category Orissa is showing a significant decreasing trend. In severe storm category of Tropical cyclone West Bengal and Andhra Pradesh are depicting significant increasing trend.

Table 2: State-wise trend in cyclone incidences

State	**Trend (cyclone/100yr)**		
	Depression	Storm	Severe Storm
West Bengal	**0.884***	-0.229	**0.313***
Orissa	**-0.979***	**-0.925***	-0.011
Andhra Pradesh	0.187	-0.345	**0.54***
Tamil Nadu	0.0044	-0.154	0.116
Gujarat	**0.532***	-0.074	-0.067
Note: The values with * sign are significant at 5% level			

Year-wise distribution of tropical cyclones in different categories has been depicted (Figure 3). It is evident that both depressions and storms are showing decreasing trends while severe storm shows increasing trend. This is very alarming and in line with observations in other basins for severe cyclonic storms. Also, experiments with global circulation models (GCMs) produce increase in intensity of cyclone in warming world. Therefore, India should be equipped to deal with calamities caused by increased frequency of severe cyclonic storms. There is need to develop a resilient society and infrastructure in the region of high severe cyclone incidences in India.

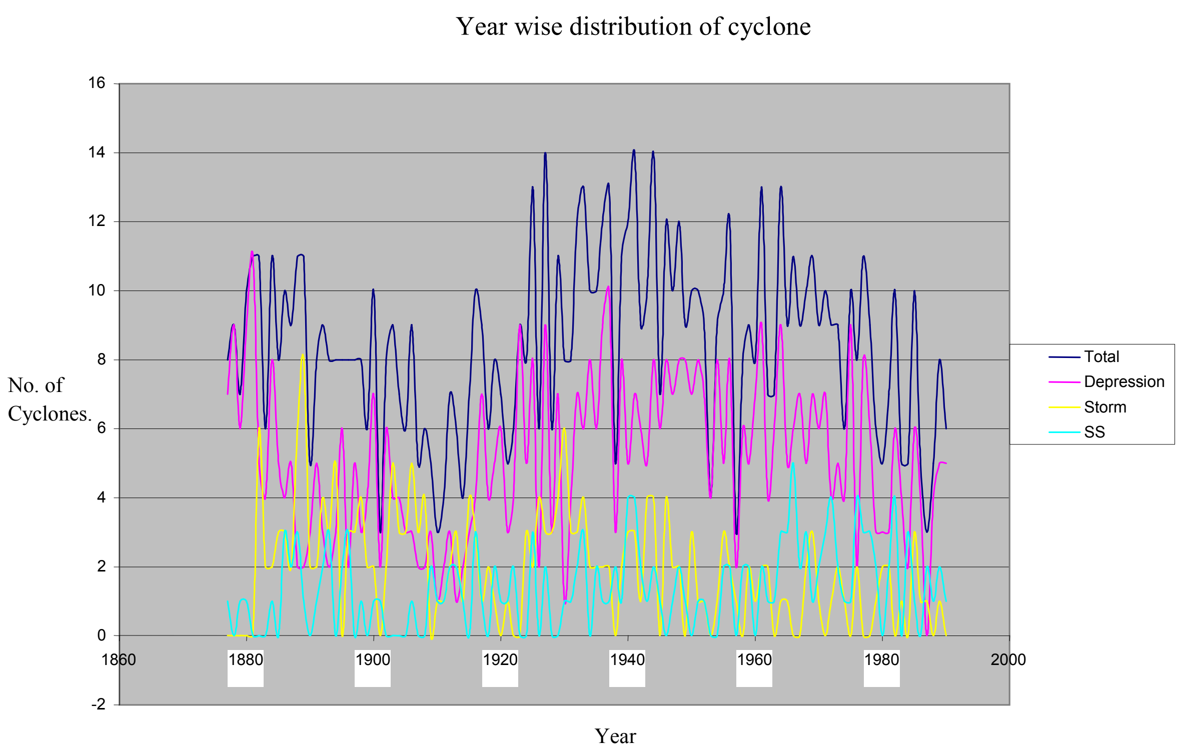

Figure 3: Absolute number of cyclones in the three categories from 1877 to 1990

CONCLUSIONS

In view of undergone analysis and discussions, the following conclusions can be drawn.

- It was observed that about 9 cyclones crossed Indian coastline per year during 1877 to 1990. At the state level, Orissa experienced the maximum number of cyclones incidences (422) over the period. At the district level, North Twenty Four Paraganas has experienced the maximum number of cyclones in terms of total cyclonic incidences. It was observed that the highest number of depressions, storms and severe storms were in Bhadrak (66), Puri (27) and South Twenty Four Paraganas (14) respectively.

- Bhadrak (1.210), Puri (0.275) and Karnikal (0.187) were the districts most prone to hazard in respect to depression, storm and severe storm category when normalized *w.r.t.* coastline length, respectively. Bhadrak (1.467) was found the most hazards prone region in total cyclone after the normalization. When normalized with the coastline area, Bhadrak (0.026), Puri (0.008) and Chennai (0.011) were found most hazard prone for depression, storm and severe storm respectively. Overall Bhadrak (0.032) was found most hazards prone for total cyclones after the normalization *w.r.t.* coastline area. Probability of any cyclonic event crossing a district was observed highest for north 24 Paraganas.

- For depression, West Bengal and Gujarat are showing significant increasing trend while Orissa is revealing significant decreasing trend. Andhra Pradesh and Tamil Nadu are depicting insignificant increasing trend in depression crossings. It is observed that all the five states are showing decreasing trend in storm incidences but only Orissa is showing a significant decreasing trend. For severe storm, West Bengal and Andhra Pradesh are depicting significant increasing trend. Orissa, Tamil Nadu and Gujarat are showing insignificant trends in severe storm incidences.

In the light of the pattern in the distribution of tropical cyclones making landfall to Indian coastline, it is of utmost importance to develop proactive strategies to cope with the spatial and temporal behaviors of these events in making socio-economic and ecological systems resilient. Upward trends of severe cyclonic storms in West Bengal and Andhra Pradesh need special attention to enhance adaptive capacity in the region. The impact of tropical cyclones on humans and ecosystem depends on the number of people and ecosystem exposed and their vulnerability, as well as the frequency and intensity of storms. It is therefore of great importance to know: how will the cumulative effects of climate change, demography and vulnerability affect risk? Conventionally, reports assessing tropical cyclone risk trends are based on reported losses, but these figures are biased by improvements to information access. There is an urgent need for new methodology based on non-conventional variables including physically observed events and related contextual parameters. It is important to explore the linkage between mortality risk and tropical cyclone intensity, exposure, levels of poverty and governance. It is anticipated that despite the projected reduction in the frequency of tropical cyclones, projected increases in both demographic pressure and tropical cyclone intensity over recent future can be expected to enormously increase the number of people exposed per year and aggravate disaster risk, despite potential progression in development and governance, regionally as well as globally.

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