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Assembling and (Re)Assembling Critical Infrastructure Resilience in Khulna City, Bangladesh

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Abstract

Extreme Weather Events continue to cause shocking losses of life and long-term damage at scales, depths and complexities that elude robust and accountable calculation, expression and reparation. Cyclones and storm surges can wipe out entire towns, and overwhelm vulnerable built and lived environments. It was storm surges that was integral to the destructive power of Hurricane Katrina in the USA (2005), Typhoon Haiyan in the Philippines (2013), as well as Cyclone Nargis (2008) and the 1970 Bhola Cyclone in the Bay of Bengal. This paper report on work which concerns itself with the question of, given what we know already about such extreme weather events, and their associated critical infrastructure impacts and recovery trajectories, what scenarios, insights and tools might we develop to enable critical infrastructures which are resilient?

With several of the world's most climate vulnerable cities situated in well-peopled and rapidly growing urban areas near coasts, our case study of Khulna City speaks globally into a resilience discourse, through critical infrastructure, disaster risk reduction, through spatial data science and high visualisation. With a current population of 1.4 million estimated to rise to 2.9 million by 2030, dense historical Khulna City may well continue to perform a critical role in regional economic development and as well as a destination for environmental refugees.

Working as part of the EU—CIRCLE consortium[1], we conduct a case study into cyclones and storm surges affecting the critical infrastructure then discuss salient developments of loss modelling. The research aims to contribute towards a practical framework that stimulates adaptive learning across multiple stakeholders and organisational genres.

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Keywords: climate change; critical infrastructure; extreme weather; resilience

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1. Introduction

Global policy on disaster risk reduction is in its second generation, and runs aspects of climate adaptation and sustainable development goals. Succeeding the Hyogo Framework for Action 2005-2015, the Sendai Framework for Disaster Risk Reduction 2015-2030 moved beyond hazard awareness to diplomatic, financial and technological engagements with the moving targets of growing human vulnerability and disaster losses. Focusing on the reduction of risks and loses, in terms of lives, livelihoods and health, Sendai prioritises the understanding of (disaster) risk, the strengthening of its governance, investment in resilience and a build back better approach to post-disaster reconstruction.

This EU Horizon 2020 funded EU-CIRCLE work engages with Sendai Target 4 that relates to the ‘integrity and function of infrastructure’, a sociotechnical milieu that we characterize with assemblage thinking that is well suited to mixed infrastructure networks comprising physical equipment (pylons, power stations, roads, sluice gates), institutions (infrastructure operators), and dynamic hydro meteorological substances (storm surges, cyclones).

Assemblage thinking is an approach that captures the idea of a whole with multiple heterogeneous parts, human and nonhuman, with agency, linked together to form some kind of relational whole, that produces new behaviours [1]. Energy systems [2], electricity blackouts [3] and gas transportation networks have been studied in this way [4] as is the South Asian monsoon [5]. This paper develops a framework which to model the assemblage of critical infrastructures (CI) of communications, water, power, sanitation and health in Khulna City, Bangladesh, its response to intense cyclone and storm surge scenarios and potential for reconfiguration through critical infrastructure operator and designer engagement with the project’s CI toolkit.

2. Salient Cyclones and Critical Infrastructure: A Historical Narrative

Disasters like hurricanes, cyclones and storm surges have had catastrophic impacts on critical infrastructure (here in referred to as CI) and have inflicted severe socio economic impacts to public and private assets all over the globe [6]. Vivid global images of long-term destruction to the built and lived environments are not in short supply, whether at the core or periphery of the world system. From Hurricane Katrina in the U.S. (2005), to Typhoon Haiyan in the Philippines (2013) and the series of deadly cyclones from 1970 (Bhola Cyclone) to 2009 (Cyclone Aila) in the Bay of Bengal the frequency, magnitude and material damage of such events is increasing [7], with vulnerable low-lying coastal areas are facing catastrophic losses [8].

Certainly, the degree of catastrophic impacts and the associated fatalities of historic cyclones varied greatly over the past 50 years. The two deadliest cyclones were in 1970 and 1991 in Bangladesh, with over 500,000 and almost 140,000 deaths, respectively. The number of fatalities was reduced in the 2007 to 4,036 deaths, ostensibly following the introduction of early warning systems and the Cyclone Preparedness Program [9]. During Cyclone Sidr (2007), there was also no outbreak of disease reported due to the timely involvement of government agencies and NGOs in enabling medical teams and supplies from multiple international organisations [10]. However, following Cyclone Aila (2009) there were several outbreaks of disease (i.e. skin disease, diarrhoea, and dysentery), which reached epidemic proportion, especially in the Khulna district [11]. Perhaps counter-intuitively, while the number of fatalities created by this series of cyclones has decreased, the number of people affected and properties damaged has increased [12]. Many of these losses have not been recovered, even after effective mitigation and adaptation measures [13]. Understandably, the trajectory of recovery to a pre-disaster situation for survivors, the economy and infrastructure system are deeply challenging as disasters tend to accelerate existing economic, social, and political trends [14].

The economic losses of this purposive sample of cyclones vary considerably, with the scale of storm and the location of the CI being key. Hurricane Katrina (2005) in the U.S caused the highest economic losses, of approximately $300 billion. The higher number of properties and the density of infrastructure in New Orleans made its recovery trajectory costlier than others. The hurricane caused extensive damage to national energy and chemical sectors, both of which were concentrated in the Gulf of Mexico, which cascaded into the complete failure of all key infrastructure (e.g. electrical, communication system) in New Orleans [15]. The hurricane exposed several vulnerabilities stemming from human and non-human factors (e.g. the network of complex CI) that contributed significantly to the disaster. The levee system that was supposed to protect the city from flooding ended up collapsing causing water from Lake Pontchartrain to enter the city. Consequently, physically and spatially dependent CI were significantly destroyed by the flood. Gas mains and underground water mains located in the same area were damaged [16] and several pumping stations and electrical generators that were physically dependent upon the levee system for protection from flood, were inoperable during the disaster [17]. Some argued that key pumping stations were highly dependent upon human operators, and subsequently, left without the operators when the hurricane hit, compounding the problem [18]. Despite the series of “table top” exercises pre-Katrina, the government failed to address the problems flagged CI and the levee system before the hurricane struck, causing significant exposure of the CI assemblage to such a disaster event and begging questions as to the purpose and effectiveness of preparatory work.

The destructive storm surges that frequently accompany cyclones in the Bay of Bengal have focus damage in the coastal areas, the cyclones affect the prime agricultural areas, which are the nation’s main source of food. In 1970 Cyclone Bhola caused an estimated crop loss of USD63 million and the loss of over 300,000 livestock and poultry [19]. This impact and poor emergency action made it impossible to recover anywhere near pre-existing social and economic conditions in the short term, even if war (1971) and famine (1974) had not unfolded thereafter. Four months after the disaster, 600,000 people lacked adequate shelter and one million people were dependant on relief [20]. More recently in neighbouring Myanmar, Cyclone Nargis (2008) ravaged coastal areas that were nationally important sources of food [21]. Local people understand that the tidal surge was able to penetrate further inland and destroy homes due to the removal of mangrove forests along the coastal areas [22]. Another consequence is the saline contamination of surface water, used for drinking. Food and agriculture sectors have multiple and entanglements with the water system, for irrigation, for transportation and drainage [23] therefore during these events, the loss and damage of any one CI could spread beyond the immediately related sector and transfigure wider infrastructure capacities and relationships. This complexity invites responsible agencies to consider impacts in new ways and create effective countermeasures to account for the complex reality of disasters to minimize the death and damages to people, property, CI and their interrelations.

Each disaster event evoked responses and readjustments within hours to months and years depending upon the magnitude of storm and the degree of local preparedness. Political influences are, as always. The case of Cyclone Nargis in Myanmar and Hurricane Katrina in the U.S., which evoked responses widely acknowledged as inadequate. Cyclone Nargis exposed political problems and social vulnerabilities in Myanmar, particularly the poor relationship between the state and local community in the country. The State Peace and Development Councils (SPDC) in Myanmar were criticized by local people for reasons including the imposition of heavy restrictions on rescue and relief activities of both domestic and foreign organisations [24]. In the case of Hurricane Katrina, slow intergovernmental response due to failure of communication system, systematic inequality and lack of pre-planned measures amplified poor performance among the various municipal governments and agencies in responding to the disaster [25]. The tendency to create order by imposing a tight command structure in New Orleans failed as there was no legitimate, trusted central command organisation in the city. In contrast, Myanmar had a strong central command organisation, the SPDC. However, this was insufficient as the overriding modus operandi was the preservation of state power.

These examples illustrate how human and economic factors influence the impact and response trajectories of a cyclonic disaster. Next we look at the Bay of Bengal cyclones as a series and the response as a multi-generational transformation.

3. Long-Term Responses to Cyclonic Disasters

Disaster responses from governments vary according to their resources, sophistication, political hue and perception of victims and beneficiaries of any (in) action. It is instructive at this point to look at responses to cyclones in recent decades which focused on awareness and evacuation and dramatically reduced the loss of life. Resource-constrained countries as ever, are more reliant upon the aid and technical support from with wider international community. For instance, the United Nations called for USD187 million in funds for Myanmar relief following Cyclone Nargis [26]. In this case, Myanmar was not prepared to face such destructive event, and a slow and passive response ensued ensuring massive loss of life.

On the other hand, the scale of destruction and inadequate response to the 1970 Bhola Cyclone had heavy political, technological and collaborative ramifications, with the implementation of early-warning, cyclone-tracking systems and the construction of thousands of cyclone shelters [27]. Historically transfigured by centuries of famine, cyclone and flood, the area now known as Bangladesh has had a Ministry of Disaster management and Relief since soon after its national formation in 1972. The recent cyclone experiences of 2007 and 2009 have highlighted that maintenance, communications and placement remain issues and behaviours sought by evacuation planners are often out of step with practice. Despite decades of cyclone shelter construction and early warnings, many locals were found to still favour the 'wait-and-see' approach during Sidr and Aila [28]. Interestingly, studies suggest that over-technical language and jargon in communications causes misunderstanding of warning signals [29], and alongside educational inequality, alongside poor communications contribute to the amplification of vulnerability of people in coastal areas [30].

The cyclone shelter network along the coastal areas of Bangladesh remains unevenly distributed. Although more than 2000 new shelters were built after Sidr, their number and location remained inadequate to fully support well populated coastal areas during Aila [31]. Here, time and distance matter as much as concrete. With early warnings received just a few hours prior to cyclone strike, there was limited time for people to go to shelters located 3 to 4 kilometres away. Surface communications was also an issue for relief and recovery efforts following Aila, as government agencies and NGOs struggled to access affected areas [32]. The economic and productive impacts of Aila extended in the long run, because of destruction of agriculture lands and houses. Typically, salinized land takes two years to recover as so affected communities' required significant external support due to their lack of financial resources to cover recovery.

Ultimately, the recovery efforts by government of international organisations are short-term measures that provide basic support to the victims immediately after the disaster. They do not however provide the prolonged health or education services, which are essential in building resilience, transformation and 'building back better' [33]. Moving beyond simple recovery into discourses about Critical Infrastructure and Climate Adaptation encourages a practical and policy relevant translation of both field's longer time horizons.

4. A Tripartite Assembly of Disaster, Adaptation and Damage

The power, communications, water, sanitation and health infrastructures at the core of this study can be considered as a heterogeneous assemblage of humans and non-humans in a process of becoming, interacting according to and in violation of rules, and situated within wider, fluid political, economic and ecological relationships. Taking a perspective on the assemblage, one with a focus on disaster situations (e.g. cyclones and storm surges) creates additional participants and relationships and recognizes there will be an emergent newness and reconfiguration with each disaster. For example, a power station will operate so long as its supply of fuel, environmental operating conditions, physical integrity and staffing are maintained. The arrival of a cyclone and storm surge would affect these relationships, properties and functions of the power station, in both immediate and longer term.

Of course Disaster Risk Reduction (DRR) is just one approach to Critical Infrastructure Resilience here. Climate Change Adaptation (CCA), a somewhat younger, longer term and hydro-meteorologically delimited field overlaps significantly though occupies a more 'environmental' bureaucratic space [34]. Furthermore, given the climatically modified disaster profile and the wider project's objectives to provide simulations, decision support and quantified cost projections of extreme weather impacts on critical infrastructure, the even younger Loss and Damage agenda (L&D), which addresses losses associated with climate change impacts in vulnerable developing countries is of policy relevance.

While CCA policy and research is relatively mature in the area, L&D research is in its infancy. Bangladesh-focused studies of not however have covered cyclone impacts [35] sea-level rise [36] salinity [37] and connections to DRR [38]. This study contributes to a gap in the knowledge of the critical infrastructure - extreme weather assemblage, one which speaks to DRR, CCA and L&A fields of investment, decision-making and design.

5. Introducing the Khulna Case Study Framework for the EU-CIRCLE Project

Natural hazards in developing countries as discussed above have impacted the social fabric in some of the countries and Bangladesh is no exception. As part of the EU-CIRCLE project, we develop the case of Khulna in Bangladesh, which is a significant interior coastal city [39] situated roughly equidistant between the C40 megacities of Dhaka Bangladesh and Kolkata, India. The city of Khulna is the second port city of Bangladesh and the third largest in size Approximately 100 km from the coast and just north of Mongla Export Processing Zone and port complex and the under construction Rampal coal power station and Khan Jahan Airport, Khulna is a growing regional hub with a dense historic experience of tropical cyclones [40] a persistent urban drainage problem and a projected storm surge risk [41] [42]. With a population of 1.4 million projected to reach 2.9 million by 2030, it is a site of current infrastructural development, rural to urban migration, and a strategic refuge for environmental refugees responding to impacts of upstream water withdrawal, extreme weather events and climate change. Situated in the South West region of Bangladesh, the city regularly features in the international climate change impact literature as one of the cities that are most vulnerable to climate change [43]. For its part, the national planning authority has highlighted the importance of climate-proof and resilient infrastructure and developed a suite of resilience indicators, including infrastructure and multiple hazard types [44].

Khulna's critical infrastructure has been assembled, disassembled and reassembled, since its establishment as a municipality in 1884. Here we draw critical hydro political, technological and geo-economics narratives together to enrich understanding of the externalities and internal dynamics of the city's CIR context.

With the first partition of British occupied India upon decolonisation in 1948, and the hardening of the Indian border on the eastern side, Khulna's significance as a trade hub suffered, which was compounded by impacts of the Farrakha Barrage completed in 1975 on the River Ganges. Intended to flush and revive Kolkata port and surrounding agricultural areas, the impact on the Bangladesh (eastern) side of the delta was to increase salinity of water and soils, and, as a consequence, limit agricultural and industrial activity in the south west region [45].

Another dimension to CI development is the experience of the water and agriculture sector with 'polderisation', a technique of embankment enclosure building established since the formative Krug Mission Report on flood control and water management in the then East Pakistan (1957). The Krug Mission was prompted by particularly devastating floods in three successive years (1954-56). Over the course of the 60s and 70s 139 polders were created along the coast of the country, enclosing a total area of 1.2 million hectares. Protecting croplands from flood inundation and tidal surges in this way has had several unintended consequences, for example waterlogging and river siltation [46]. Of significance for the aims of the EU-CIRCLE project toolkits, is that there is a consensus amongst both champions and detractors of polderisation that the placement of sluice gates, as well as maintenance and management structures have been problematic over the years [47]. Significant World Bank financed investment is underway in updating the geotechnical aspect of coastal embankments [48].

Cyclones are known to severely impact the agricultural sector, with inundated land often requiring two years for the resumption of cultivation and farmers seeking alternatives in urban areas and regional disparities entrenched in coastal areas with successive severe and extreme weather events [49].

The wider industrial economy around Khulna is also important to consider, alongside the observation that a lot of new infrastructure is presently being assembled. Established in 1950 the Mongla port, 60 km inland, served the regional import export economy until challenges like the jute price decline of the 1980s triggered closures of local mills and reorientation of exports towards sectors like Ready Made Garments. The underdevelopment of the port facilities and river navigability is presently being addressed by significant central government investment. Developments include the construction of a local airport, the coal-fired Rampal power plant and the reopening of the Khulna-Kolkata rail connection. Coupled with the opening up of ecological and heritage tourism, there is a positive economic, if not ecological and social, trajectory for the region and its Export Processing Zone.

Moving into the city, which sits on 40.8 square kilometres of land, and is divided into 31 wards on the west bank of the Rupsha River just to the north of the Khan Jahan Ali Bridge, the CI landscape of Khulna presents a complex array of built structures, organisations, relationships and performances, some of which are established and others that are still in their formative stage. Here the idea of the assemblage [50] again invites a fluid way of thinking about heterogeneous sociotechnical formations, like critical infrastructure, that are in relation to each other with agency and the capacity to surprise.

For example, a cyclonic storm could knock out electricity distribution and the road transport links supporting Khulna's health, drainage and sanitation maintenance regimes, exacerbating the impact of waterborne illness and delimiting the operations of health services. Here, the assemblage's resilience has both predetermined and emergent behaviour, the former of which can be modelled with a systems-of-systems approach and the later co-created through adaptation decisions and actions. This works well with the speculative aspects of the tool that the EU-CIRCLE will deliver, based on scenarios and consequent CI performance which will allow operators and decision-makers to develop adaptive responses to them and express benefits and costs in visually immediate, policy relevant terms.

6. Methodological Development

This section integrates previous discussions of cyclone impact history, Khulna and critical infrastructure as assemblage to develop a methodology to engage infrastructure operators and decision makers in data-sharing, development and validation of EU-CIRCLE's state of the art CI Resilience toolkit.

The EU Circle framework for case studies development consists of a four step process; establishing the context, planning the exercise, conducting the exercise and finally assessing and reporting results (see Figure 1). Below we breakdown those steps with more detail:

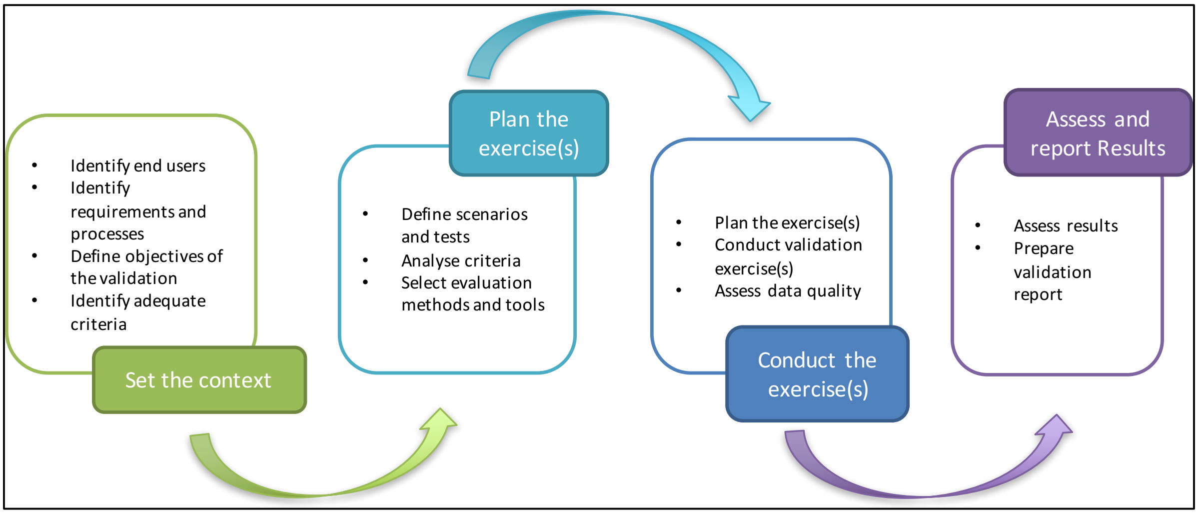

Fig. 1. Case study methodology of EU-CIRCLE
(Source: Deliverable 6.1 of EU-CIRCLE – see www.eu-circle.eu for more details)

- *Step A: Set the Context*

Key introductions will be established though known gatekeepers, literature review and an infrastructural map of concerned organisation to set an outer limit on participation. Urban areas are advantaged by their relative infrastructural density, and assemblage thinking is open to the diversity and mixed relationality of CI forms (public, private, mixed), sectors (communications, power, water, sanitation and health) and scales (national, regional, and municipal) present in the field study area.

Relationships will be consolidated through a field visit, during which CI operators, experts and decision makers will be approached for semi-structured interviews and institutional data sharing. The draft interview schedule can be found in Appendix A and is divided into three sections reflecting the human, material and relational constituencies of the Critical Infrastructure assemblage; organisational matters, asset register and interrelationships. Interviews will be recorded on maps and audio where possible and information used to set the objectives, criteria and narrative content of three scenario test exercises.

- *Step B: Plan the Exercise*

Following delivery of critical asset data to project partners, modelling work from them and joint selection of evaluation tools and methods, a prototype modelling toolkit will be developed using serious game ideas and validated through an online immersive exercise conducted with CI participants who have as yet not been involved in the study. The three scenarios to be developed from historical and projected data are; (a) a direct hit from an intense cyclonic depression, (b) an indirect hit from intense cyclonic depression and (c) an intense cyclonic depression accompanied by unprecedented storm surge reaching Khulna City.

- *Step C: Conduct the Exercise*

The actual validation exercise will be conducted both online for initial testing and physically during the final field visit. Participants will be asked to complete feedback forms and record messages relating to their experience with the toolkit.

- *Step D: Assess and Report Results*

A critical assessment of results and the validation exercise will be written and documentation produced for the project's stakeholders.

7. Conclusion

This paper provides the context and method for a detailed case study into the critical infrastructure subject to climate change pressures in Khulna City, Bangladesh. The aim of this paper is to present a challenging real-world urban environment in which to collaboratively and computationally explore how critical infrastructure planning could be enhanced with proper identification and analysis of the current resilience measures and context specific influences such as 'polderisation' and operationalised with the 'assemblage' thinking laid out here. As a way forward, the methodological framework shows how primary data collection and analysis will flow through an extended peer-review process, of critical infrastructure operators connected by current and future weather related risks in Khulna, and Bangladesh.

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