TROPICAL CYCLONES: FROM AN INTEGRATED 'DNA' PERSPECTIVE

1. Introduction

Our understanding of hazards has evolved through the course of history from a simplistic submission to the spiritual unknown to a complex paradigmatic approach (Smith 2013). It began with perceiving forces of nature as personifications of spiritual beings. For tropical cyclones, this can be validated by the etymological origins of the words hurricane, cyclone and typhoons. The word hurricane owes its origin to an evil god of winds and destruction called by different names such as "Huracan", "Hunraken" and "Jurakan" by inhabitants of the Carribean, Mexico and Mayan civilization in Central America (Emmanuel 2005, p.18). With time, spiritual constructions were followed by scientific framings. While the engineering, behavioural and development paradigms (Smith 2013) have their advantages, they are also beset with certain limitations and this has driven several members of the scientific community (Petley 2009; Wenger 2006, Messerli et al. 2000) for the need for a new approach. As noted by Mc Entire (2004), the future disaster paradigm must interpret the complex nature of hazards as a function of physical, technological, social as well as institutional variables.

Acknowledging these complex interconnections, the **complexity paradigm** offers a theory which recognizes the interactions within and between different components of a system (Smith 2013). This paradigm places disasters "at the interface between natural, or quasi-natural, systems and human systems where the interactions are characterized by complexity" (Smith 2013, p.47). Smith (2013) uses the DNA model to illustrate the "coupled human-environment system (CHES)" in order to explain the "complexity in disaster causation" (Smith 2013, p.47) (Refer to Fig.1). The two intertwined strands of the model represent the social and physical component of the system resembling the double helix and are linked to each other by a number of interconnections, completing the DNA model. The complexity paradigm differs from the previous paradigms in giving equal weightage to both social and physical components and in particular highlighting the importance of the linkages (Smith 2013).

This paper aims to provide a comprehensive understanding of the tropical cyclone hazard from the perspective of the complexity paradigm. In order to do this, the DNA model of the complexity paradigm (Smith 2013) is used as the foundation of the framework (Fig. 1). The objective is to describe and critically reflect on the physical and social dimensions in understanding tropical cyclones and particularly focus on the linkages between the two.

The physical dimension is analysed by integrating the characteristics of an environmental hazard as proposed by Burton et al. (1978) to the 'physical (blue) strand' of the DNA model and applying them to tropical cyclones. The social dimension and the inter-linkages are analysed by integrating the five concepts of the Keller and DeVecchio (2012) framework to the 'social (yellow) strand' and '(pink) inter-linkages' of the double helix of the DNA model. Fig.1 illustrates this and serves as a visual guide to the underlying conceptual structure of this paper.

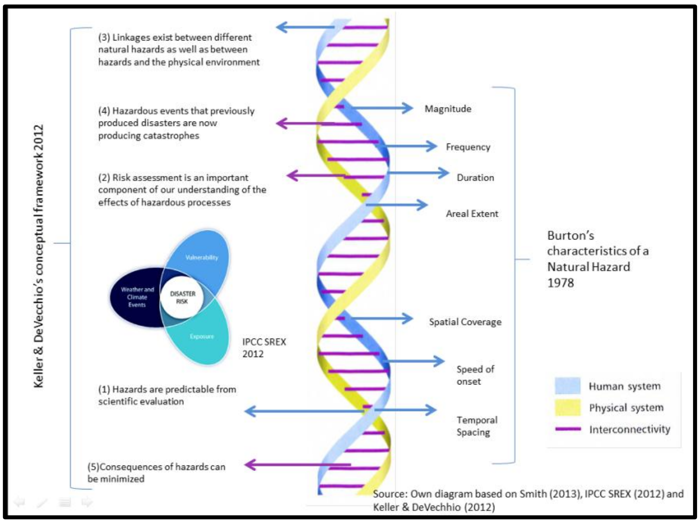

Fig 1: A conceptual framework to offer a comprehensive understanding of hazards within the complexity paradigm

The first chapter provides an overview on the characteristics of tropical cyclones with respect to the features of a natural hazard outlined by Burton et al. (1978) and the impact of climate change on tropical cyclone activity on the basis of these features. The second and third chapter will take a closer look at the five concepts of the Keller and DeVecchio framework (2012) and investigate in detail its' applicability and relevance in the context of tropical cyclones by situating the concepts in the CHES in the DNA model (Fig.1). To understand tropical cyclone risk, it will also include the IPCC SREX framework in order to examine how far the concepts explain the interconnectivity in the CHES in the complexity model to understand tropical cyclones. The fourth chapter gives a critical reflection by problematizing this integration of frameworks and will conclude by discussing the challenges and research gaps for the scientific community dedicated to the study of tropical cyclones.

2. Tale of a tempest

"Conceived over warm tropical oceans, born amid torrential thundershowers, and nurtured by water vapour drawn inward from far away, the mature tropical cyclone is an offspring of the atmosphere with both positive and negative consequences for life" (Anthes 1982). Tropical cyclones are defined as "non-frontal, low pressure, synoptic-scale systems with strongly organized convection that form over warm oceans" (Smith 2013, 236).

This section analyzes features of tropical cyclones with respect to the features of a natural hazard as outlined by Burton et al. (1978) namely "magnitude, frequency, duration, areal extent, speed of onset, spatial dispersion and temporal interval (Alcantra and Goudie 2010, p.270). These characteristics are situated in the physical dimension of the DNA model of the complexity paradigm and furthermore, are studied in how far climate change impacts these characteristics. This in turn contributes to understanding the “weather and climate events” component of the IPCC SREX framework used in this paper as guidance for explaining tropical cyclone risk.

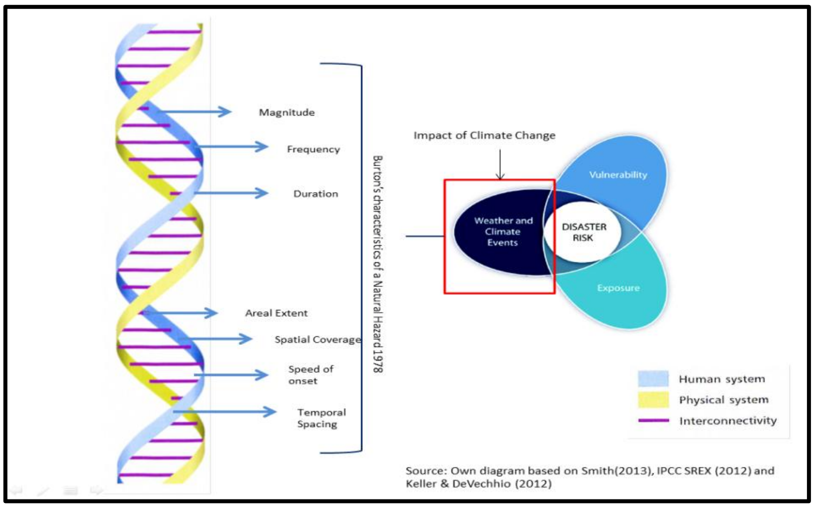

Fig 2: Illustration for the analysis of tropical cyclones with respect to Burton’s characteristics of natural hazards and impact of climate change on these characteristics in order to understand disaster risk as framed within the IPCC SREX framework (2012)

Burton regards **magnitude** or **intensity** as the benchmark level or the threshold beyond which a natural event can be characterized as extreme or a hazard. There are a number of reasons why magnitude or intensity alone cannot be taken as a benchmark for characterizing a hazard and in particular in the case of tropical cyclones. Hurricanes are classified on the basis of their sustained wind speed which is only the maximum wind speed and does not account for other determining factors such as size of the storm’s wind field, gusts and squall strengths. The main limitation of the scale can be pointed out to its inability for accounting “for other hurricane-related impacts, such as storm surge, rainfall-induced floods, and tornadoes” (NOAA n.d.a). This underestimates the damage potential of low intensity tropical cyclones which can have damaging effects due to heavy rainfall and storm surge. Addressing the limitations of the Saffir Simpson scale, scientists at Florida State University have come up with a new comprehensive metric called TIKE (Track Integrated Kinetic Energy) for tropical cyclones on the Atlantic basin which accounts for its intensity, duration and size (Misra et al. 2013).

“Frequency asserts how often an event of a given magnitude may be expected to occur in the long run average” (Burton et al. 1993, p.35). There has been a large incoherence in the frequency and intensity of tropical cyclone with wide fluctuations making it difficult to determine a long term trend. However, future modeling projection results indicate that the global average intensity of tropical cyclones will register an increase of 2-11% by 2100 and current modeling studies have drawn up a scenario in which global average frequency is set to decrease by about 6-34% (Knutson et al. 2010).

On **magnitude-frequency relationships** in the future, the current scientific debate does not revolve around the question of whether global warming impacts tropical cyclones activity but to what extent. The correlation of an increasing sea surface temperature (SST) with increasing magnitude and frequency has only been confirmed for the North Atlantic basin. Going by the latest results, studies have found that in general tropical cyclones frequency is set to decline in a warmer climate, however there are exceptions and these results are by no means definitive.

“**Duration** refers to length of time over which a hazard event persists” (Burton et al. 1993, p. 35).Tropical cyclones can last from several hours to weeks, the longest one being Hurricane/Typhoon John lasting for 30 days and affecting both the Northeast and Northwest Pacific basins (NOAA n.d.a). Studies have shown that on a global average there is a decline in frequency and duration of tropical cyclones in all basins with the exception of the North Atlantic. Its positive correlation with a statistically significant positive trend in SST presents a dilemma about the question on the impact of global warming on these characteristics (Webster et al. 2005). A longer event can probably allow for more time to mitigate or evacuate but also puts a strain on the coping capacity of the system (Burton et al. 1993, p.35). In addition, tropical cyclones may lead to other cascading events which can pose greater threats and often for longer durations, for example, a transition to an extra tropical cyclone or consequent coastal erosion.

Areal extent refers to the spatial coverage of a hazard event while **Spatial Dispersion** “refers to pattern of distribution over the space in which it can occur” (Burton et al. 1993, p.36). According to Burton (1993) this dimension demarcates the territorial boundaries where hazard response is needed. But this can be problematic as natural hazards do not always follow administrative boundaries (Smith 2013). According to a study conducted by Kossin et al. (2014), tropical cyclones are headed for the poles. They looked at satellite observations from 1982-2009-averaged across eight ocean basins- and located the lifetime maximum intensity (LMI) of tropical cyclones and found it to be occurring farther away from the equator at the rate of 30 miles (approximately one degree of latitude) per decade in all except the Atlantic basin. This presents a significant gap in research, making it essential to monitor future cyclone tracks and change in future tropical cyclones activity as this could be putting new geographical regions to risk by increasing exposure (Kossin et al. 2014).

Speed of onset refers to the “length of time between the first appearance of an event and its peak” (Burton et al. 1993, p.35). Tropical cyclones are placed under rapid onset events, although the length of time required for a disturbance to evolve into a mature hurricane can vary. This dimension is particularly important to government organizations and relief agencies for mobilizing their early warning systems, emergency preparedness measures and coping capacity.

Temporally, tropical cyclones are seasonal events and occur through the months of May and November in the Northern Hemisphere and between October and May in the

Southern Hemisphere. However, it is not true that hurricanes have not occurred outside the hurricane season but they represent 97% of tropical cyclone activity (Neumann 1993).

3. Tropical cyclones within the Keller and DeVecchio framework (2012) and linkages to Burton's characteristics (1978), IPCC SREX (2012) and DNA Model (Smith 2013)

This section is dedicated to providing a comprehensive understanding of tropical cyclones following the five concepts of the Keller DeVecchio framework. The chapter does not follow the numerical sequence of the concepts but re-arranges the sequence and establishes a connection between the concepts, linking it to the IPCC SREX framework and the DNA model as the foundation.

3.1 Need for a multi-hazard approach and recognizing the benefits of tropical cyclones

In the DNA model, the strand representing the physical system contains interactions both within the components of the system as well as with the human system. This section analyzes the interactions between tropical cyclones and other hazards as well as with the physical environment by presenting its destructive and beneficial consequences. The three main effects of tropical cyclones are **storm surge, high winds and heavy rain**.

The local rise in sea level due to the "water that is pushed towards the shore by the force of the winds swirling around the storm" is called **storm surge** (NOAA n.d.a). Severe flooding and coastal erosion are the main potential outcomes of an increase in sea level due to storm surges (NOAA, Keller & DeVecchio 2012). Although the damage from a storm surge is greater, hurricanes are known for their **strong winds** as they affect larger areas. In view of this it is important to take note that the Hurricane centers issue statements about wind speed and categories according to the Saffir Simpson scale which refers to sustained wind speed and does not include gusts and squalls (NOAA)[1] The relationship between hurricane wind speed and damage caused is not linear but on the contrary, exponential (increasing by a factor of four for each category) (Pielke et al. 2008). Thus a Category 4 hurricane may produce 250 times more damage than a Category 1 hurricane (NOAA). In contrast to the above effects of tropical cyclones which are mostly associated with hurricanes, **heavy rains** can be found to occur even with tropical storms and depressions. A recent example from the rare occurrence of a tropical cyclone in the Arabian Sea near the coast of Yemen which reduced to a Category 1 cyclone on land fall produced over 600mm of rain in some of the worst affected areas. This amount was equivalent to seven years' worth of rain in a period of 48 hours. (Leister 2015)

Although storm surges, strong winds including gusts and squalls and heavy rains have direct destructive consequences on life and infrastructure, they can trigger other severe hazards which magnify the intensity of the damage due to a tropical cyclone. It can result in cascading events which can possibly end up presenting more risk to areas than the cyclone itself. These include coastal erosion, several types of flooding, mass wasting, landslides and debris flows, tornadoes, severe thunderstorms, blizzards and snowstorms and their transition to an extra tropical cyclone can sometimes reach higher wind speeds and affect new areas. This linkage to other hazards brings out the limitation of Burton's characteristics as it does not include a multi-hazard element: duration (can trigger slow onset events like coastal erosion which last longer and on the other hand immediate impacts like flooding for example can last for several days after landfall),areal extent (flooding can extend several km and winds can affect larger

[1] "Gusts are short but rapid bursts in wind speed and are primarily caused by turbulence over land mixing faster air aloft to the surface. Squalls, on the other hand, are longer periods of increased wind speeds and are generally associated with the bands of thunderstorms which make-up the spiral bands around the hurricane."(NOAA n.d.a). Please refer to Annex for a tabular representation of the Saffir Simpson scale.

areas), spatial dispersion (cyclone in one area can trigger blizzards in another part, transition to extra tropical cyclones),speed of onset (landslides/flash flooding/coastal erosion)

These linkages between tropical cyclones and other hazards are evidence for the first part of the **third concept** of Keller and DeVecchio's framework **"Linkages exist between different Natural Hazards and the Physical Environment"**. This concept offers an interesting take on the concept of a natural hazard because the second part of the concept can be analysed with the flip side argument that while tropical cyclones can trigger hazards, they also offer certain natural services which actually make them beneficial and crucial to the Earth's environment as they maintain certain natural processes.

Natural services and benefits of tropical cyclones

Despite the associated hazards, it must not be forgotten that tropical cyclones perform an important natural thermodynamic role in the weather system by equalizing or regulating temperature as they transfer heat energy stored in the oceans to the troposphere and distribute it to the poles with the help of upper level winds (NOAA n.d.a). The same torrential rainfall which has immense destructive potential can also bring relief to moisture starved areas and have acted as "drought breakers" in Australia and China enhancing agricultural production (Ryan 1993; Lam et al. 2012, 16; Zhang et al. 2009). Typhoon Nida in 2004 in the Philippines enhanced fish catch as the vertical mixing and upwelling of water which occurs as the strong winds cross over warm tropical oceans, bring "nutrient rich water from the depths to fuel photosynthetic water supply" (Lam et al. 2012, 16; Galvin 2005).

Tropical cyclones produce strong winds which present potential for providing wind energy when harnessed. Studies on wind power density at certain stations have shown that they are a significant contributor to wind energy in Hong Kong (Lam et al. 2012). An analysis of daily mean temperature records at the Hong Kong Observatory during Typhoon Fengshen showed an average cooling of 1°C per tropical cyclone day. Tropical cyclones also provide beneficial ecosystem services mainly by enhancing species diversity, maintaining forest health, and rejuvenating some ecosystems (Keller and DeVecchio, p.350). There is little data on benefits of hurricanes and more research in this area would better inform decisions concerning hurricane modification and perhaps offer an interesting dimension or approach to risk reduction if its benefits are realized and valued (Sugg 1968).

In trying to frame the third concept of the Keller and DeVecchio framework within the complexity paradigm, a particular shortcoming is noticed, i.e. no linkage between the natural hazard and the social component- the second strand of the DNA model for understanding hazards, is mentioned.

3.2 Linking the social system for a comprehensive assessment of tropical cyclone risk

Environmental hazards occur at the interface between the natural and social components within the CHES (Smith 2013). In fact even the definition of a natural hazard by UNISDR (2009) suggests an element of probability that a natural hazard is "any natural process or phenomenon that **may** cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage". As Keller and DeVecchio put it "Central to our understanding of natural hazards is awareness that hazardous events result from natural processes that have been in operation for millions and possibly billions of years before humans experienced them. These processes become hazards **when they threaten human life or property** and should be recognized and avoided" (Keller and DeVecchio 2012, p.22). Hence this goes to prove that the probability depends on the social component and to explain the risk and continuous increase in loss and damage associated with tropical cyclones, the IPCC SREX framework offers a holistic understanding. Figure 3 illustrates the integration of the social component to concept 3, addressing the shortcoming.

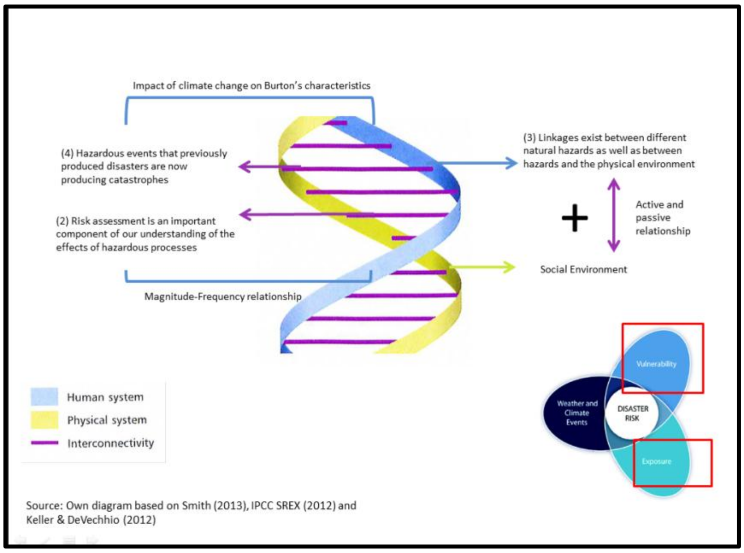

Fig 3: Figure showing the integration of Keller DeVecchio's concepts with the complexity model (Smith 2013), IPCC SREX framework (2012) and Burton's characteristics (1978)

In addition to the 'hazard' component of the IPCC framework, tropical cyclone risk is also dependent on the 'exposure' and 'vulnerability' components. According to Peduzzi et al. (2012), the average annual exposure to tropical cyclones has increased from 73 million in 1970 to 123 million in 2010. While exposure of human lives is most in the low lying deltaic regions in the LDCs which have a very high population, exposure of material assets with high economic value is high in the urbanized coastal stretches in developed countries (Smith 2013).

However storm intensity and exposure of lives and assets are not enough to give an accurate picture of tropical cyclone risk. Japan has roughly 1.4 times more people exposed to tropical cyclones than the Philippines but due to factors like high GDP per capita and a high HDI, mortality in the Philippines would be 17 times higher if both were struck by the same cyclone (Peduzzi et al. 2009). This underlines the need for a **vulnerability** approach in analysing the impacts of a disaster. The interconnection of the hazard with the human component is not just passive whereby humans are victims but also an active one whereby their actions also govern the hazard potential (Smith 2013). Therefore, settling in coastal regions and placing themselves and their property at risk, destroying natural protection measure like coastal dunes, constructing sea walls and dykes which aggravate the problem further and not adhering to building codes, all contribute to increasing risk.

Hence, in order to understand the impacts of the hazardous event, a risk assessment is crucial which incorporates the following questions: the intensity, the probability of occurrence of the event and the extent of loss (Smith 2013)(Refer to Figure 3). In order to answer these questions, an objective risk assessment would be a quantitative analysis of the magnitude-frequency relationship of the hazard and to estimate the loss, answers would not be found without looking into the **exposure and vulnerability** components of the framework. Since these three dimensions are constantly changing, a comprehensive risk assessment should be dynamic (Peduzzi et al. 2012). A study conducted by Peduzzi et al. (2012) indicates the following factors as the main contributors of tropical cyclones mortality risk: “intensity of the hazard, the level of population exposure, the level of poverty and the level of governance” (Peduzzi et al. 2009, p.290). It was also found that vulnerability parameters have more weight for less intense tropical cyclones and conversely, the role of population exposure in mortality risk grows with the intensity of the tropical cyclones. This brings about an interesting relation between the magnitude, exposure and vulnerability components in impacting mortality risk.

Thus, the fourth concept of the framework **“Risk assessment is an important component of our understanding of the effects of hazardous processes”** is valid for the case of tropical cyclones. In fact, this assessment is not just crucial for understanding the effects but also provides an insight into the root causes when each component, especially vulnerability, is analysed. The impact of climate change on the characteristics of tropical cyclones (according to features outlined by Burton et al. (1978)) in combination with other factors influencing exposure and vulnerability as discussed above, contribute to proving the fourth concept of the framework "**Hazardous events that previously produced disasters are now producing catastrophes**". These two concepts also form the foundation for risk management which is an important step in reducing their effects.

3.3 Preparing by predicting

Prediction and issuing forecasts and warnings are the first among several other measures which can be taken to this effect. This section explores the first concept **"Hazards are predictable from scientific evaluation".** Predictability of tropical cyclones falls into three categories: predicting the track of a current tropical cyclone, seasonal probability of occurrence and the impact of global warming and climate change. Meteorologists need to predict if the hurricane will make land fall at all, where and when it will strike (location of the eye and timing), magnitude- strength of the winds, areal extent and amount of rainfall and storm surge accompanying the tropical cyclones (Keller & DeVecchio 2012). For this they use several tools such as weather satellites, aircrafts, radar systems and weather buoys. One of the main challenges in predictability of tropical cyclones remains in predicting its intensity**.** Intensities can change very rapidly and this makes the lack of knowledge in this field even more crucial to make timely decisions for evacuation and preparedness. Studies (Judt et al. 2016, Vukicevic et al. 2014 and Keller & DeVecchio 2012) have identified variability in wind shear and non-representativeness of the metric used to measure tropical cyclones intensity as some of the problems. Despite the high volume of research in this topic, it still remains a gap in this field. While forecasts, early warning and evacuation contribute to increasing coping capacity, we need to devote more consideration to reducing vulnerability to achieve long term risk reduction. The need for a shift from a reactive response to anticipative action can be strongly supported by a finding of the UNISDR which states “For every dollar invested into disaster preparedness, seven dollars are saved in disaster aftermath” (2016)

In the light of this finding the next section presents measures targeted at reducing vulnerability and building adaptive capacities of the CHES to tropical cyclones.

3.4 Adaptive strategies to survive the storm

Cuba’s disaster preparedness system exemplifies that lives can be saved with accurate and timely forecasting in combination with comprehensive risk reduction strategies which are a balance of top down and bottom up approaches. (Thomson 2004; Reed 2005; Leoni 2014). The risk from tropical cyclones is greater in view of the effects of climate change on increasing sea level and associated increase in storm surges and flooding. Coastal vegetation performs functions through which they attenuate waves striking the shore thereby providing coastal protection and preventing erosion and flooding. Grey and artificial measures of coastal protection including dykes and sea walls are expensive, sometimes counterproductive and not suitably designed to adapt to changing conditions due to climate change. On the contrary natural ecosystem based solutions like mangrove dams offer a cost effective, adaptive and multi-beneficial solution (Duarte et al. 2013). However, some grey lines of defence have shown and proven to be successful too when built appropriately. Looking at Hong Kong’s approach to adapting to typhoons, by building structures on stilts, “dimpled surface structures” on bridges, underground drainage tunnels and reservoirs, the city has employed engineering design to protect itself against the impacts of strong winds, storm surge and flooding (SCMP n.d.a).

To contrast both green and grey lines of defence and engineering advances which Hong Kong can afford, it must not be forgotten that indigenous building designs contrary to costing billions of dollars are simple, sometimes more effective and inexpensive. For example, cyclone shelters built using traditional knowledge and locally available material proved to be far more successful than those built with iron roofs in withstanding the Category 5 Hurricane Pam which struck Vanuatu in March 2015. This highlights the importance of preserving traditional knowledge in disaster risk reduction (Minowa 2015).

In summary it can be said that there are possibilities waiting to be harnessed and opportunities to become resilient to tropical cyclone risk and proves the last concept of the framework "**Consequences of hazards can be minimized**".

4. Critical reflection and problematization of this integration

In analysing the integration of the characteristics of hazards outlined by Burton and its integration with the conceptual framework proposed by Keller and DeVecchio superimposed on the DNA model of complexity, three key problems are identified. The first problem pertains to the physical 'strand' of the double helix, the second to the human 'strand' and the third is a shortcoming observed in the interconnectivity between the two.

The **first problem** is a shortcoming in the third concept of the framework (Linkages exist between different natural hazards and the physical environment) and calls for a **multi-hazard approach and multi-dimensional framework**. It is particularly important in the case of tropical cyclones as a significant amount of the loss and damage is attributed to its effects like storm surge, strong winds and heavy rainfall, triggered cascading events and its transition to extra-tropical cyclones. However, this is not included or taken into consideration in any of the characteristics outlined by Burton. A low magnitude tropical cyclones can also cause significant damage due to its effects/trigger events, being a rapid onset event it can lead to slow onset consequences like coastal erosion, duration and areal extent of the event may not prove as catastrophic as a tropical cyclones unless for example it triggers a tornado affecting a new area or flooding which may last several days after landfall. Thus, all these shortcomings are observed when the cascading events of a hazard are not included and viewed only in terms of characteristics pertaining singularly to it. Hazards cannot be treated in water-tight compartments and requires a multi-dimensional framework including different trigger hazards, spatial and temporal scales.

However, even this third concept has a missing link and this brings forward the **second problem**. This refers to the social system. Linkages exist between the hazards, the physical environment and the social environment. It was this drawback which called for the inclusion of the DNA model and the IPCC SREX framework. A comprehensive understanding of the hazard cannot be possible without inclusion of crucial risk components like exposure and vulnerability. This presents a **shortfall in risk assessment** which relies solely on international loss databases because they do not explicitly account if the increasing loss is due to high exposure, vulnerability or intensity (Peduzzi et al. 2012).

The **third problem** identified which bridges the gap between the two systems and builds on the first concept (Hazards are predictable from scientific evaluation) is the **clear and timely communication of forecasts and communication between science and policy making.** Issuing early warning plays a determinant role in shaping people's risk perception towards cyclones. While overestimating intensities can reduce risk perception and induce indifference to warnings; underestimation on the other hand, can lead to significant loss and damage. Hence a balance needs to be struck, uncertainties need to be clearly communicated and associated consequences with regard to storm surge and flooding also should be explicitly conveyed and prepared for. This need for clear communication also applies to another level and this is the interaction between the science and policy making which would lead to more informed decision making and identification as well as prioritization of research gaps.

5. Conclusion: challenges and research gaps

“There is one issue that will define the contours of this century more dramatically than any other and that is the urgent threat of a changing climate” (Barack Obama). With Hurricane Katrina being the most expensive disaster to have occurred in history and Cyclone Sidr causing the largest number of deaths attributable to a single catastrophe, tropical cyclones are probably the most significant manifestations of climate change and are a cause for concern (Keller and DeVecchio 2012).

In view of this, the current scientific debate revolves around the magnitude-frequency relationship of tropical cyclones and poses challenges in understanding due to the complex nature of the hazard and its physical processes. Nevertheless, it is a critical input required for understanding hazards and are a prerequisite for concept 1 (Hazards are predictable from scientific evaluation) especially in an environment of increasing SST. With occurrences of tropical cyclones outside the “hurricane season” and outside the tropics, temporal and spatial characteristics are rapidly changing and research is geared towards understanding these trends (NOAA n.d.a, Kossin 2014). While knowledge gaps exist in the formation of cyclones due to its complex nature- for example-the formation of the eye is still not properly understood; impacts of climate change further complicate the analysis and especially with variations across different ocean basins.

Research is also under way on options for mitigating the hazard component of tropical cyclone risk by modifying its physical characteristics. Several attempts have been made to reduce the strength of the hurricanes for example- cloud seeding with silver iodide, liquids which prevent evaporation from the ocean surface, alter heat balance with reflecting particles etc. (NOAA n.d.a). Their enormous energy even presents the potential to be harnessed as wind energy. However, all these efforts have not been very successful but still present potential for future research. However, instead of focusing solely on the hazard component of the IPCC SREX framework, efforts should also be directed to the exposure and vulnerability aspects. The aim should be to 'build better before' instead of 'build back better'.

It is important to remember that tropical cyclones are essentially natural processes which have been in operation even before the existence of humans and play an important role in regulating the Earth system and providing beneficial ecosystem services. Burton's characteristics of a natural hazard provide an important set of criteria to understand a hazard but it lacks the crucial linkage to other hazards and the human system. The Keller and DeVecchio framework is mostly comprehensive in analyzing the physical component but again, it fails to explicitly draw the link to the human component. To some extent in my opinion, this presents a major loophole as the human system is one of the catalytic factors which make a natural process a hazard and understanding risk is incomplete without it. In view of this shortcoming the DNA model within the complexity paradigm provides a foundation for a comprehensive framework to be developed which encompasses a multidimensional and dynamic (since dimensions are changing with time) approach and most importantly it recognizes the linkages between the human and physical system.

Bangladesh was affected by Cyclone Bhola in 1970 which killed 500,000 people and over the years it was hit by more cyclones, the latest being in May this year where the number of deaths were 24 (ReliefWeb 2016). This remarkable reduction in loss of lives is attributed to better preparedness owing to investment in local systems and volunteer networks. This is only one of the many success stories which goes to prove that after all "Impossible is not a fact, it is an attitude" (Figueres2016).

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